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Visualizing the Spatial Network of Cultural Heritage Based on Spatial Genes: A Case Study of Kulangsu, Xiamen

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KEYWORDS

Spatial Gene;
Cultural Heritage;
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ABSTRACT

Grounded in the theoretical framework of spatial genes, this study focuses on 51 core heritage elements of Kulangsu to explore multi-dimensional visualization approaches for the spatial network of cultural heritage. Through systematic analysis across four dimensions—construction period, architectural function, stylistic features, and spatial layout—time-series maps and spatial distribution maps were constructed. These maps reveal the characteristics of spatial genes underlying Kulangsu's evolution from an indigenous settlement to an international community. Combined with a "point-line-plane" hierarchical identification, a heritage spatial network structure encompassing historical, social, and cultural values was established and visualized to demonstrate its integrity and diversity. The research demonstrates that the identification of spatial genes and their multi-dimensional visualization of Kulangsu's core heritage elements can effectively elucidate its historical evolution and cultural significance. Future work requires continuous improvement in data precision enhancement, multi-stakeholder collaboration, and public participation mechanisms to enhance the scientific rigor and communicative efficacy of cultural heritage spatial representation, thereby better serving heritage conservation and revitalization practices.

INTRODUCTION

Cultural heritage, as a witness to the long course of history, serves not only as a spatial medium carrying social identity and emotional resonance but also as a spiritual coordinate of human civilization evolution. In the current era of accelerating digitalization and informatization, the spatial patterns and cultural values of traditional cultural heritage face the risks of fragmentation and homogenization (Xie et al., 2022). Consequently, how to scientifically categorize and systematically express the

profound values underpinning heritage has become an urgent issue. Recent academic research has focused on constructing frameworks for heritage value systems and precisely deconstructing core values based on spatial characteristics and cultural essences (Jones, 2017; Łaskiewicz et al., 2022; Alonso, 2014). Traditional value assessments often prioritize the conservation of physical entities and explicit features, while neglecting the underlying spatial genes that shape the individuality and spiritual character of heritage. Spatial

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genes, representing the spatial order, functional organization, and cultural symbolism sedimented over the long historical process of a heritage site, are the key to understanding the uniqueness of cultural heritage. They also provide a novel perspective for the scientific identification and systematic interpretation of heritage values.

Against the backdrop of digitalization and informatization, integrating spatial gene theory with cultural heritage research to explore pathways for constructing the spatial networks of cultural heritage has emerged as a critical topic in digital heritage studies. Based on this premise, this study proposes a visualization study of the cultural heritage spatial network based on spatial genes: **1)** Using spatial gene theory as the methodological foundation; **2)** Focusing on 51 core heritage elements of Kulangsu as the research objects; **3)** Employing multi-dimensional analysis across construction period, architectural function, architectural style, and spatial layout to construct time-series maps and spatial distribution maps; **4)** Systematically visualizing the heritage spatial network based on the "point-line-plane" hierarchical identification method.

This research aims to explore:

- 1) How to reveal the core characteristics and evolutionary trajectory of heritage through the extraction of spatial genes;
- 2) How to visualize the multi-dimensional values and structural relationships of the heritage network;
- 3) How to leverage visualization to facilitate precise heritage conservation, dissemination, and revitalization.

Through this research, we aim to move beyond the traditional "mere listing of elements" approach to interpretation. Instead, we seek to construct an integrated pathway of "spatial genes – multi-dimensional network – visualization expression," thereby providing new theoretical support and methodological insights for the in-depth understanding, precise conservation, and dynamic transmission of cultural heritage.

CULTURAL HERITAGE AND SPATIAL GENES

Cultural Heritage

In 1972, UNESCO adopted the Convention concerning the Protection of the World Cultural and Natural Heritage (referred to as the World Heritage Convention), which was the first document to define the concept of cultural heritage. Cultural heritage refers to the material and intangible heritage that has been preserved in the course of human history and cultural development and holds significant cultural value. The World Heritage Convention has made a preliminary and relatively clear definition of the concept of cultural heritage (internationally, the forms of existence of cultural heritage are considered to include tangible cultural heritage and intangible cultural heritage, but here it refers to tangible cultural heritage), classifying it into three types: ancient sites, architectural complexes and ruins (**Table 1**).

The case study site, Kulangsu, which is the focus of the research in this article, is a renowned World Cultural Heritage Site. World Cultural Heritage is defined by the level of cultural heritage. It is the highest level of cultural heritage of mankind and will be supervised and assisted by the World

Table 1 | Definition of cultural heritage

Type	Value dimension	Content
Ancient sites	Historical, artistic or scientific value	A combination of buildings, carvings and paintings, components or structures of an archaeological nature, inscriptions, caves and landscapes
Architectural complex	Historical, artistic or scientific value	A single or connected architectural complex in terms of architectural style, uniform distribution or integration with the surrounding scenery
Ruins	Historical, aesthetic, ethnographic or anthropological values	Areas such as human engineering or combined natural and artificial engineering, as well as archaeological sites

Source: World Heritage Convention

Heritage Committee. In terms of type, Kulangsu is a tangible cultural heritage. It brings together a unique type of architectural complex and is a witness to modern civilization. But at the same time, its historical and cultural heritage is also inseparable from the intangible cultures of Kulangsu, Xiamen and even Minnan. Therefore, when the concept of cultural heritage is mentioned in this article, it encompasses both the tangible cultural heritage of Kulangsu itself and the intangible cultural heritage of Gulangyu culture.

Spatial Genes

"Gene" is the basic functional unit that carries genetic information in organisms. By guiding protein synthesis, it determines the traits, characteristics and some instinctive behaviors of organisms under environmental regulation (Suzukiet al., 1986). "Spatial genes" originated from the theory of urban complex systems (Holland, 1995; Priogogine & Stengers 2018). The concept of spatial genes mentioned by the team of Academician Duan Jin from Southeast University of China internationally in 2019 aims to take "genes" as the biological basis and morphology as the main means to discover the genetic elements that can be stably inherited in the region and reconstruct the spatial characteristics of the region (Jin et al., 2022). Spatial genes do not simply point to a single isolated spatial element. Instead, they evolve into a unique and relatively stable spatial composition method and organizational logic under the interaction of multiple factors such as the natural environment, historical culture, and social structure (Duan, 2019). Duan Jin (2023) further pointed out that the core characteristics of spatial genes include the correlation of spatial elements, the interaction between natural ecology and urban systems, as well as the social identity demonstrated by indigenous people. Therefore, spatial genes are not only representations of form but also spatial coding carriers of cultural and social relations.

On this basis, spatial genes have gradually become the integrated bond connecting natural, material and immaterial spatial elements. Their formation, inheritance and development are deeply influenced by external variables such as the natural environment, social policies and economic and technological factors (Zhang & Yang, 2024). In recent years, the academic community has continuously expanded the application of spatial genes, especially demonstrating significant value in the protection of rural heritage and traditional settle-

ments. On the one hand, spatial genes are regarded as the core carrier of cultural diversity in traditional villages. By constructing diversity indices, the risk of cultural decline is diagnosed, and the role of public Spaces in social cohesion is emphasized (Xiang, 2022). On the other hand, some studies have revealed the intrinsic mechanisms of material form generation based on quantitative inheritance models, providing a scientific basis for heritage protection and cultural revitalization (Nie, 2024). The research of these two aspects has jointly promoted the application shift of spatial genes in cultural value identification and sustainable management.

In conclusion, the proposal of the spatial gene theory not only deepens the understanding of regional spatial structure and cultural logic, but also provides a concrete and structured analytical path for the identification, assessment and regeneration of cultural heritage, increasingly becoming an important bridge connecting physical space and cultural connotations.

The Association Between Cultural Heritage and Spatial Genes

Spatial genes are unique and relatively stable spatial composition patterns formed in the interaction with the natural environment and historical culture (Jin et al., 2022). It not only focuses on the spatial elements themselves, but also emphasizes the structural connections among the elements, highlighting the dynamic interaction among the ecosystem, urban form and social identity. As a deep-level spatial expression mechanism, spatial genes embed and convey the cultural information and historical memory of a specific region through carriers such as architectural forms, urban textures and landscape features.

Cultural heritage, as the material and intangible carriers of local culture and historical experience, forms a deep coupling relationship with spatial genes. On the one hand, spatial genes provide a stable morphological basis and cultural logic for cultural heritage, making heritage no longer an isolated static entity but an organic node embedded in the regional spatial network. On the other hand, the protection, activation and reuse of cultural heritage are constantly enriching and updating the connotation of spatial genes, endowing them with the ability to evolve over time and adapt to culture. The interaction between the two jointly maintains the historical continuity and cultural vitality of regional space: spatial genes endow cultural

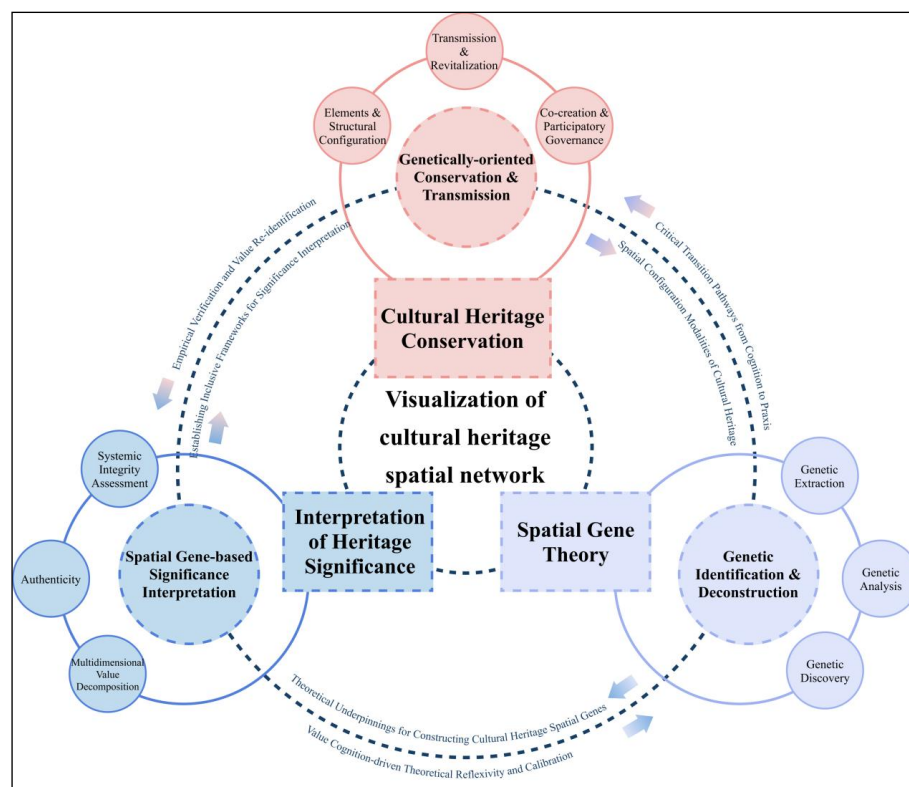


Figure 1 | Theoretical framework for the study of spatial pedigree construction of cultural heritage

heritage with structural support and a sense of identity, while cultural heritage in turn nourishes the cultural expression and social significance of spatial genes. Therefore, to understand the value of cultural heritage, it is not only necessary to interpret its surface material form, but also to delve into the spatial genetic logic behind it, so as to achieve the overall protection and sustainable development of cultural space.

Overall, the spatial foundation provides deep structural support and cultural logic for cultural heritage, while cultural heritage continuously updates and enriches the connotation of spatial genes through protection and revitalization. Both jointly maintain the historical authenticity and cultural vitality of the regional space.

RESEARCH FRAMEWORK AND OBJECTS

Research Framework

In this study, Kulangsu in Xiamen was selected as a typical case. Through a systematic analysis of the spatial genes of historical building remains, the internal logic and presentation path of its cultural heritage value were explored. As important carriers of cultural inheritance, these historical buildings not only record the glorious development of

Kulangsu over more than a hundred years, but also maintain a relatively stable structure in spatial form, presenting unique features of the integration of Chinese and Western styles and the interweaving of local traditions and international styles in different periods. Based on this, this study analyzes the spatial combination mode and local characteristics of architectural heritage as well as its constituent elements, constructs a cultural heritage spatial network to interpret the heritage value, and achieves the inheritance of cultural heritage through targeted means of "understanding through interpretation, appreciating through understanding, and protecting through appreciation" (Tilden, 2009). The research framework is shown in **Figure 1**. As the foundation and methodology of research, the spatial gene theory, by identifying and analyzing the material spatial elements such as historical buildings and street textures and their combination patterns, reveals the natural, social and cultural imprints behind the spatial form of Kulangsu, providing a key perspective for understanding the spatial essence of cultural heritage. Interpretation of heritage value is the core objective of the research. Through systematic analysis based on spatial genes, its authenticity, integrity and the multi-dimensional values (history, culture, art, etc.) it carries are demonstrated and evaluated to make the expression of heritage value more

Table 2 | Classification and summary of heritage elements

Classification dimension	Subclass	Typical representatives/examples	Core value
Construction year	The period of accumulation of local culture (Song Dynasty - 1840	Dafudi Courtyard, Four-courtyard Mansion, The Minor branch of the Huang family, Zhongde Taoist Temple	It reflects the historical evolution and spatial network of Kulangsu from its local cultural roots, to the influence of foreign cultures brought about by the opening of concessions, and then to the diverse integration of the local and Western cultures
	The Period of Foreign cultural Dissemination (1840-1902)	Former Japanese Consulate, Former HSBC Bank Managers' Residences, American Consulate Site, Former Hope Hospital and the Nurses' Residence	
	The period of multicultural integration (1903-1941)	Hai Tian Tang Gou Mansion, Fanpo Mansion, Trinity Church, The Chuncao Mansion, Huang Rongyuan Villa	
Style and pattern	The traditional style of southern Fujian	Sunlight Rock Temple, Four-courtyard Mansion, Dafudi Courtyard	Present the diversity of the spatial genes of Kulangsu: the introduction of foreign styles, the continuation of local traditions, and the unique architectural art forms formed by integration and innovation
	Nanyang decorative style	Bagua Building, Fanpo Mansion	
	Colonial eclecticism	Catholic Church, Union Church	
Building function	Religious buildings	Catholic Church, Trinity Church, Zhongde Taoist Temple	Showcase the functional diversity and openness of Kulangsu as a modern and contemporary international community and settlement for immigrants
	Consulates and public institutions	Former British Consular Residences, Former Kulangsu Mixed Court	
	Residential building	Huang Family Villa, Huang Cimin Villa, Former HSBC Bank Staffs' Residences	
	Public service facilities	Former Hope Hospital and the Nurses' Residence, Enlightenment School Site	
	Commercial cultural space	Former HSBC Bank Managers' Residences, Yanping Theater	
Spatial layout	Religious and cultural district	Concentrated areas of temples and churches	Following the natural terrain and the texture of the streets and alleys, we strengthen the complementarity of themes and the interconnection of functions, and build a spatial layout with distinct layers and rich experiences
	Historical features Exhibition area	Concentrated areas of consulates, banks and mansions	
	Art and Humanities Experience Zone	Concert halls, garden villas, etc	
	Commercial, educational and health district	Markets, schools, hospitals, etc	
	Residential residential area	Local residents, overseas Chinese communities, etc	
Value presentation	The value of historical testimony	A complex of architectural exhibitions from all over the world	Enrich the comprehensive value system of Kulangsu as a World Cultural Heritage site and strengthen its public awareness and educational functions
	The value of cross-cultural communication	The fusion of Chinese and Western styles and overseas Chinese architecture	
	Social memory and identity recognition	The cultural context of Southern Fujian and the memories of overseas Chinese	
	Architectural art and aesthetic value	Diverse styles and exquisite craftsmanship	

concrete, systematic and based on regional characteristics (Lan et al., 2025; Łaszkiewicz et al., 2022). The protection of cultural heritage is the ultimate goal of research. Based on a profound understanding of spatial genes and their values, targeted protection and activation strategies should be formulated, with emphasis on protecting the elements and structural relationships of spatial genes. Public education and community participation should be combined to achieve contemporary expression and sustainable inheritance of values. The three interact with each other, jointly forming a closed loop of "identification - interpretation - protection", achieving a complete path from recognition to action, and promoting the true preservation and contemporary activation of cultural heritage.

Research Objects

The 51 core heritage element buildings on Kulangsu are classified and summarized in terms of "construction period - style and pattern - architectural function - spatial layout - value presentation" (Table 2). Through the sorting out of the construction period, it can clearly show that Kulangsu has evolved from the period of local cultural accumulation (Song Dynasty - 1840) to the period of foreign cultural dissemination (1840-1902). Then to the development context and historical spatial network during the period of multicultural integration (1903-1941): There were not only traditional red brick residences and temple buildings of southern Fujian, but also consulates and mansions of foreign styles, as well as innovative buildings that combined Chinese and Western styles, fully demonstrating the evolution and diversity of the spatial genes of Kulangsu (Li et al., 2022).

In terms of style and form, these buildings combine local, foreign and integrated characteristics: they not only preserve the structural and decorative features of traditional Minnan architecture, but also introduce Western styles such as Victorian and Gothic, and through localized innovation, have formed a unique blend of Chinese and Western architecture. The functions of the buildings cover various types such as religion, diplomacy, residence, commerce, education and medical care, reflecting the complexity and internationalization of social life on Kulangsu at that time.

In combination with the spatial layout, the author proposes that heritage buildings can be integrated into functional zones such as religious and cultural areas, historical and cultural display areas, art and humanistic experience areas, commercial, educa-

tional and health areas, and residential areas based on their organizational models and functional characteristics in space. This not only highlights different historical and cultural themes but also achieves complementarity and interaction in space. At the same time, from the perspective of value presentation, the diverse values carried by the architectural complex of Kulangsu, such as historical testimony, cross-cultural exchange, social memory and architectural art, are further refined.

RESEARCH ON SPATIAL GENE IDENTIFICATION AND SPATIAL NETWORK VISUALIZATION OF KULANGSU

Kulangsu, as a brilliant pearl of Xiamen City, has attracted much attention for its profound historical accumulation, diverse cultural background and unique architectural style. To more systematically reveal the historical context and cultural logic behind the spatial pattern of Kulangsu's heritage, this chapter takes the spatial gene theory as the core method and combines data visualization techniques to conduct multi-dimensional analysis and expression of 51 core heritage elements of Kulangsu.

Temporal Visualization Analysis of the Core Heritage Elements of Kulangsu

This section is based on the 51 core heritage elements of Kulangsu on the World Cultural Heritage List, and combines the drawn time series diagram (Figure 2) to conduct a comprehensive analysis from four dimensions: construction year, building function, architectural style and spatial area. Through multi-perspective image expression and data interpretation, this paper explores the historical evolution path, functional organizational structure, and feature relationship of Kulangsu's cultural heritage. The research attempts to integrate the time dimension, architectural symbols, and social memory into the visualization design of the spatial network, which is similar to the digital image art through methods such as unmanned aerial vehicle remote sensing and collage photography. The research idea of exploring the temporal form and symbolic space of photographic art is consistent (Li et al., 2025). It also provides multi-dimensional visualization support and a basic cognitive framework for the subsequent "point-line-

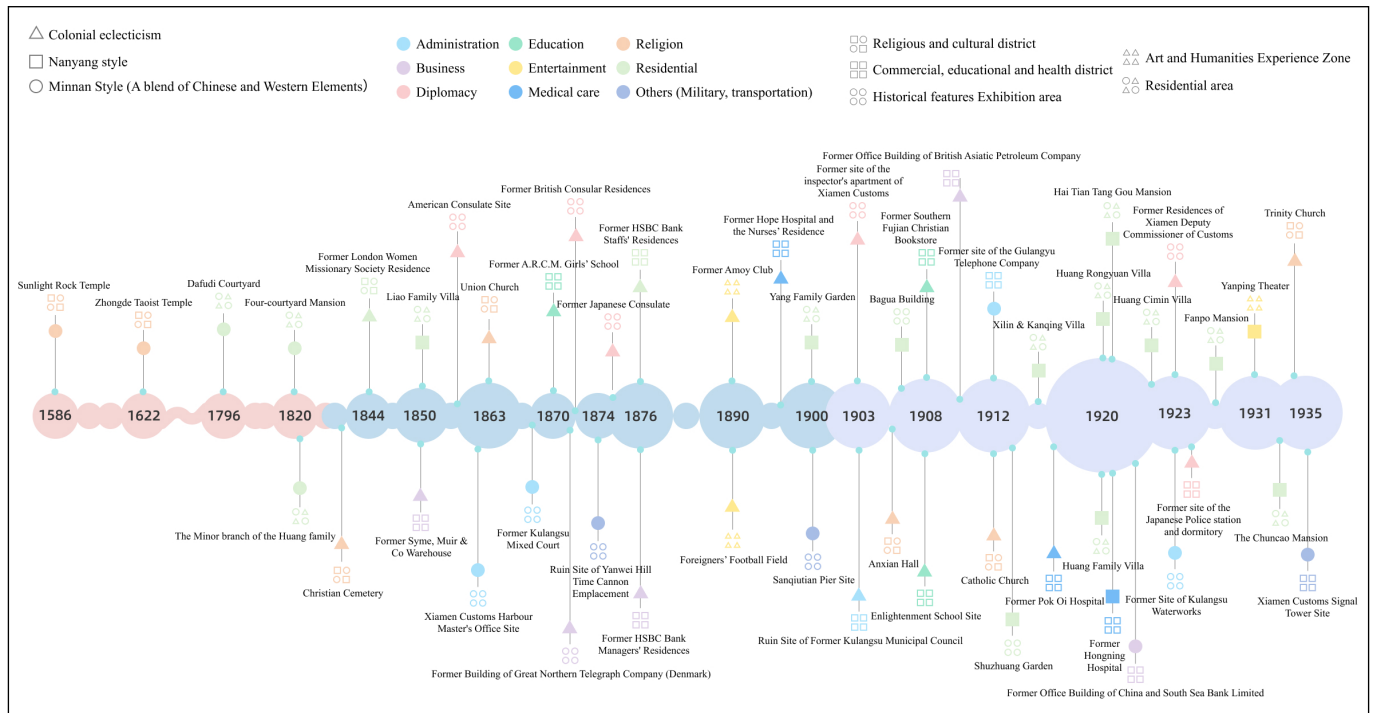


Figure 2 | Timeline of the 51 Core Heritage Buildings on Kulangsu

surface" multi-level spatial recognition and network structure analysis.

It is worth noting that the construction and visualization of the spatial network of cultural heritage are not merely the results of technical or rational analysis, but are closely related to emotional identification, social memory and ethical values. As some studies have pointed out, the acceptance of technological applications often goes beyond instrumental rationality and is profoundly shaped by emotional vulnerability and moral tension (Fu et al., 2022). In the research on the visualization of spatial genes on Kulangsu, this social emotion and cultural identity have also profoundly influenced the screening and value expression of spatial elements, making the spatial network not only a presentation of historical information but also a medium for public emotional resonance and collective memory.

Construction Period: The concentrated construction period of the core heritage and its historical evolution

From 1586 to 1840, it was the period of accumulation of local culture. The buildings mainly consisted of local temples and traditional residences, such as Sunlight Rock Temple, Zhongde Taoist Temple, and Four-courtyard Mansion, which reflected the early religious belief system and local

settlement form of Kulangsu. The spatial genes of this period possess the organizational characteristics of a "religious core - neighborhood dependence" type, emphasizing locality, continuity and a sense of spiritual belonging. From 1840 to 1902, it was a period of the spread of foreign cultures, as well as a stage of strong intervention by foreign forces and cultural collisions. With Kulangsu being listed as a "Public Settlement", foreign consulates, churches, banks and other buildings emerged densely (such as American Consulate Site and Former HSBC Bank Managers' Residences). At this stage, spatial genes did not naturally fuse but presented a "forced embedding type" transformation, reflecting the initial entry of the modernization process and colonial influence into the island space. From 1903 to 1941, it was a period of multicultural integration and the most concentrated construction period of heritage buildings on Kulangsu. During this stage, social functions expanded diversely. A large number of buildings have emerged one after another, covering educational (such as Enlightenment School Site), religious (such as Catholic Church), medical (such as Former site of the Hong Ning Hospital), commercial and financial (such as Former site of the Central South Bank), entertainment (such as Former site of the Yan Ping Cinema), and many other types of buildings. During the same period, some overseas

Chinese built villas and residences with Nanyang style on the island, usually in areas with higher terrain and superior views.

These heritages integrate Chinese and Western elements in spatial organization and architectural vocabulary, becoming a spatial expression of "cross-cultural identity" and further enriching the "private residence - social symbol" dimension in the spatial genes of Kulangsu. The spatial genes of this period were characterized by a "multi-dimensional superposition type", that is, under the constraints of multicultural logic and natural landforms, functional coordination and spatial coupling were achieved, which was a crucial stage for Kulangsu's transformation from a local settlement to an international community. This historical evolution not only reflects the changes of The Times but also shapes the spatial heritage structure of Kulangsu today: early buildings are scattered, while modern ones are dense, forming a multi-layered spatial pattern along the street and alley axes - along the coastline - built against the mountains.

Overall, the spatial genes of Kulangsu have undergone an evolutionary process from a single endogenous source to exogenous embedding and then to multi-source fusion in three historical stages. This process not only encodes the historical texture of cultural heritage, but also shapes the spatial network structure of Kulangsu today, which is both layered and continuous.

Building Function: Spatial Mapping of Diverse Social Demands

The evolution of architectural functions on Kulangsu reflects the continuous transformation of the social structure and lifestyle on the island, and also reflects the response and shaping ability of spatial genes to multiple functional demands in different periods (Jing et al., 2022).

Before the mid-19th century, the spatial genes of Kulangsu were mainly centered around local life and religious beliefs. The architectural types were mainly temples and traditional residences, presenting a "religious-life" type of settlement pattern, emphasizing the spatial connection between the faith center and the community. From the late 19th century to the early 20th century, with the opening of ports for trade and the entry of Western forces, functional buildings for diplomacy, commercial finance, religion, etc. gradually emerged, marking the "institutional embedding type" reconstruction of spatial genes. Functional nodes with foreign institutional attributes, such as consulates, banks, and

churches, have begun to be embedded in the local spatial texture. The spatial structure tends to be multi-axis parallel and functionalized, reflecting the needs of island society for external communication and capital circulation. From the early 20th century to the 1930s, a large number of social service facilities such as education, medical care and cultural entertainment were built on the island, demonstrating the refinement of social life demands and the integration of urban functions. At this point, the spatial gene further transforms into a "composite functional type", that is, on the basis of the original living and power system, it superimposes public attribute spatial units such as education, health, and culture, forming an urban living structure oriented towards the middle class and knowledge groups.

Furthermore, during this period, many overseas Chinese built villa residences on the island. These villas not only reflected the overseas Chinese's borrowing of Western architectural forms, but also retained the local traditional courtyards and decorative customs of southern Fujian, presenting the dual characteristics of a combination of Chinese and Western structures and "private - social" functions, such as Shuzhuang Garden, Huang Cimin Villa, etc. It often has multiple functions such as a residence, reception and cultural activities, reflecting the "cross-cultural self-shaping" feature in the spatial genes of Kulangsu. Overall, the historical evolution of architectural functions on Kulangsu shows a progressive process from "single religious life" to "diverse social demands". The network structure composed of buildings with different functions not only reflects the complex trend of social life on the island but also constructs a spatial gene network with hierarchy and heterogeneity.

Architectural Style: The Spatio-temporal Evolution of the Fusion of Chinese and Western Styles

The evolution process of architectural styles on Kulangsu demonstrates the convergence and adaptation of local and foreign cultures at different historical stages, and also reflects the continuous renewal of spatial genes at the morphological level and their cultural coding capabilities.

Before the late Qing Dynasty, the architectural style on the island was mainly in the traditional Minnan style, emphasizing the adaptation to the natural landscape, the use of local materials, and the enclosed spatial layout, thus forming a spatial genetic form centered on clan order and local be-

liefs. The architectural style of this period demonstrated a strong sense of locality and continuity, serving as the foundation for the spatial expression of local culture. In the middle and late 19th century, with the entry of European and American powers, typical colonial architectural styles such as Gothic and Victorian began to appear on the island, such as the former site of the British and American consulates and the Catholic Church. This type of architecture often emphasizes verticality, decoration and institutional symbolism. As a result, the spatial genes undergo a disruptive variation, presenting an "forced embedding" exogenous style feature, that is, the local spatial layout is strongly intervened by foreign architectural language, forming a heterogeneous superposition in cultural vision.

At the beginning of the 20th century, under the joint influence of the foreign exchange economy, cross-cultural exchanges and the construction practices of local artisans, Kulangsu gradually developed the "Nanyang Style", "Sino-Western Fusion Style" and "Colonial Eclectic Style" that integrated Chinese and Western elements. Representative buildings such as the Bagua Building and the Huang Rongyuan Villa often organically combine traditional Chinese symmetrical axes and carved decorations with Western architectural elements like arches, balconies, and brick and stone structures, demonstrating an adaptive mechanism of spatial genes under "cultural re-encoding". The architectural style of this stage is not only an aesthetic expression but also a spatial practice of identity construction and cultural recognition, marking the transformation of the spatial genes of Kulangsu from a "single traditional type" to a "mixed and integrated type", demonstrating the selective absorption and local re-creation of regional culture under the influence of foreign influences.

Visual Interpretation and Presentation of Heritage Value

Through a systematic review and multi-dimensional visual expression of 51 core heritage elements, the cultural heritage value of Kulangsu can be interpreted in a three-dimensional way from multiple dimensions such as historical process, artistic style, social function and cultural memory.

Historical value: The core heritage buildings bear witness to the entire process of Kulangsu's evolution from a local settlement to an international community, and carry the spatial imprints of politi-

cal, economic and cultural changes in different periods. **Artistic and architectural value:** The diverse integration of architectural styles and the spatial layout along streets and alleys, against mountains and along the coast reflect the deep convergence of Chinese and Western architectural art in specific natural landforms and cultural contexts. **Social and life values:** Multi-functional buildings such as those for education, religion, healthcare, and commerce coexist and thrive, reflecting the increasingly diverse structure of modern urban life and the spatialization of social division of labor. **The cultural memory value:** The overseas Chinese patriotic sentiments, modern diplomatic history and local life traditions carried by the architectural complex constitute the unique cultural identity and collective memory field of the island.

This study breaks through the limitations of traditional textual description and visual presentation by visualizing the value of heritage. It not only strengthens the spatial perception and image cognition of value interpretation, but also provides intuitive support and multi-dimensional perspectives for subsequent "point-line-surface" spatial recognition and spatial network relationship analysis, further promoting the transformation of cultural heritage from static display to dynamic understanding and structural cognition.

Point-Line-Surface Spatial Identification of the Core Heritage Elements of Kulangsu

This section is based on the 51 core heritage elements of Kulangsu and conducts the identification and analysis of spatial genes from the three levels of point, line and surface (**Figure 3**). By means of geographic information visualization and classification analysis, this paper explores its distribution characteristics, spatial connections and aggregation patterns, reveals the spatial structure features of the diverse symbiosis and distinct context of the cultural heritage of Kulangsu, and lays a solid foundation for the subsequent construction of the spatial network.

Point: Spatial Distribution and Character Interpretation of Core Heritage Sites

This study takes the 51 core heritage elements listed in the UNESCO World Cultural Heritage directory of Gulangyu as the starting point for identifying spatial genes. These architectural entities, officially recognized based on multi-dimensional evaluations including historical, artistic, and social values, represent the most concentrated expression of the cultural and spatial DNA of Gulangyu.

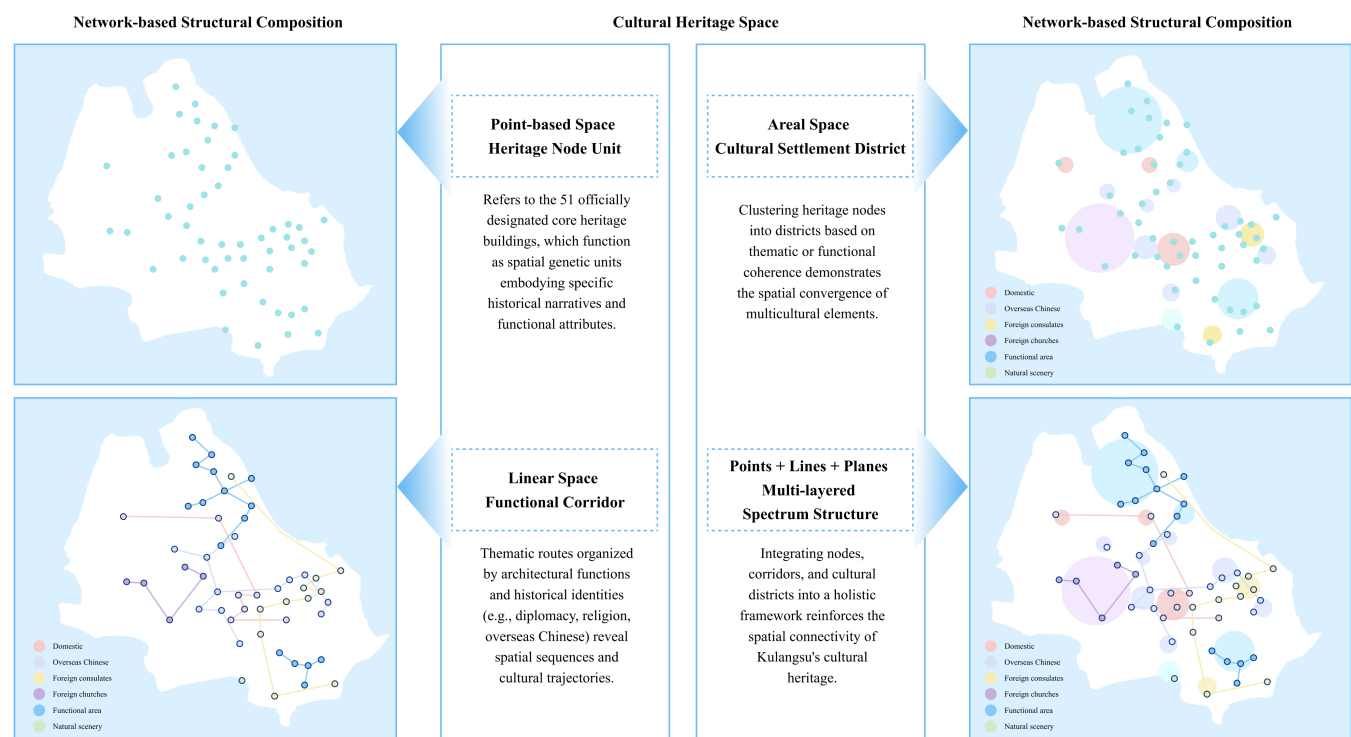


Figure 3 | Kulangsu Cultural Heritage Spatial Genetic Identification Model

An analysis of the official spatial distribution map of these 51 core elements reveals a dispersed, multi-nodal layout characterized by an organic integration of inner street axes, coastal lines, and natural landforms. Traditional local buildings are predominantly situated along natural topographies, often clustered near features such as Sunlight Rock, forming a landscape closely interwoven with the environment. In contrast, consulates, foreign firms, and Western-style buildings tend to align linearly along the coastline, facing the harbor to emphasize their diplomatic functions. Overseas Chinese residences are typically located adjacent to Western-style architectural zones, creating transitional spaces that embody the fusion of Chinese and Western cultures.

From a temporal perspective, these buildings span across distinct historical phases, including the period of indigenous cultural accumulation, the era of foreign cultural dissemination, and the subsequent stage of multicultural integration. They bear witness to the transformation of Gulangyu from a traditional settlement into an international community. In terms of stylistic expression, the architecture encompasses a range of types, including Western consulates, hybrid Sino-Western dwellings, and vernacular red-brick houses. Functionally, the heritage elements reflect a wide spec-

trum of uses—diplomatic, religious, commercial, educational, and residential—demonstrating the diversity of social organization and lifestyle on the island. As the fundamental units of spatial genetics, these officially designated heritage sites encapsulate the historical evolution, regional characteristics, and cultural richness of Gulangyu. They thus provide an authoritative and robust foundation for the thematic route design and regional classification in subsequent spatial analysis.

Line: Spatial Linkages of Functional and Cultural Themes

On the basis of point-based distribution, multiple thematic and functional routes are constructed according to architectural functions—such as religion, diplomacy, commerce, education, and residence—as well as historical identities (including indigenous buildings, Western consulates, and overseas Chinese architecture) and associated cultural themes. The Local Life Memory Route uses vernacular architectural elements such as red-brick dwellings, ancestral halls, and traditional residences as core nodes to connect indigenous communities and traditional living spaces, thereby reflecting the local cultural fabric. The Diplomatic and Cultural Axis links various former consulates, embassy sites, and associated structures, tracing the spatial trajectory of Gulangyu’s international

exchanges during the modern period. The Religious and Humanistic Route interconnects Christian and Catholic churches, illustrating the spatial diffusion and clustering patterns of religious heritage on the island. The Overseas Chinese Memory Route integrates the residences of overseas Chinese, mansions of prominent community leaders, and related educational institutions, highlighting the significant role of the diaspora in the development of their hometown. The Natural Landscape Experience Route is anchored in key natural features such as Sunlight Rock, Shuzhuang Garden, and the coastline, emphasizing the dynamic interplay between ecological landscapes and architectural heritage. These functional and thematic pathways transform isolated heritage points into an integrated spatial network with narrative coherence and functional continuity, thereby embedding architectural heritage more deeply within the island's historical evolution and social life.

Plane: Functional Zones and Spatial Aggregation Patterns of Heritage

Building upon the linear connections, this section further identifies planar spatial units and functional zones through an integrated analysis of spatial distribution density and topographical conditions.

The Traditional Indigenous Residential Zone is characterized by compact spatial morphology, human-scale environments, and the preservation of traditional architectural forms, lifestyle patterns, and local cultural practices. The Consular District comprises a concentration of consulates from various nations and their associated diplomatic facilities, fostering a strong atmosphere of international cultural exchange. The Religious and Cultural Zone centers on Christian and Catholic churches, supplemented by religious schools and institutions, forming a key spatial domain for religious activities. The Overseas Chinese Residential Zone features a dense distribution of overseas Chinese mansions and Chinese-funded educational buildings, reflecting the distinctive characteristics and collective memory of the diasporic community. The Natural Ecological and Recreational Zone, with Sunlight Rock and Shuzhuang Garden as its core scenic resources, establishes a leisure space that integrates ecological preservation with cultural heritage.

These planar aggregations not only reflect the spatial responses to historical evolution and functional differentiation, but also form a complementary and diverse regional layout, highlighting the

integrity and complexity of Gulangyu's spatial genes. Collectively, they demonstrate the layered spatial interplay and functional overlap among natural landforms, indigenous living patterns, international engagement, and religious-educational practices—ultimately shaping a multifaceted, hierarchically structured spatial configuration of coexistence on the island.

Integrated Hierarchies of Point–Line–Plane

Through the analysis of point distribution, thematic linkage via lines, and functional aggregation in planar zones, the spatial characteristics of Gulangyu's cultural heritage manifest a comprehensive pattern composed of multi-point dispersion, interwoven functional lines, and the convergence of diverse districts. **1)** Points represent the fundamental units of spatial genes, comprising individual heritage sites; **2)** Lines serve to connect these points through thematic and functional routes, enhancing cultural and operational relationships among heritage elements; **3)** Planes form through the spatial aggregation of functions and themes, exhibiting the integrity, stratification, and cultural diversity of the overall landscape.

This hierarchical integration of point–line–plane reveals both the intrinsic structure and external morphology of Gulangyu's heritage spatial genes. More importantly, it establishes a clear spatial foundation and logical entry point for the construction of the cultural heritage spatial network discussed in the following section.

The identification of point–line–plane is not merely a categorization of tangible heritage, but a spatialized interpretation of its historical trajectory, functional interrelations, and cultural logic. It provides a robust analytical framework and foundational basis for subsequent visualization of spatial networks and the comprehensive interpretation of heritage value.

Comprehensive Interpretation and Value Discussion of the Spatial Gene Network Visualization

This section constructs a visual analysis framework based on the temporal evolution, functional interconnections, stylistic transitions, and spatial distribution of Gulangyu's heritage by means of time-series analysis of 51 core heritage sites, statistical evaluation of functional attributes, and “point–line–plane” spatial identification. The resulting visualization clearly delineates the structure and evolutionary logic of Gulangyu's cultural heritage spatial network.

Overall, the cultural heritage spatial network of Gulangyu exhibits the following typical characteristics. **1) Multilayered Temporal Context:** The evolution of architectural styles and functional structures on Gulangyu has transitioned from a period dominated by indigenous constructions, through phases of external influence, to an era of multicultural integration. This process forms a spatial historical tableau with clearly defined strata and progressive evolution, reflecting both the continuity and the phased characteristics of its spatial genes. **2) Functionally Integrated Spatial Connections:** The coexistence and intertwining of diverse social functions—ranging from diplomacy, religion, education, and healthcare to commerce—transform isolated heritage sites into spatial nodes embedded within the social life and collective memory network. This reveals the dynamic social value of the heritage spaces. **3) Regionally Aggregated Network Layout:** Functional districts—such as the religious zone, consular area, overseas Chinese sector, and indigenous residential area—organically converge and mutually reinforce one another. While each retains its unique cultural characteristics, together they construct a diverse yet integrated spatial structure across the island.

Through the visualization and comprehensive interpretation of the spatial gene network, this study not only unveils the generative logic and underlying mechanisms of Gulangyu's heritage spaces but also provides a structured and graphical theoretical framework along with practical pathways for cultural heritage preservation and value interpretation.

SUMMARY AND DISCUSSION

This study takes 51 core heritage elements on Kulangsu as the object, based on the spatial gene theory, combined with time series analysis and the multi-level spatial identification method of "point-line-surface", systematically explores the historical evolution, functional distribution, style features and spatial aggregation relationship of heritage buildings, and constructs a visualization model of the cultural heritage spatial network. It aims to provide new understanding paths and methodological support for the protection, display and research of cultural heritage.

Main Findings and Conclusions of the Research

In terms of the temporal dimension, the research has drawn a chronological evolution diagram of the heritage buildings, revealing that the cultural heritage of Kulangsu has gone through three stages: "accumulation of local culture - infiltration of foreign culture - integration of diverse cultures". In the early stage, the buildings were mainly religious and residential. In the middle stage, a large number of Western-style diplomatic, religious and commercial buildings emerged. In the late stage, it developed into an international community pattern with complex functions and mixed styles. This evolutionary trajectory clearly reflects the dynamic transformation process of spatial genes from endogenous stability to exogenous fusion and then to native regeneration.

In the spatial dimension, the research, through the three-level recognition method of "point - line - surface", has extracted the following features; At the point level: Core heritage buildings are distributed along the mountain terrain, along the coast, and along the streets and alleys, demonstrating a high degree of coupling between natural form and functional organization, and forming a network of heritage nodes with diverse textures. At the line level: Extract functional cultural channels such as the "diplomatic Cultural axis", "religious and humanistic route", and "Overseas Chinese Memory Path", achieving a spatial logic transformation from isolated nodes to narrative corridors. At the surface level, spatial units such as the consulate area, religious and cultural area, overseas Chinese villa area, local residential area and natural leisure area have been summarized, demonstrating the structural hierarchy and regional agglomeration of the heritage space on Kulangsu.

Through the above analysis, the constructed spatial network visualization model not only realizes the medium transformation from textual description and two-dimensional drawings to dynamic network expression, but also enhances the perceptibility and dissemination potential of the spatial characteristics of heritage, providing multi-dimensional support for the cognition and interpretation of heritage value.

Research Innovation and Contribution

In terms of methods, this study introduces the "spatial gene" theory and time-space composite visualization technology to construct a multi-dimensional visualization path suitable for heritage

analysis in historical urban areas. In terms of content, it presents in a three-dimensional way the interactive logic of the time series, functional structure, style evolution and spatial organization of the buildings on Kulangsu, revealing the internal mechanism of the spatial generation of cultural heritage. In practice, it provides structured, visualized and networked cognitive models for heritage protection, exhibition design and management decision-making, and expands the forms of expression and dissemination methods of traditional heritage research.

Research Limitations and Prospects

This study still has certain limitations. The data sources mainly rely on the 51 core heritage elements officially announced, and have not yet comprehensively covered a wider range of historical buildings and intangible cultural elements. Spatial network analysis mainly relies on visual expression, lacking the support of quantitative indicators and the intervention of social network analysis methods. Visualization presentation still mainly relies on two-dimensional static images and has not yet fully integrated emerging expression technologies such as interactive and immersive ones.

Future research can be expanded in the following directions: broadening the scope of data and incorporating non-core heritage sites, intangible cultural expressions, and folk memory resources; Introduce GIS spatial analysis and network analysis indicators to strengthen the quantitative modeling and evaluation of spatial structure; Explore immersive visualization methods such as AR/VR and digital twins to enhance the interactivity and experience of heritage value dissemination.

Overall, this study takes the spatial gene theory as its core framework and uses visualization methods to decode the structural logic and evolution path of Gulangyu's cultural heritage. It not only provides a concrete and networked interpretation paradigm for the research of local historical heritage, but also offers beneficial theoretical references and methodological inspirations for the identification, value interpretation and digital display of spatial heritage in other historical urban areas.

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