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RESEARCH ARTICLE

Morphological resilience evaluation research on the conservation and renewal of historic districts: A case study on *Xijie* Historic District, Quanzhou

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Abstract In recent years, the focus of tangible cultural heritage conservation has gradually shifted from static protection to the stimulation of dynamic vitality and refined guidance. Historic districts frequently encounter various challenges and uncertainties in conservation and renewal practices, including the decay of physical spaces and the adverse impacts of commercial development. Addressing whether existing conservation and renewal models can enable historic districts to sustain their capacity for resistance, adaptation, and transformation constitutes an urgent issue. This study adopts a morphological resilience framework to construct an evaluation system. It takes *Xijie* Historic District as a case study to identify regions of weak resilience and propose targeted optimization strategies. The findings of the study reveal that: (1) Establishing a multi-level indicator system can systematically assess the resilience level of historical districts. (2) It is possible to enhance integrated resilience and support adaptation to tourism by increasing public facilities, dividing plot series into 1500–2000 m^2, and upgrading buildings with low quality and value. (3) Advancing a hierarchical conservation strategy of macro-level protection and meso- and micro-level classified renewal contributes to providing a valuable reference for responding to the complex challenges of urban renewal and promoting the refined conservation of heritage.

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1. Introduction

Many developing countries, with China as a representative example, face the contradiction between rapid urban growth and the gradual decline of historic districts. These historic districts consist of both tangible elements (historical buildings, cultural heritage sites, street landscapes) and intangible elements (cultural traditions, rituals, and community organizations) (Li et al., 2021). They serve as spatial carriers and palimpsest of history and culture, continuously accumulating and renewing over time. As a physical microcosm of urban heritage, historic districts are commonly used as a heritage complex in research and planning. They encompass complex relationships involving historical information, social structure, and the distribution of interests. Balancing conservation and renewal is both a key and a challenge in these areas (Hosseini et al., 2017). Nowadays, historic districts are faced with pressures such as infrastructure deterioration, social and economic transformation, and modern urban development (Mohamed Tahoon et al., 2023). Since the second half of the 19th century, as cities have been built and expanded, people have started to consider protecting historic districts while adapting to new functional demands and spatial forms. Conservation and renewal have undergone the following three stages: partial heritage protection, integral conservation of historic districts and surroundings, and city-coordinated *development* (Meskell, 2014). The academic focus on historic districts has shifted from a singular perspective on cultural relics and historical sites to a more integrated approach that emphasizes the mutual promotion of heritage and cities (Kou et al., 2018).

Existing research on the conservation of historic districts primarily focuses on two aspects: social relationships and physical space. Research on social relationships critiques gentrification and social inequity during the renewal process (Zhu and González Martínez, 2022), emphasizes the fair distribution of benefits generated by renewal (Abastante et al., 2020), and advocates for the transmission of traditional culture and customs (Esposito et al., 2021), promoting the value recognition of indigenous residents and enhancing community vitality (Yung et al., 2017). Research on physical space applies more technical tools and quantitative analysis, using urban sensors to identify street and district vitality (Li et al., 2021), analyzing the integrated perceptions of tourists and residents through points of interest (POI) data (Liu and Wang, 2014), and conducting accessibility analysis of street networks based on spatial syntax (Ye and Nes, 2014a). However, these studies focus on only one or a few aspects of historic districts, making it difficult to fully understand them from a spatial perspective. This results in a lack of guidance for integrated scientific zoning and refined conservation. In recent years, resilience has provided new ideas and innovative approaches for the sustainable development of historic districts (Elmqvist et al., 2019). Urban resilience research has shifted from a singular ecological and disaster prevention perspective to a comprehensive social and spatial perspective (Meerow et al., 2016), offering new angles to explore the changes, responses, and evaluations in the spatial functions and social system restructuring of historic districts in the face of capital and industry intervention.

Resilience research focused on historic districts emphasizes determining whether a district has effectively retained its spatial characteristics and social life, whether it can withstand the pressures and disturbances brought by urban construction and renewal, and how to evaluate the strength of this capability. Based on the research of Feliciotti et al. this study adopts the definition of urban morphological resilience as follows: *the ability of the spatial components of a district to resist, adapt to, and transform in the face of social changes, meaning it can maintain stability or complete renewal without large-scale spatial destruction and heavy reconstruction operations* (Feliciotti, 2018). This study utilizes geographic information technology, spatial analysis, and urban data to reconstruct the understanding of historic districts effectively, builds an analytical and quantitative framework based on morphological resilience evaluation, and conducts regional cognitive assessments of the integrated morphological resilience. It also proposes conservation and renewal strategies applicable to different types of historic districts.

This study addresses the following questions: (1) How can the spatially vulnerable units of historic districts be accurately identified? (2) What morphological and resilience attributes of historic districts are primarily focused on and described? (3) What conservation and renewal measures and strategies are proposed? Section 2, based on a literature review, constructs a universally applicable research framework for different types of historic districts, addressing Question (1). Sections 3 and 4 present an empirical case study, using Quanzhou *Xijie* Historic District, a World Heritage site, as the research subject. These sections describe the relevant methods and results, completing a quantitative analysis of integrated resilience and addressing Question (2). Section 5 further discusses the findings derived from the research data and analyzes practical and operational strategies, responding to Question (3).

The main contributions of this study are as follows: (1) It refines and applies the theory of morphological resilience, providing an innovative perspective for understanding historic districts. (2) It establishes a relatively universal evaluation system for historic districts, introducing a new method for the integrated identification of these areas. (3) It uncovers the correlation patterns of spatial morphological conservation at different levels and proposes hierarchical guidance, offering a new reference perspective for the refined conservation and renewal.

2. Literature review

2.1. Multi-level theory and urban morphometrics

The hierarchical interpretation of urban morphology has undergone a series of theoretical evolutions. The built environment of cities exhibits complexity and diversity, and the hierarchical structure based on the *part-whole* relationship has been widely applied in urban morphology. This structure serves as a fundamental approach for defining and analyzing the compositional patterns of urban form elements (Kropf, 2014; Salingaros, 2000). Among these theories, Conzen proposed that buildings, plots, blocks and streets are the fundamental elements of urban form analysis (Conzen, 1960) (Fig. 1(a)). The Caniggia typological school further refined the hierarchical relationships within buildings (Caniggia and Maffei, 2001) (Fig. 1(b)). The typological school first proposed the concept of *plot series* as a sequence of plots adjacent to the same street and interconnected in form or function, typically sharing similar shapes, sizes, or subdivision logic. This unit represents a typical development pattern and serves as an important meso-micro level in the analysis of urban form. Kropf inherited and developed both classical theories, enhancing the multi-level urban morphology framework. He categorized urban morphology into urban tissue, single tissue, plot series, streets, plots, buildings, and rooms, which better clarified the relationships between elements (Kropf, 2014). Additionally, by incorporating different types of *voids*, such as open areas, Kropf complemented the gap regarding the description of residual space (Kropf, 2017) (Fig. 1(c, d)). The multi-level urban morphology theory provides a foundation for the hierarchical classification of historic districts in this study, enabling a more comprehensive understanding of the complex built environment of cities.

In recent years, with the advancement of geospatial data research, a series of data-driven urban morphology studies have emerged, referred to as *urban morphometrics* (Bobkova et al., 2021; Fleischmann et al., 2022; Gil et al., 2012). Existing research has constructed a spatial indicator system for urban growth and shrinkage (Reis et al., 2016), evaluating the method of urban thermal environment (Wu et al., 2022) at the *urban* scale. It developed space syntax, improving the study of street network (Marshall et al., 2018), connectivity, and pedestrian volume (Hajrasouliha and Yin, 2015; Porta et al., 2006) at *street* scale. The research analyzed the impact of various indicators on urban vitality (Ye et al., 2018), the design of urban public spaces (Cozzolino et al., 2020), and other aspects at the *block* scale. The *plot* is the smallest land unit regarding urban physical form, cadastral property and planning utilization. The *plot* and *plot series* scale are important research directions, with lots of existing quantitative research focusing on plot patterns and property behavior (Kropf, 2018), economic activities (Bobkova et al., 2019), and urban prescription (Monteiro and Pinho, 2021).

2.2. Morphological resilience and indicator analytic dimensions

There is a mutual interaction and constraint between modern urbanization and urban heritage protection, requiring sustainable and resilient thinking to balance and coordinate the relationship (Ahern, 2011; Kuhlicke et al., 2023). The concept of *resilience* has gained popularity in academic and policy fields, providing insights into understanding complex systems and their sustainable management (Meerow and Newell, 2015). *Resilience* originated from engineering and ecology, focusing on how systems resist stress and return to a balanced state (Pendall et al., 2010). With the development of theory, *evolutionary resilience* focuses on studying the capacity of complex adaptive systems (CAS) that constantly adjust, evolve, endure, and regenerate in the face of uncertain external challenges and internal changes (Anderies, 2014; Holling, 1973). Cities have complexity under multiple factors like social, economic, institutional and spatial elements. Like engineering and ecological systems, cities require resilience theory to guide their construction and development (Vale, 2005). The rapid development of urbanization implies socio-economic disruptions, as well as sudden, spontaneous and man-made disasters (Meerow et al., 2016). Enhancing urban resilience ensures the complexity and diversity of the built environment, maintaining stability amid long-term changes, and has become an important principle in urban design (Feliciotti, 2018).

Morphological resilience, or *urban form resilience*, combines urban morphology and resilience theory, focusing on the city's physical space, involving a comprehensive analysis of various factors such as social, economic, and institutional elements (Sharifi and Yamagata, 2018). The key point is how urban morphology enhances resilience by improving the capacity to plan for, absorb, recover from, and adapt to adverse events (Sharifi, 2019a). Urban form is considered a complex adaptive system, revealing the

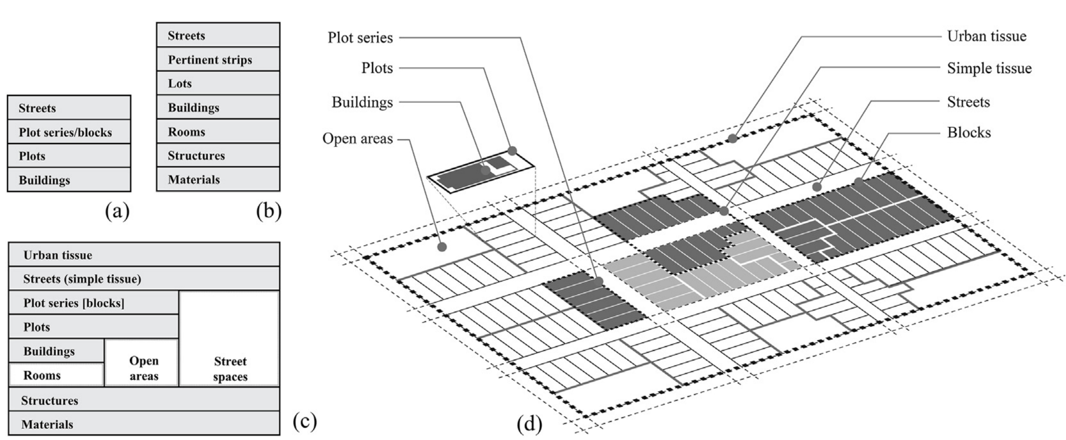

Fig. 1 Multi-level hierarchy proposed by various scholars: (a) Conzen's theory; (b) Caniggia and Maffei's theory; (c) Kropf's theory; (d) diagram with elements by Kropf's theory. Source: Authors, Kropf (2017).

interactive relationships between spatial elements at different scales. It intuitively presents the resilience capacity of urban morphology to resist, adapt to, or co-evolve with the environment (Feliciotti, 2018). Existing studies have preliminarily established the correlation between morphological hierarchy and resilience theory, focusing on the resistance and adaptability of urban morphology (Fusco and Venerandi, 2020; Sharifi, 2019a, 2019b). Table 1 presents an assessment framework for morphological resilience attributes at different scales. Among these resilience dimensions, redundancy, self-organization, and efficiency are more relevant at the macro-scale, addressing the adaptability of overall urban social and economic resources. In contrast, diversity, connectivity, modularity, and robustness are applicable at the meso- and micro-scales, providing guidance for improving and enhancing the physical spaces.

Empirical studies on urban morphological resilience primarily focus on the macro-scale like cities, with relatively few case studies at the meso- and micro-scales examining the operative physical space and underlying social factors. As a result, current research has limited applicability in guiding urban design practices. Additionally, the classification of morphological hierarchies in existing studies is primarily based on classical urban morphology schools, such as the Conzen approach, which lacks sufficient interpretation of the interactions between different morphological levels and the relationship between morphological elements and resilience attributes. There is also a lack of spatial enhancement strategies at more operational levels, such as plot series and individual plots, which are crucial for practical urban spatial interventions. This study focuses on the meso- and micro-scale resilience of urban morphology. Based on operability and adaptability, four resilience dimensions, *diversity*, *connectivity*, *modularity*, and *robustness*, are selected as proxies to construct a morphological resilience indicator system.

Table 1 Conceptual framework for assessing resilience of urban form. Source: Sharifi and Yamagata (2018).

Scale	Elements of urban form	Resilience attributes
Macro-scale	Scale hierarchy	Robustness
	City size	Stability
	Development type	Redundancy
	Distribution pattern of people and jobs	Resourcefulness
		Modularity
	Degree of clustering	Complexity
	Landscape/habitat connectivity	Flexibility
		Multi-functionality
Meso-scale	Structure and shape of neighborhoods	Self-organization
		Adaptability
	Typology of transportation network	Efficiency
		Diversity
	Access to amenities	Connectivity
	Open and green space	…
Micro-scale	Block type	
	Site layout	
	Building configuration/layout	
	Building typology	
	Density	
	Roof type	
	Street geometry	
	Design (street front/street edge)	
	Design of emergency route	

2.3. Research framework

Resilience cognition is a multidimensional and comprehensive game. Specific spatial areas have different attributes across various dimensions of resilience. For example, a particular morphological unit may have high functional diversity that promotes resilience. However, its relatively low protection value may hinder robustness, making it difficult to figure out the overall level of resilience directly. Therefore, through quantitative evaluation, on one hand, the resilience properties of each dimension can be weighted, achieving an integrated and scientific understanding and revealing issues that qualitative methods may not reveal. On the other hand, correlational analysis of the indicator values allows for balancing and considering multiple high-resilience indicators in the conservation and renewal strategy, ultimately enhancing the integrated resilience.

Based on multi-level urban morphology theory and resilience indicators, this study constructs the framework of *Morphological Hierarchical Division—Resilience Quantitative Cognition—Differentiated Unit Control*, as illustrated in Fig. 2. As shown in Fig. 3, in the field of urban morphology and resilience research, the widely accepted analytical framework primarily addresses the following questions: the objects and issues of resilience assessment (*to what*), the attributes and meanings (*of what*), the improvement goals (*for what*), and the morphological hierarchy (*with what*) (Sharifi and Yamagata, 2018). The focus of the research method is to transform the abstract concept of resilience into an evolutionary process, computational value data, and spatial level units through assessment, thereby making it specific and visual.

3. Materials and methods

3.1. Case study introduction

Quanzhou Ancient City is located in the southern part of Fujian Province (commonly named *Minnan*), China, serving as the starting point of the *Maritime Silk Road*. It is characterized by a blend of Chinese and foreign influences, multiple ethnic groups, and various religions. Whether in social activities, urban space, or architectural culture, Quanzhou exhibits strong characteristics of integration. In 1982, Quanzhou was listed as one of China's first batch of *famous historical and cultural cities*. In 2021, the project *Quanzhou: Emporium of the World in Song—Yuan China* was approved by the UNESCO World Heritage Committee and included in the World Heritage List (Li et al., 2016). Quanzhou Ancient City is the core area for heritage application, and its layout and spatial texture are well preserved (Fig. 4). Among Quanzhou's 22 World Cultural Heritage

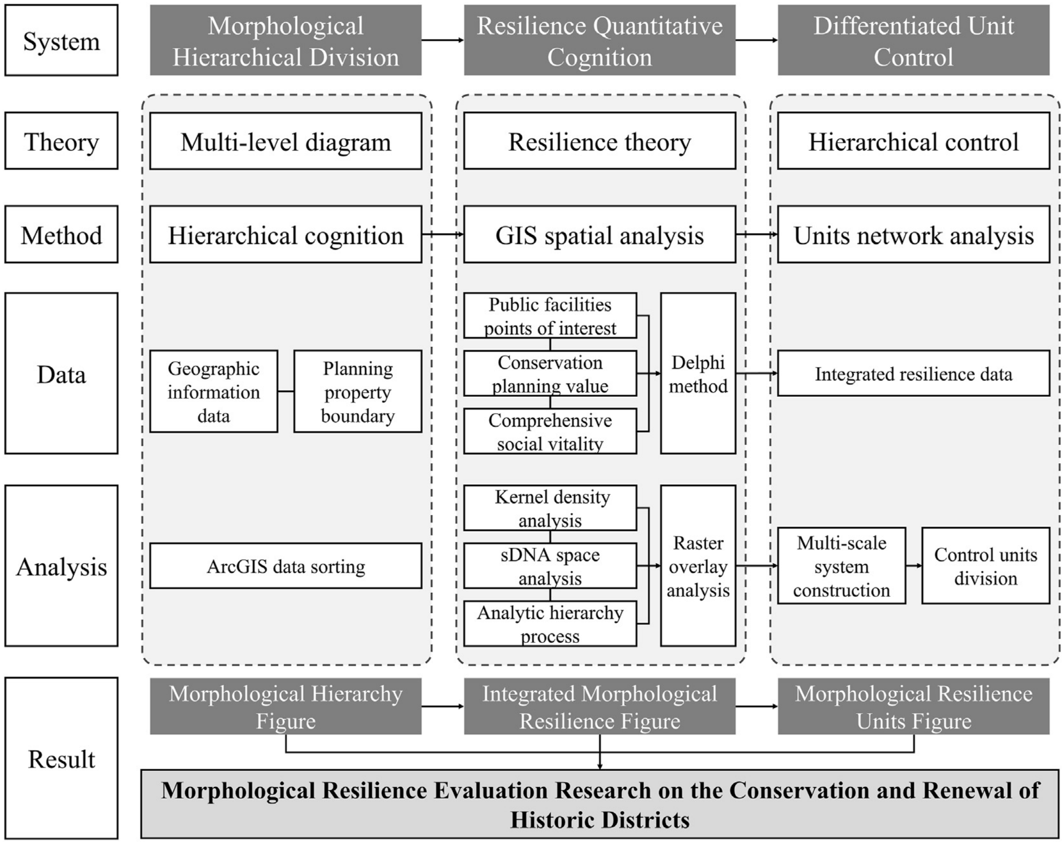

Fig. 2 Assessment framework of *Morphological Hierarchical Division—Resilience Quantitative Cognition—Differentiated Unit Control*.

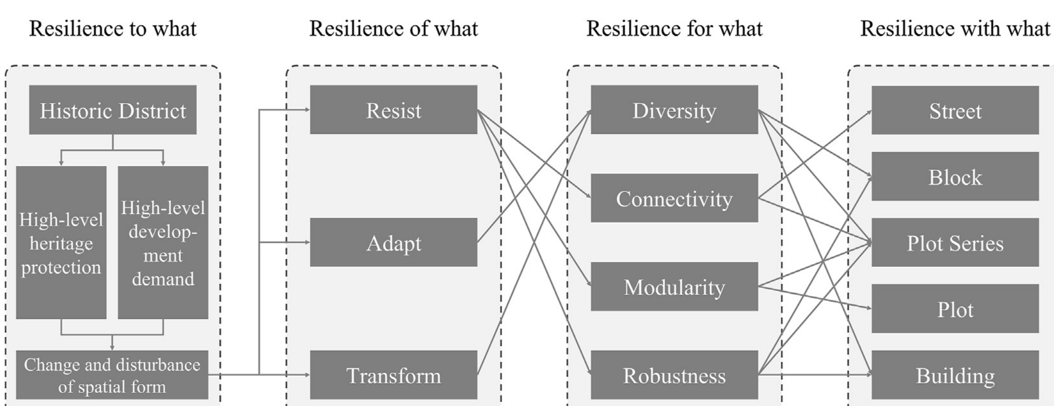

Fig. 3 Analytical framework of morphological resilience in historic district.

sites, 8 are within the Quanzhou Ancient City. According to data from the Quanzhou Bureau of Culture and Tourism, the ancient city received nearly 16 million visitors in 2024.

Xijie Historic District is located in the core area of the ancient city. This study determined the research area based on the historical and cultural district protection zoning of *Xijie* in the *Quanzhou Historical and Cultural City Protection Plan (Revision)*, with an area of 51.52 hm^2 (Fig. 5). Currently, *Xijie* Historic District faces dual pressures of high protection levels and high development demands, primarily reflected in the following aspects: (1) Two heritage preservation contexts and standards place higher demands on the resistance of the urban form. (2) Tourism development requires urban form to have stronger adaptability to change, with significant demand for tourism stimulating spontaneous private renovations and diverse business activities. (3) A balance between residential environment and style preservation must be struck. In non-tourist areas, some spaces face challenges such as dilapidated buildings and community decline due to resident migration.

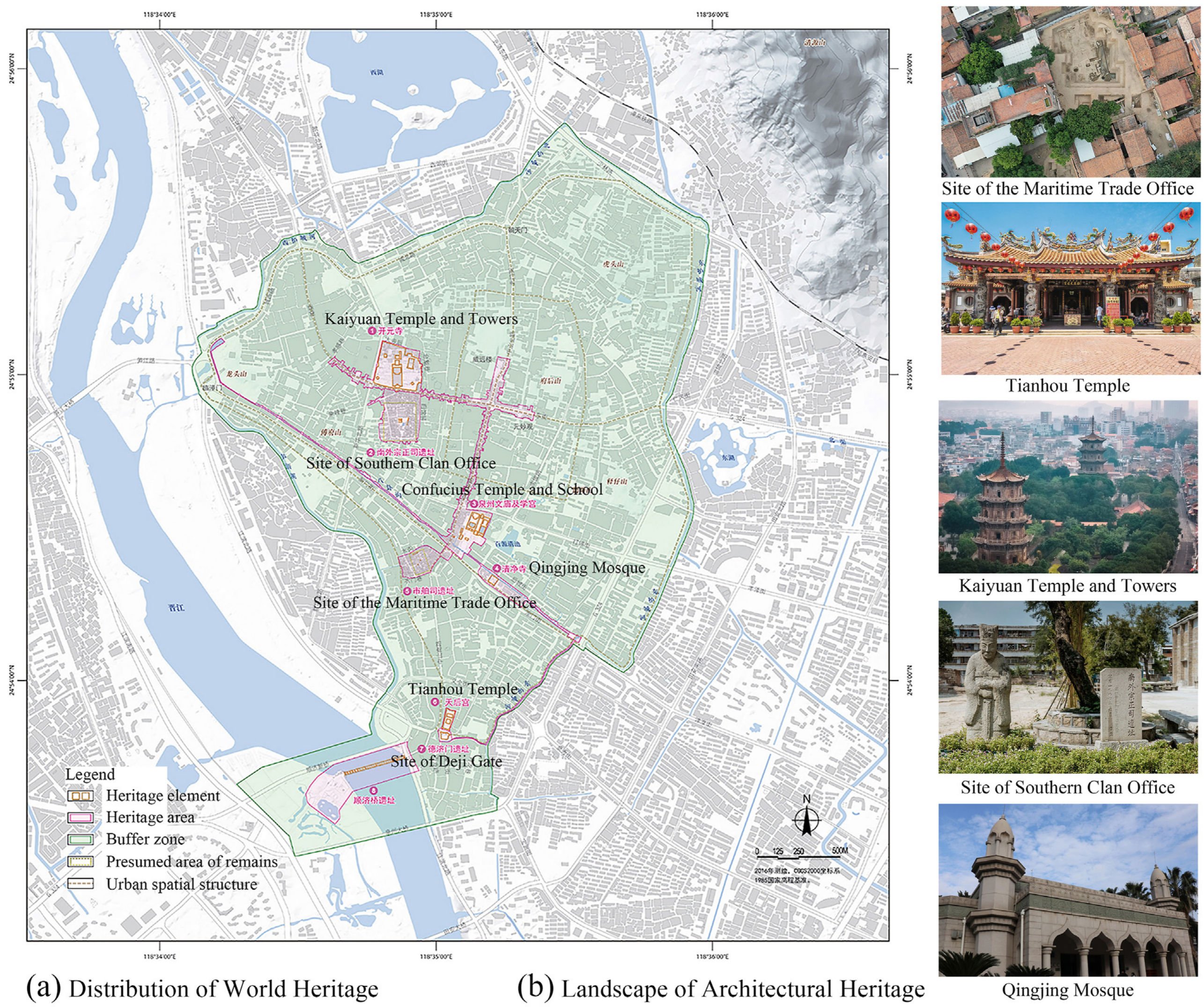

Fig. 4 Study area of Quanzhou Ancient City: (a) distribution of world heritage; (b) landscape of architectural heritage. Source: Authors, the Quanzhou Maritime Silk Road World Heritage Center.

Fig. 5 Study area of *Xijie* Historic District: (a) area of protection zoning; (b) overall view of *Xijie* Historic District; (c) differences of space resilience in various areas. Source: Authors, the Quanzhou Maritime Silk Road World Heritage Center.

Therefore, conservation and renewal research based on morphological resilience evaluation contributes to the sustainable development of *Xijie* Historic District.

This study adopted multi-level morphology theory (Kropf, 2014) and divided *Xijie* Historic District into five levels: street, block, plot series, plot, and building. Among them, the block was defined by public streets, and the plot was the smallest unit of property rights and urban morphology. Plot series (Kropf, 2017), as a collection and combination of series of plots, served as the intermediate and crucial control level between the block and the plot. We divided the *streets* (Fig. 6(a)) into three scales. The north-south *Xinhua Road* and the east-west *Xijie Street* were classified as primary streets. Based on primary streets of 8–15 m and secondary streets of 5–8 m, the study area was divided into 34 *blocks* (Fig. 6(b)). Using tertiary streets of 3–5 m and planning documents, the study area was further divided into 240 *plot series* (Fig. 6(c)). Finally, based on building units and property boundaries (Fleischmann et al., 2020), a total of 1660 *plots* (Fig. 6(d)) were identified.

It should be noted that since the study focuses on the meso- and micro-scale of the historic district, macro elements as urban tissue and micro elements as rooms and structures are not included. Meanwhile, the definition of the study area is based on the protection zoning in the plan document. There are certain differences between the zoning and the actual boundaries of the blocks and plots. To minimize the marginal effects in the quantification process, the calculation area was slightly expanded to ensure the district's integrity within the area.

3.2. Data collection

In this study, the spatial dataset was obtained from OpenStreetMap (OSM) and the spatial boundary of Licheng District, Quanzhou City was corrected using the standard map service of the China National Administration of Surveying, Mapping, and Geoinformation. We preprocessed the dataset using ArcGIS 10.8 software, and to ensure data uniformity, all geospatial data were converted to the World Geodetic System (WGS) 1984 Albers projection coordinate system.

POI data was obtained from the Gaode Map in 2024. The attributes of POI include latitude and longitude coordinates as well as facility categories. These data were converted into point elements using the coordinate transformation in ArcGIS. An accurate location map of heritage protection units was obtained from the Quanzhou Maritime Silk Road Heritage Center. The geographical locations of folk religious temples were sourced from the book *Quanzhou Old City Pujing Map*, written by the Local Chronicles Compilation Committee of Licheng District. The spatial boundaries were corrected in ArcGIS based on satellite imagery from Google Earth.

Fig. 6 Study area and morphological hierarchy of Xijie Historic District: (a) street layer; (b) block layer; (c) plot series layer; (d) plot and building layer; (e) details of urban form.

3.3. Research methods

The key to morphological evaluation of historical districts is the selection of indicators, which is closely related to the type of disturbance sources and the morphological resolution. For urban areas under different types of disturbance, it is necessary to consider the multiple interactions between spatial indicators and incorporate social factors behind the space. This study mainly concentrates on the resilience evaluation of material space, using four resilience proxies: *diversity*, *connectivity*, *modularity*, and *robustness*, as primary indicators (Feliciotti et al., 2016), which are most suitable for space operations as mentioned in Section 2. These indicators describe the resilience levels of morphological factors such as public facilities, streets, blocks and plots. Based on the spatial characteristics of Quanzhou Ancient City, 13 secondary indicators for different morphological levels were proposed (Table 2).

The determination of resilience attributes in this study incorporates the social background and historical information of *Xijie* Historic District, such as the classification and selection of POI in the Socio-spatial Kernel Density analysis. However, this indicator system retains a certain degree of universality when applied to other study areas. The types of public facilities, conservation planning, and the intrinsic characteristics of morphological elements are common aspects across various historic district studies. Thus, the selection of indicators can be appropriately adjusted based on specific contextual conditions.

3.3.1. Diversity

Diversity is currently recognized as one of the most important resilience attributes in morphological resilience research, and it reflects the attributes of the system's heterogeneity, variability, multifunctionality, etc (Sharifi, 2019b). In this study, diversity is defined as the ability of a system to contain multiple composite attributes, which refers to the degree of variation in types such as form, function, and social integration. The diversity of a system can be divided into two aspects: richness and evenness, which enables urban systems to simultaneously respond to multiple needs without requiring any structural changes (Feliciotti et al., 2016). The diversity primarily focuses on the complexity of urban form and its socio-functional attributes. In this study, diversity is categorized into: functional mixedness with 8 types of facilities, and land-use mixedness with 3 commonly used categories of land-use. These two approaches assess the urban morphological system from complementary perspectives.

Public Facilities Kernel Density (*PFKD*) reflects the distribution of urban public facilities. The higher the kernel density, the stronger the public service capacity, which

Table 2 Morphological resilience evaluation indicators system of *Xijie* Historic District.

Primary indicator	Resilience ability	Morphological hierarchy	Secondary indicator	Explanation
Diversity	The system's ability to support multiple functions that can be used simultaneously	Block	PFKD Public facilities kernel density	The density distribution and heatmap of various public facilities
		Plot series	PFM Public facilities mixedness	The degree of mixed public facilities per unit area
			FD Facilities density	The number of public facilities per unit area
		Building	LUM Land-use mixedness	The degree of mixed land-use of housing, working and amenities
Connectivity	The connectivity between elements within the system	Street	SC Street connectivity	The accessibility of the network and the importance of its connection to the entire area
		Plot series	PAC Plot accessibility	The accessibility of plot series
Modularity	The ability of a system unit to maintain independence from others and the overall system	Plot/Plot series	PAR Plot area	The size and scale of plot
			SQC Square compactness index	The regularity of the geometric shape of plot
Robustness	The strength and resistance of units such as buildings and other structures within the system	Block	SKD Socio-spatial kernel density	The density distribution and heatmap of social activity spaces
		Plot series	CP Control planning	Protection level of heritage zoning control planning
		Building	CV Conservation value	The protection value level of building
			BQ Building quality	The existing and protecting quality of building
			BA Building age	The construction year of building

benefits resilience. This study selected Gaode Map POI data as the primary data source, supplemented by field surveys for correction, and calculated kernel density on the POI data of various public facilities.

Public Facilities Mixedness (*PFM*) represents the variety of public facilities within a unit area (Haghighi Fard and Doratli, 2022), which is positively correlated with the functional complexity of the plot series. During the analysis, 1400 POI data were selected and categorized into 8 major types: tourist, dining, accommodation, religious, and other facilities. The calculation formula is as follows:

$$PFM = -\sum_{i=1} N_n \left\{ \left(\frac{P_i}{P_n}\right) \times \ln\left(\frac{P_i}{P_n}\right) \right\}, \tag{1}$$

where N_n is the sum of all types of facilities in plot series n, P_i is the number of POI for facility type i in plot series n, and P_n is the total number of POI in plot series n.

Facilities Density (FD) reflects the number of public facilities within a unit area, and it represents the degree of functional aggregation. The calculation formula is as follows:

$$FD = \frac{T_n}{S_n}, \tag{2}$$

where T_n is the number of facilities in plot series n, S_n is the area of plot series n.

Land-Use Mixedness (*LUM*) represents the degree of 3 mixed land-use of housing, working and amenities in a building (Ye et al., 2018). The Mixed-use Index (MXI) measures the proportion of three types of land-use and converts the values into coordinate points on a ternary plot through triangular coordinates (Ye and Nes, 2014b). This is an important and proven method for studying urban mixedness of land-use and function. Based on the function data for Quanzhou Ancient City heritage zoning and field survey findings, the composite conditions of functions of buildings were determined. This study used building floor area as the measurement criterion, mapping the areas of the three land-use types of buildings onto their respective plot, plot series, and block levels. The area proportions were then calculated, and MXI ternary plots were created to reflect land use across all spatial levels. The calculation formula is as follows:

$$A(H_{plot}) = A(H) + \frac{A(HA) + A(HW)}{2} + \frac{A(HWA)}{3}, \tag{3}$$

where $A(H_{plot})$ is the area of housing functions at the plot level, $A(H)$ is the area of housing single-function buildings, $A(HA)$ and $A(HW)$ are the area of housing dual-function buildings, $A(HWA)$ is the area of housing multi-function buildings. The calculation for others follows the same method.

3.3.2. Connectivity

Connectivity refers to the ability of components within a system to be connected, representing the system's accessibility, integration, collaboration, and other attributes. With the advancement of spatial syntax and other theories (Hillier et al., 1976), morphological studies have proposed numerous methods for analyzing street networks. Among them, axial models, segment models and other indicators can be used to measure street accessibility and district vitality (Jiang and Claramunt, 2002; Porta et al., 2006; Turner, 2007). Connectivity has a dual relationship with resilience: high connectivity facilitates the flow and spread of resources and helps recovery after disruptions, while low connectivity can reduce the spread of disturbances and help preserve memory areas. From the perspective of morphological conservation and continuity, in assessing historical districts resisting disturbances, highly connected morphological elements are lower in resilience. In other words, resilience is negatively correlated with connectivity.

Street Connectivity (*SC*) represents the accessibility of the network and the importance of its connection to the entire area. In spatial syntax theory, both closeness centrality and betweenness centrality can measure the accessibility. Closeness centrality evaluates global accessibility, that is, whether an entire street can efficiently connect to the city network. Betweenness centrality, on the other hand, evaluates the central role of network nodes, or the effectiveness of street segments in connecting different areas (Brandes, 2001; Newman, 2005). Since the research focuses on the historical districts of Quanzhou Ancient City, which requires a more detailed study of street accessibility at the segment level, betweenness centrality is chosen to represent the connectivity. The calculation formula is as follows:

$$SC = -\sum_{i \neq x \neq j} \frac{\sigma(i,j|x)}{\sigma(i,j)}, \tag{4}$$

where $\sigma(i,j)$ is the number of all shortest paths from node i to node j, $\sigma(i,j|x)$ is the number of the paths that passes node x, the number of times node x appears as an intermediary node in all shortest paths. To reduce the impact of boundary effects, this study used the sDNA tool to analyze the overall transportation network of the entire Quanzhou Ancient City in ArcGIS, and extracted a portion within the study area.

Plot Accessibility (*PAC*) is the accessibility attribute of plot series. Since this study is based on the overlay analysis of spatial polygon elements, the street connectivity, a linear attribute, should be converted into the plot sequence. The conversion from streets to plot series is achieved based on a distance decay model (Ye and van Nes, 2013, 2014). The calculation formula is as follows:

$$PAC = \sum_{i=1} B_t AR_{(x)i} \frac{L_i D_i^{\alpha}}{\sum_{i=1} L_i D_i^{\alpha}}, \tag{5}$$

where $B_t AR_{(x)i}$ is the connectivity results of street i around a plot series, L_i is the road centerline length of street i, D_i is the shortest geometric distance from the road centerline of street i to the edge of the plot series. α is the distance decay coefficient. In this study, α is set to -1, representing global accessibility decay.

3.3.3. Modularity

Modularity is defined as the ability of a system unit to maintain independence from other units and the overall system, reflecting attributes as independence, flattening, and decentralization. In complex adaptive systems, each unit is both an independent element and part of the system, with a certain degree of autonomy (Ahern, 2011). In urban morphology, modularity controls the interactions between urban elements and across different scales. The evaluation object mainly focuses on the geometric form at the plot level.

Plot Area (*PAR*) is an important measure of modularity. Within a certain scale range, larger plots imply more complex and well-developed spatial forms and internal functions. Plot area is positively correlated with modularity.

Square Compactness Index (*SQC*) is the regularity of the geometric shape of plot. Plots with higher square compactness have more regular boundaries, and their likelihood of aggregation or fragmentation after disturbances is lower. Plots with lower compactness, such as elongated or strip-shaped plots, tend to have lower resilience. The calculation formula is as follows:

$$SQC = \frac{S_i}{C_i} \times \frac{4\sqrt{S_i}}{S_i} = \frac{4\sqrt{S_i}}{C_i}, \tag{6}$$

where S_i is the area of plot i, C_i is the perimeter of plot i. The calculation is defined as the ratio of the plot area to its perimeter, divided by the ratio of the perimeter to the area of a square with the same area. When the square compactness approaches 1, the shape becomes more square-like; when it approaches 1.13, the shape becomes more circular.

3.3.4. Robustness

Robustness refers to the ability of a system and its elements to withstand external shocks without significant performance loss (Ayyub, 2014). In urban form resilience, it is defined as the ruggedness and resistance of units such as buildings and other physical structures within the system. *Xijie* Historic District is a socio-spatial composite urban system. Thus, we incorporated the social system behind material spaces into evaluation, enhancing the local relevance and distinctiveness of resilience assessment.

Socio-spatial Kernel Density (*SKD*) reflects the strength of spatial stability under social influence and maintenance. This study concentrated on the integrity and influence of official religious sites such as Kaiyuan Temple, and folk religious sites such as local temples, and intangible cultural heritage preservation sites, such as local theaters. Quanzhou Ancient City preserves the historical continuity of religious culture, with a large number of local temples within the city, used for spontaneous community rituals and daily life. The planning documents also list a series of intangible cultural heritage sites. Through a combination of field surveys and POI data, religious sites were labeled and subjected to analysis.

Control Planning (*CP*) and *Conservation Value* (*CV*) reflect top-down policy enforcement. The *Quanzhou Historical and Cultural City Protection Plan* (*Revision*) divided the plots of Quanzhou Ancient City into four control levels: protection, preservation, gradual updating, and transformation. The buildings were classified into five levels: protection, preservation, repair, improvement, and transformation.

Building Quality (*BQ*) can reflect the level at which it maintains stability in the face of disturbances. The longer the *Building Age* (*BA*) is, the more it indicates its ability to endure through changes. Based on the architectural evaluation data of Quanzhou Ancient City and field surveys, these two measures' data were incorporated into the study. Due to varying degrees of renovation and repairs, the selection of building dates in this study is based on the earliest reliable construction time.

3.3.5. Weight definition

The calculation of the evaluation indicator weights used expert survey method (Delphi Method) and analytic hierarchy process (AHP). First, through literature verification and expert scoring from universities and planning departments, the 13 evaluation indicators were assessed for their positive and negative correlations, and relative importance on a scale of 0—9. Then, an AHP matrix model was constructed to perform pairwise comparison matrices and normalization for each sub-indicator. Finally, data correction and consistency testing were carried out, resulting in the weight table.

AHP is a multi-criteria decision-making method that performs quantitative analysis of qualitative issues, which is widely used for weight calculation in evaluation models (Saaty, 1990). In brief, the structural equation of the AHP model used in this study is as follows (Xiang et al., 2024):

$$Y_{ij} = \frac{a_{ij}}{\sum_{m=1}^{i} a_{mj}}, X_i = \sum_{m=1}^{j} Y_{im}, W_i = \frac{X_i}{\sum_{m=1}^{i} X_m}, \tag{7}$$

$$Z_i = AW_i = W_i \sum_{m=1}^{j} a_{im}, \tag{8}$$

$$\lambda_{max} = \frac{1}{i} \sum_{m=1}^{i} \frac{Z_m}{W_m}, \tag{9}$$

$$CI = \frac{\lambda_{max} - i}{i - 1}, CR = \frac{CI}{RI}, \tag{10}$$

where i and j are two comparison factors: a_{ij} is set as the result of the comparison between i and j, and a_{ji} is the opposite comparison. Y_{ij} is the normalized result of the column vector in the expert comparison matrix, X_i is the result of rows in the expert comparison matrix, and W_i is the final weight corresponding to the i-th indicator. Z_i is the total weight value, A is the expert comparison matrix, CI is the consistency index, CR is the consistency ratio, and RI is the average random consistency index.

Based on the results of sub-indicators, an integrated morphological resilience system for *Xijie* Historic District was constructed as follows: First, the shapefiles for the sub-indicators were converted into 2.5-m pixel size (basic building scale) raster images on ArcGIS to ensure consistent unit scale. Secondly, the raster data was normalized and converted into dimensionless values to ensure that the value range of each analysis map falls between 0 and 1. Finally, the integrated morphological resilience figure of *Xijie* Historic District was obtained through raster weighted overlay in ArcGIS.

4. Results

4.1. Indicator evaluation

4.1.1. Diversity evaluation

The analysis of the distribution of public facilities on *Xijie* Historic District using kernel density (Fig. 7(a)) reveals that the overall distribution exhibits a pattern of lower concentration in the western section and higher concentration in the eastern section, with key facility hotspots distributed along the street. Public facilities are concentrated near the *Zhongshan Road* side in the eastern section and around the *Xinhua Road-Xijie Street* intersection, primarily due to the clustering of facilities as *Quanzhou Cinema*, *Intangible Cultural Heritage Market*, and *Xijie Market*. In areas with concentrated public facilities, the overall resilience of adaptability and flexibility is stronger.

The mixedness of public facilities is most concentrated near *Xiangfeng Alley* and the eastern side of *Kaiyuan Temple*, the most developed tourist areas in *Xijie* Historic District. Meanwhile, the eastern section has a wider variety of public facilities, in which the mixedness is generally higher than in the western section (Fig. 7(b)). The density of public facilities is mainly concentrated on both sides of *Xijie Street*, with commercial and tourism activities being more intense in the eastern section (Fig. 7(c)). In plots located inside the blocks, away from the main road, there are many privately renovated and operated homestays, which increase the overall diversity and social operational value of *Xijie* Historic District. Figure 7(d) shows the distribution characteristics of PFM and FD, indicating that the distribution of FD in plot series is generally more even. Over 60% of these plot series have a low mixing degree and are more vulnerable to disturbances. In summary, the diversity in the eastern section of *Xijie* Historic District is higher than in the western section and along the street than in the interior plots.

According to the relevant theories of MXI, the building functions were categorized into six types: H, W, A, H + W, H + A, W + A and W + H + A, corresponding to low, medium, and high mixedness. The medium and high mixed buildings were mainly concentrated around streets (Fig. 8(a)). Subsequently, the MXI index at the plot, plot series, and block levels was calculated (Fig. 8(b–e)). Objects with a single land-use proportion greater than 95% were defined as low mixedness, those with two land-use functions greater than 5% as medium mixedness, and those with three land-use functions greater than 5% as high mixedness. It is evident that high mixedness is most significant at the plot series level, while as the morphological units become more detailed, the objects gradually tend toward a low mixedness.

4.1.2. Connectivity evaluation

From the perspective of heritage conservation, with the goal of urban form protection, a morphological system with

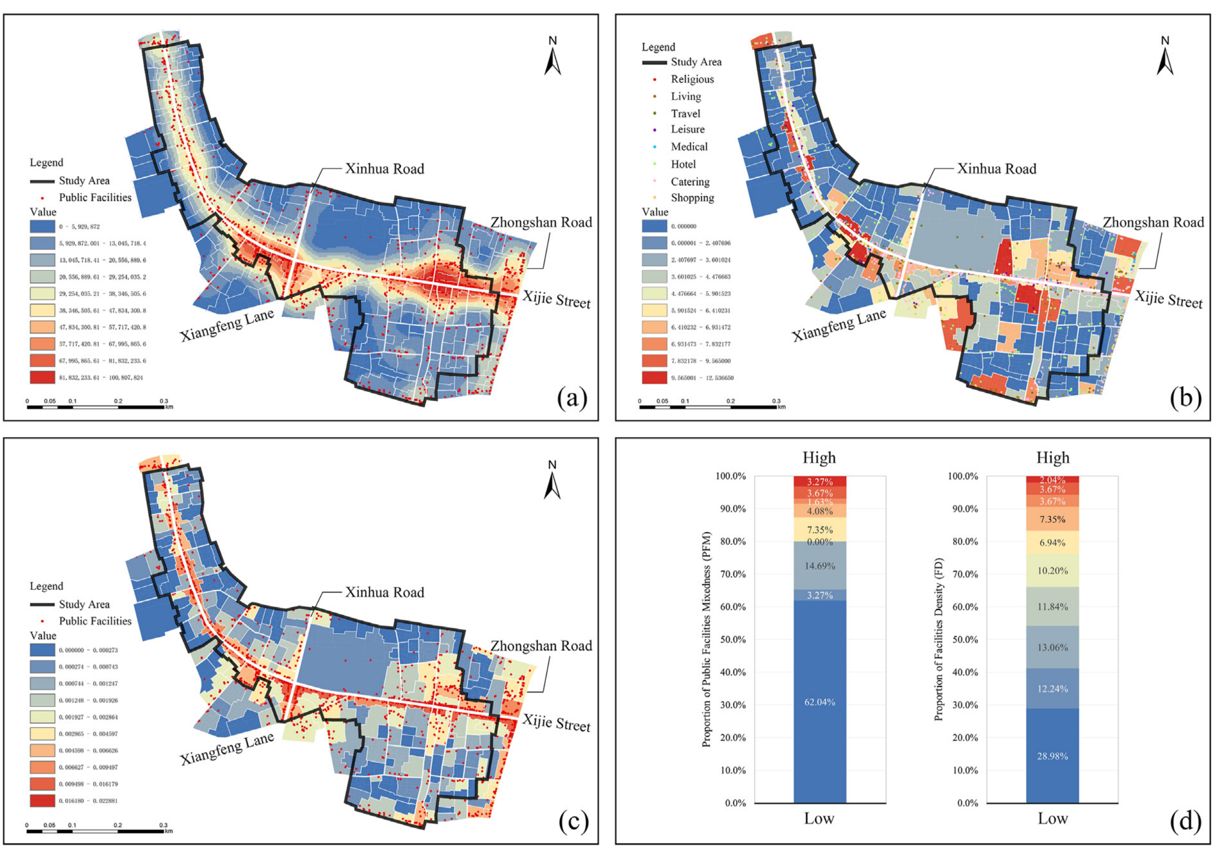

Fig. 7 Morphological resilience evaluation analysis: (a) Public Facilities Kernel Density (PFKD); (b) Public Facilities Mixedness (PFM); (c) Facilities Density (FD); (d) population distribution of PFM and FD.

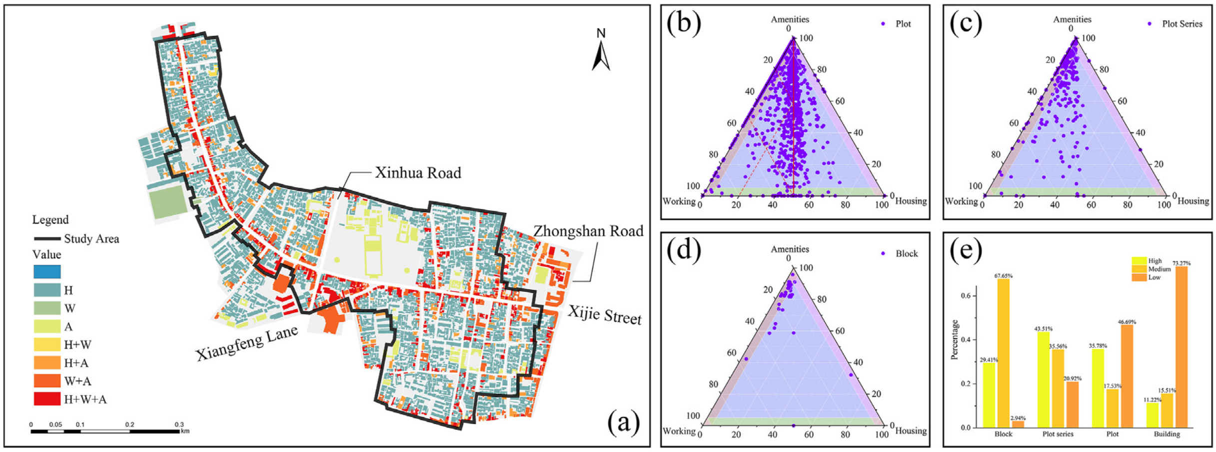

Fig. 8 Morphological resilience evaluation analysis: (a) Functional Mixedness (FM); (b) MXI analysis of plot; (c) MXI analysis of plot series; (d) MXI analysis of block; (e) distribution of mixedness of 3 layers.

low connectivity is less likely to be affected by external disturbances, meaning it has stronger resilience. From the overall street connectivity of Quanzhou Ancient City, *Xijie Street*, *Xinhua Road*, and *Zhongshan Road*, as the core thoroughfares of the ancient city, have relatively high connectivity. Due to the boundary effect in sDNA analysis, there may be errors in assessing the road connectivity at the city's edges, so the roads within the study area were selected (Fig. 9(a, b)). As the roads penetrate deeper into the blocks, connectivity decreases from *primary roads—secondary roads—tertiary roads/entrance paths*. Some secondary roads in the southeastern section have higher connectivity due to attached plazas. After converting street connectivity into plot accessibility, it is observed that the accessibility in the eastern section is generally higher than in the western section, with the highest connectivity found near the *Kaiyuan Temple and Towers* area. The plot series along primary roads like *Xiangfeng Alley*, due to their better spatial openness and views of the towers, have higher overall accessibility compared to the surroundings (Fig. 9(c)). In conclusion, connectivity gradually increases from west to east, with stronger accessibility along main roads as *Xijie Street* and *Xinhua Road*.

4.1.3. Modularity evaluation

The study of modularity is based on two levels: plot and plot series, followed by a comparative analysis. The *Kaiyuan Temple* super-plot in the study area, due to its characteristics related to cultural tourism, heritage preservation, and other factors, has the strongest ability to resist morphological changes (Fig. 10(a—c)). The plots in the western section are generally more regular, with a high square compactness, while the eastern section contains some irregular plots, mostly concentrated around Zhongshan Road. These plots are more likely to aggregate or decompose after being impacted or disturbed (Fig. 10(b—d)). As shown in Fig. 10(e—g), through the distribution plot of PAR-SQC, the plot areas are mainly concentrated below 1000 m^2, that of plot series are mainly below 4000 m^2. Meanwhile, define that plots or plot series with an SQC greater than 1 have more regular shapes. Thus, it can be observed that the overall morphology of the plot series is more complete and tends to stabilize, though their area range is more extensive, and larger areas often correspond to more irregular shapes.

4.1.4. Robustness evaluation

In *Xijie* Historic District, the local temples where spontaneous religious activities occur remain the central places for residents' activities within each block. These temples exhibit high social-spatial kernel density, and the social networks they form enhance the spatial resilience against disturbances. As shown in Fig. 11, these core temples and local theaters are primarily characterized by *Minnan* architectural features and integrated complex social activities such as daily life, rituals for deities, procession of deities and folk performances. Driven by the heritage attributes of *Kaiyuan Temple*, a social-spatial radiation system with a central node and multiple points has been formed.

Based on the existing heritage preservation data for Quanzhou, the study area is defined as the core zone for the heritage protection plan of *Xijie* Historic District, primarily classified by conservation level. In the southwest section, a few plots are undergoing gradual renewal, while buildings with higher protection levels include cultural heritage sites and traditional *Minnan* houses (Fig. 12(a, b)). As shown in Fig. 12(c, d), buildings with poor quality are primarily concentrated at the ends of the western section. Most buildings in the district were constructed between 1949 and 2000, having undergone several reconstructions and refurbishments over time. The robustness assessment reflects two aspects: the stability of grassroots self-organization and the enforceability of planning policies, illustrating the external manifestation of resilience under the combined influence of social culture and heritage preservation.

4.2. Overlay integrated resilience

Through Delphi Method of experts such as those from the Quanzhou Maritime Silk Road World Heritage Center and

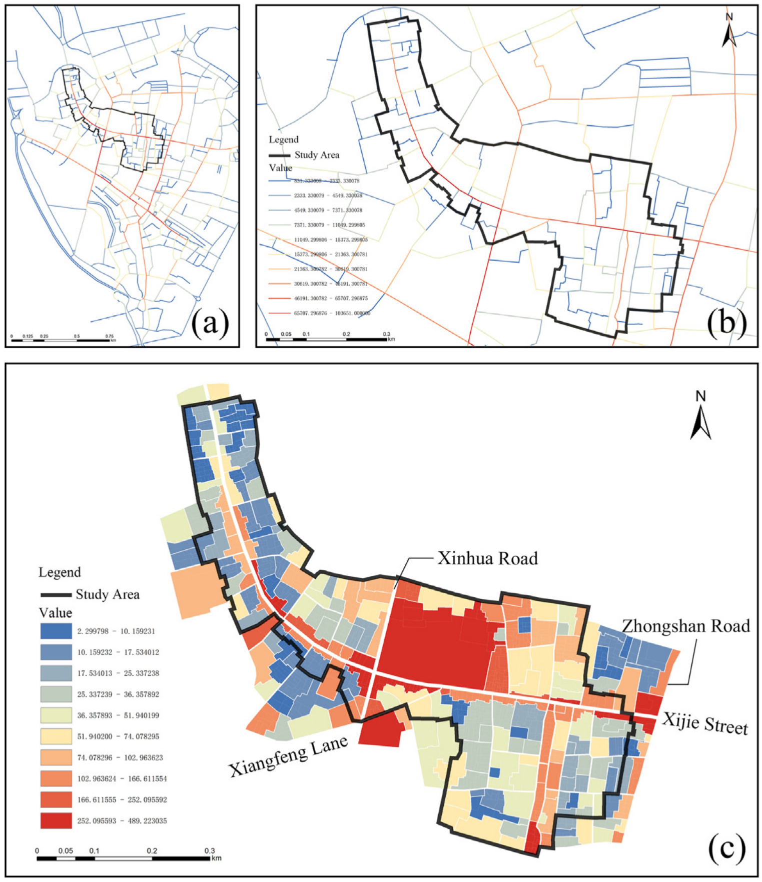

Fig. 9 Morphological resilience evaluation analysis: (a) Street Connectivity (SC) of Quanzhou Ancient City; (b) Street Connectivity (SC) of *Xijie* Historic District; (c) Plot Accessibility (PAC).

university professors, the relevance and importance of the indicators were assessed. AHP was used to construct a judgment matrix, and the weights of each indicator were calculated, as shown in Table 3. The consistency ratio was calculated to be $CR =$ 0.0261, which satisfies the consistency check $CR < 0.1$. The detailed calculation process can be found in Appendix Tables 1—5.

Finally, in ArcGIS, the resilience sub-indicators were weighted and subjected to raster overlay to obtain the integrated morphological resilience of *Xijie* Historic District (Fig. 13(a)). Overall, low-resilience areas are mainly distributed within the blocks on the south side of *Xijie Street*, while the resilience of the areas along the street and the historical heritage zones is relatively high. The evaluation results align closely with the intuitive perception of district vitality observed during the field survey. At the same time, they reveal more precise vulnerable areas that are otherwise difficult to identify qualitatively. As shown in Fig. 13(b—d), from the raster data statistics and area histogram analysis, the evaluation results generally follow a normal distribution, with a concentration of medium resilience taking the highest proportion. The calculated result of 0.234—0.429 for the three-level data is defined as low resilience, accounting for 16.10%. The resilience evaluation focuses on identifying these low-resilience areas and proposing targeted planning and development strategies.

5. Discussion

5.1. Correlation of secondary indicators based on plot series

In urban morphology theory, the concept of *plot series* is similar to *land-use unit* or *zoning lot* in control of detailed planning. It also connects the four primary indicators of this study and serves as an important level for evaluation and strategy formulation, as well as a key practical target for controlling the urban form of historic districts. Meanwhile, except for robustness, the secondary indicators corresponding to plot series in this study generally have higher weights within their primary indicators. The total sum of the corresponding indicators with plot series is 0.4363, making it the most important morphological level in the indicator system. Therefore, a Pearson correlation analysis was performed on the secondary indicators related to plot series, as shown in Fig. 14. Based on the correlation of the indicators in the analysis results, the following conclusions can be drawn.

(1) There is a significant positive correlation between the three secondary indicators, PFM, FD, and PAC. Increasing the quantity and variety of public facilities contributes to the overall enhancement of diversity,

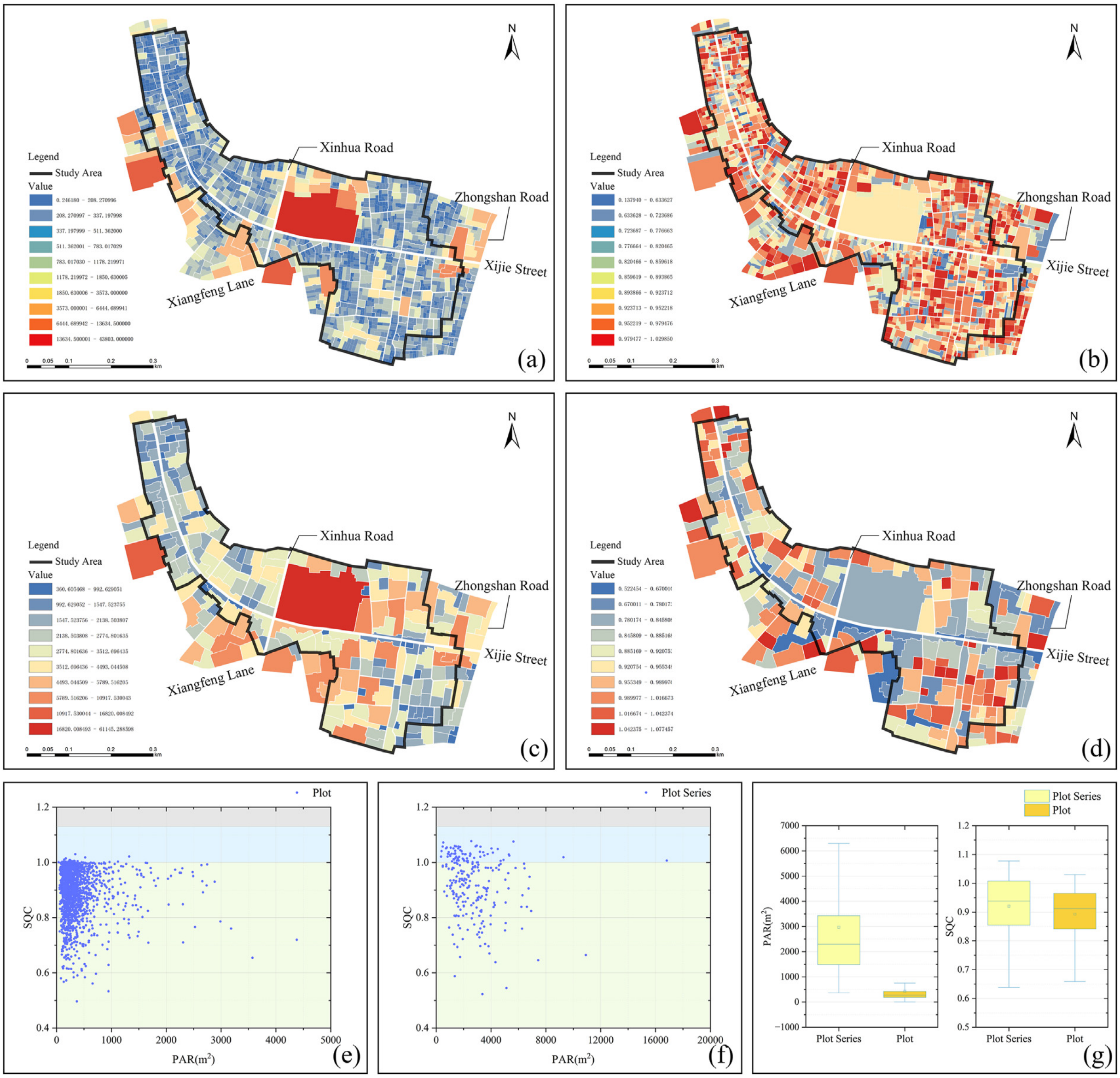

Fig. 10 Morphological resilience evaluation analysis: (a) Plot Area (PAR) of plot; (b) Square Compactness Index (SQC) of plot; (c) PAR of plot series; (d) SQC of plot series; (e) PAR-SQC scatter plot of plot; (f) PAR-SQC scatter plot of plot series; (g) Box plot of PAR and SQC.

especially in the majority of plot series with residential types. More public facilities can lead to higher attractiveness, stronger street connectivity, and more employment opportunities, thereby strengthening the historical district's ability to resist and adapt to disturbances.

(2) The three indicators mentioned above negatively correlate with SQC, which can be understood as plot forms with higher square compactness being more regular, with shorter block perimeters and street frontage lengths, making it less favorable for the distribution of public facilities and plot accessibility. Therefore, in the conservation and renewal, it is necessary to appropriately increase the diversity of public facilities in plot series with higher square compactness, while controlling excessive accessibility to prevent influence on material heritage and social memory.

(3) PAC and PAR form another group of significantly positively correlated indicators. A more minor subdivision of the plot area means more traffic passages around, which helps improve accessibility. Since improvements in other indicators are related to public facilities and protection planning, the plot area, a complete morphological attribute, is the most intuitive object in actual planning and control. Therefore, a comprehensive evaluation of these two sets of indicators is conducted. Based on the normalized $\text{PAR}^*-\text{PAC}*$ scatter distribution of 240 plot series, a correlation curve can be fitted as $y = 0.192x^{0.125}$. Substituting this into the morphological resilience weighted calculation $R_1 = 0.0180\text{PAR}^* - 0.0601\text{PAC}^*$,

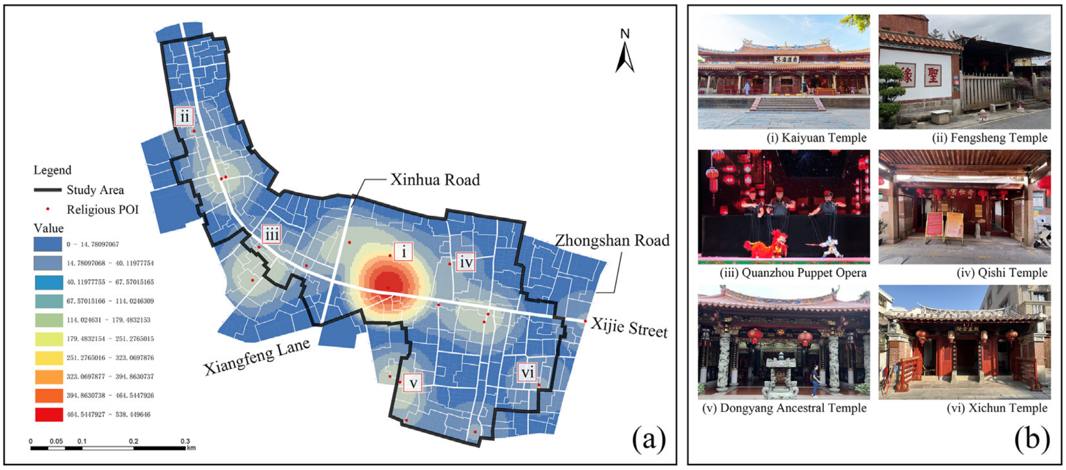

Fig. 11 Morphological resilience evaluation analysis: (a) Socio-spatial Kernel Density (SKD); (b) temples and religious spaces of *Xijie* Historic District.

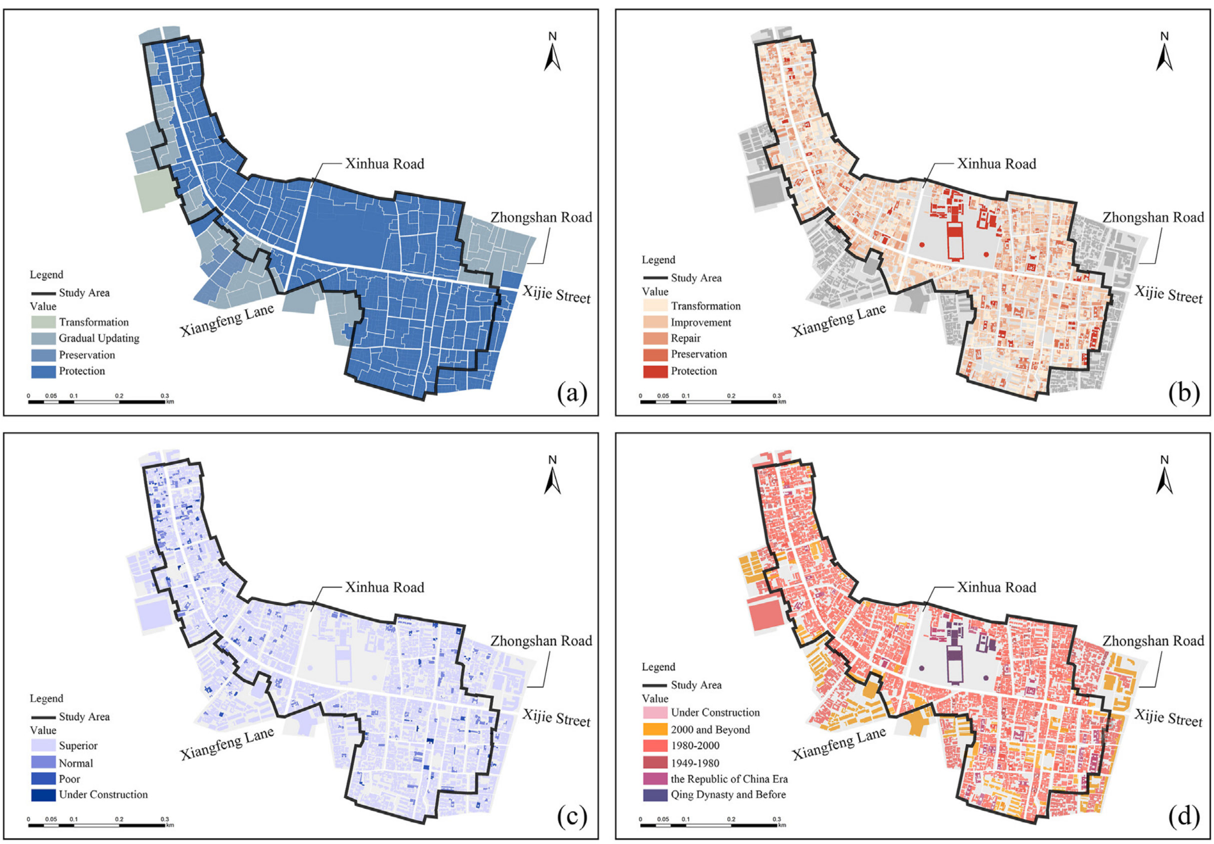

Fig. 12 Morphological resilience evaluation analysis: (a) Control Planning (CP); (b) Conservation Value (CV); (c) Building Quality (BQ); (d) Building Age (BA).

it can be calculated that when PAC∗ is 0.00163, which corresponds to PAR∗ being 0.08604, the maximum comprehensive resilience value is obtained. At this point, the plot series area is approximately 1776 m^2. It can be preliminarily concluded that when the plot series area is between 1500 and 2000 m^2, it can balance modularity and connectivity. In the control of plot series in historical districts, this scale also generally aligns with the principles of *smart plot division* (Adams et al., 2013; Liu et al., 2020).

(4) Improving robustness requires renovating and upgrading morphological units with low BQ and CV in plots with a low CP grade. At the same time,

Table 3 Morphological resilience indicator weights.

Primary indicator	Morphological hierarchy	Secondary indicator	Correlation	Weight	
Diversity	Block	PFKD	+	0.0154	0.2731
	Plot series	PFM	+	0.0823	
		FD	+	0.1013	
	Building	LUM	+	0.0741	
Connectivity	Street	SC	−	0.0592	0.1193
	Plot series	PAC	−	0.0601	
Modularity	Plot/Plot series	PAR	+	0.0180	0.1073
		SQC	+	0.0893	
Robustness	Block	SKD	+	0.0715	0.5003
	Plot series	CP	+	0.0853	
	Building	CV	+	0.2080	
		BQ	+	0.0938	
		BA	+	0.0416	
				CR	0.0261

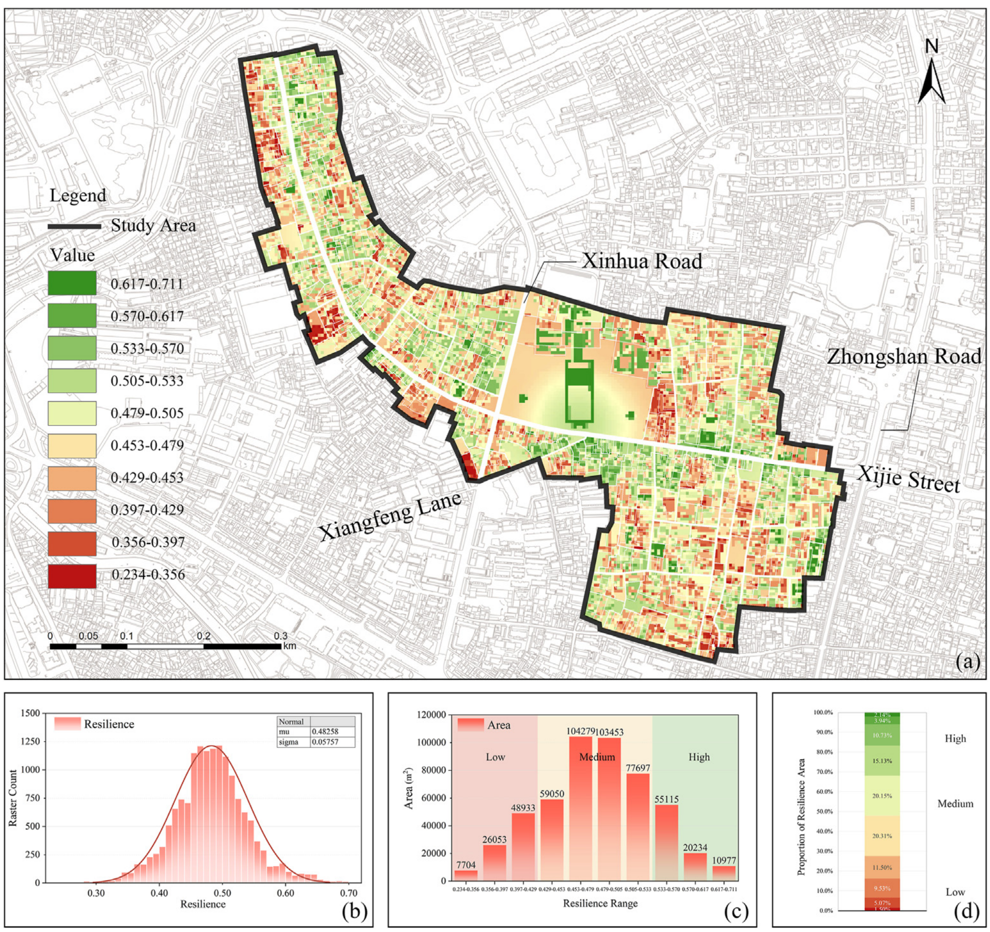

Fig. 13 Integrated morphological resilience of *Xijie* Historic District: (a) raster overlay figure; (b) histogram of raster data; (c) histogram of resilience area; (d) population distribution of resilience area.

attention should be paid to controlling the height, materials, and other aspects of the architectural style while adding functions such as intangible cultural heritage performances and old Quanzhou brand stores. This will ensure that during the protection process of historic districts, the morphological resilience and the vitality of the architectural style are well coordinated.

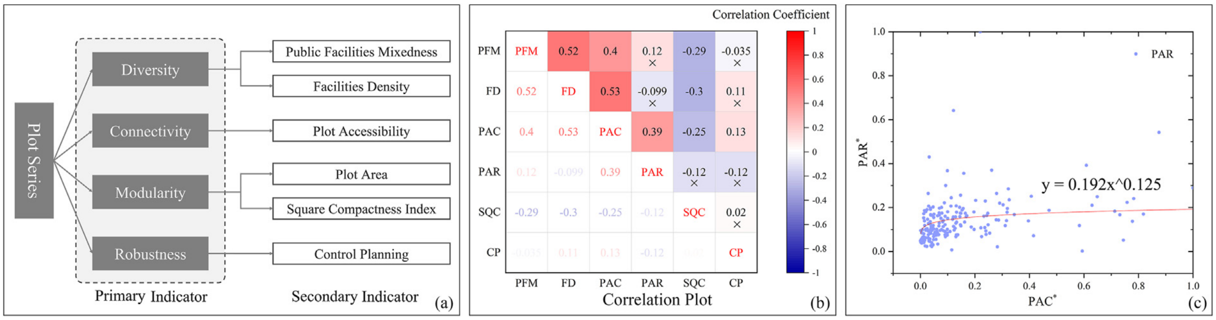

Fig. 14 Characteristics of the secondary indicators corresponding to plot series: (a) indicators of plot series; (b) correlation plot of various indicators; (c) PAR*—PAC* scatter distribution plot.

5.2. Correlation of primary indicators towards tourism orientation

The development of tourism and commercial economies is one of the most significant external pressures that *Xijie* Historic District is facing, as well as an inevitable challenge in the evolution of different historic districts. Among the four primary resilience proxies selected in this study, modularity describes the intrinsic attributes of urban morphology, while robustness focuses more on endogenous social dynamics and external policy support. Diversity and connectivity are closely related to the growth of tourism. In the assessment of diversity, a significant portion of POI pertains to tourism-related facilities such as leisure, hotel, shopping, and catering points. Meanwhile, connectivity enhances the movement of tourists within the historic district. Therefore, based on the plot series layer, the zonal mean statistics of three raster datasets, integrated resilience (RES), diversity resilience (DIV), and connectivity resilience (CON), were calculated, followed by Pearson correlation analysis (Fig. 15). The results indicate that RES is positively correlated with DIV but negatively correlated with CON, with DIV being the more significant factor, aligning with the weight determination results. A key observation is that the correlation coefficient between DIV and CON reaches 0.34, suggesting a moderate positive correlation. This implies that areas with better connectivity tend to host more public facilities. In turn, the functional diversity of these facilities further attracts the movement of both tourists and residents.

In the process of tourism development, the emergence of commercial facilities is often a spontaneous phenomenon. However, excessive diversity and connectivity can lead to overdevelopment and the disruption of the historical landscape. To address these challenges in urban form management, the following suggestions are proposed: (1) Strictly regulate commercial development in historic districts. Along commercial streets, establish a positive and negative industry list management mechanism and priority should be given to local brands, traditional handicraft and cultural creative shops, ensuring that tourism and cultural development are guided orderly. (2) Protect the daily lives of original residents. Along residential streets, encourage the continuation of existing residential functions while supplementing necessary living services. Tourist access should be moderately restricted to prevent excessive commercialization and gentrification. (3) Preserve the functional integrity of folk religious and cultural spaces. While maintaining existing functions, encourage public or partial access. Transformations that alter the historical and cultural essence of these areas should be strictly prohibited.

5.3. Conduction of multi-level morphological strategies

In complex adaptive systems, resilience is an evolutionary mechanism, while sustainability is always a proactive concept. When applied to objects as historic districts, the enhancement of resilience within control contributes to sustainable development. Currently, the focus of heritage

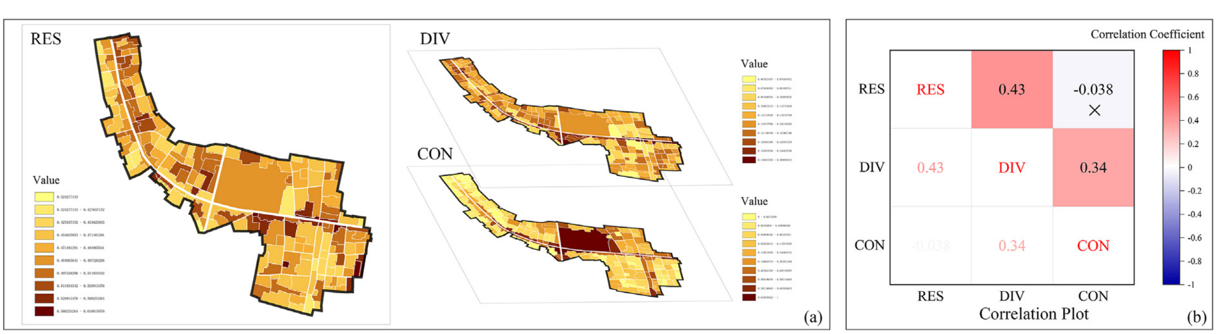

Fig. 15 Characteristics of the primary indicators corresponding to tourism: (a) mean value of integrated resilience (RES), diversity resilience (DIV) and connectivity resilience (CON); (b) correlation plot of various indicators.

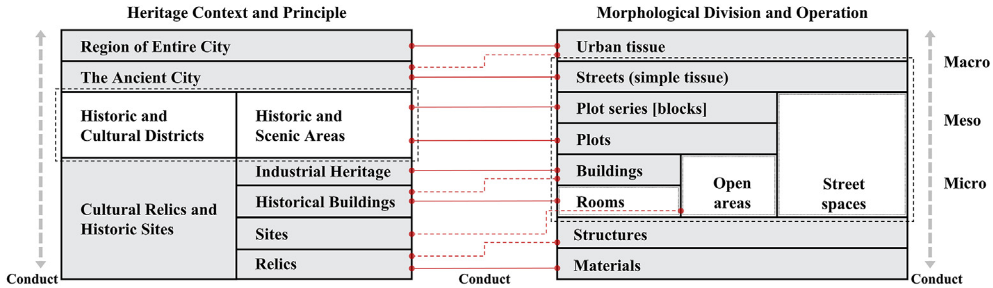

Fig. 16 Connection between heritage context in Quanzhou and multi-level diagram theory.

conservation has shifted from the heritage itself to the sustainable coordination of heritage districts with urban development. Historic districts are an important practical target for conserving and renewing heritage areas. In the process of study and practice with historic districts, it is important to avoid two extreme models: rigid and strict protection, large-scale demolition and construction. In recent years, the *small-scale and gradual* urban renewal approach has been widely accepted (Dong et al., 2022), and the protection logic for historic districts should gradually shift from control and preservation to the asset revitalization mode.

Quanzhou Historical and Cultural City Protection Plan (Revision) classified the heritage conservation into four spatial levels: the region of the entire city, the ancient city, the historic and cultural districts and scenic areas, the cultural relics and historic sites (Fig. 16). This classification has a particular connection with multi-level diagram theory. Therefore, based on the spatial layers of heritage protection, different scales from macro-to micro-should be defined, and the degree of updating strategies should present diversified and targeted characteristics. Overall, the macro level focuses on protection, while the meso- and micro-levels emphasize guided updates (Table 4).

5.4. Unit division and control implementation

Based on the hierarchical strategies and evaluation results in this study, the method of dividing resilience units is used for categorized management, thus enhancing the morphological resilience of each spatial unit (Fig. 17). First, 34 blocks were divided into primary control units to promote overall collaborative governance of the area. Then, the plot series was taken as 240 secondary control units. The average values of the integrated morphological resilience quantification results for each plot series were extracted. Categorize the secondary control units into 3 types: maintenance, enhancement, and rebuilding, with corresponding conservation and renewal strategies. Additionally, for

Table 4 Hierarchical strategies of historic district.

Scale	Hierarchy	Strategy	Approach
Macro-	Street block	Emphasize protection, minimize renewal, and focus on resistance.	Strictly follow preservation plans to maintain the overall form of historical districts unchanged. Restore historical layouts to some extent, strengthen the integrity and authenticity of the old city, and minimize new construction. Improve the public service functions of the district, shifting from an independent and self-sufficient preservation system to a dynamically stable urban functional unit, achieving interaction between the old and new parts of the city.
Meso-	Plot series	Equal emphasis on protection and renewal, focusing on adaptation.	Strengthen the preservation of the current status of protected and retained plot series in the planning. Allow some degree of flow and updates between plot series, enhancing the functional mix, accessibility and resilience. Respecting the original plot series pattern, gradually promote the construction of plot series under transformation and updating.
Micro-	Plot building	Strengthen classification and control, with appropriate updates, focusing on transformation.	Strengthen the protection and regulation of private property rights for plots to ensure the quality of the living environment. Differentiate plot and building renewal levels based on functional and development intensity variations. Implement targeted measures based on resilience evaluation, strengthening the definition and division of physical, property, and planning plots. Develop a set of regulations based on heritage value, strictly controlling architectural styles, but allowing reasonable renovation with lower protection value.

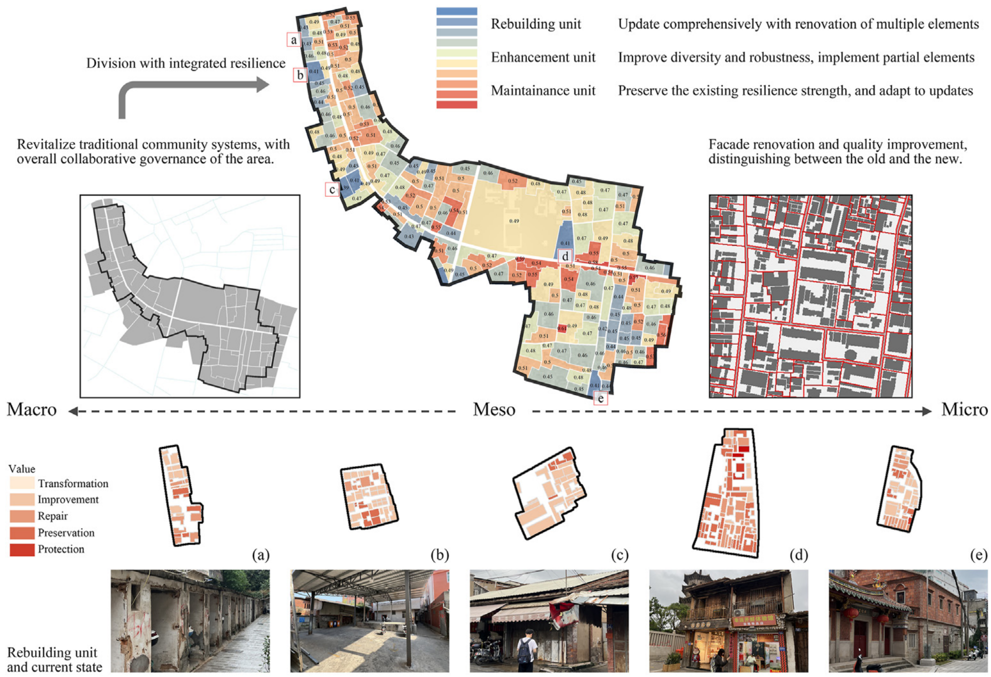

Fig. 17 Division of multi-level morphological controlling units.

particularly weak secondary units, key renovation and updates were planned. Finally, all plots and buildings were designated as tertiary control units, with strategies for facade renovation and proper transformation.

Select 5 secondary units with the lowest resilience for analysis. Units a and b have low resilience due to poor building quality, single functionality, and their location at the edge of the ancient heritage area. Unit c is located near old factories, with few public facilities and a low protection level. Unit d has a long building history, with functions that have changed multiple times in recent years. Unit e has a low protection level and a single function. These resilience units should become key monitoring targets for heritage conservation and renewal.

6. Conclusion

This study focuses on the conservation and renewal of historic districts. Based on the theory of morphological resilience, an evaluation system has been improved and applied. From the perspective of resilience and using morphological classification methods, the relationship between morphological layers and resilience indicators was further refined, and an analytical framework of *Morphological Hierarchical Division — Resilience Quantitative Cognition — Differentiated Unit Control* was proposed. We divided the material space of historic districts into 5 layers, and selected 13 relevant indicators for weighted analysis. After mathematical modeling, we assessed weak units accurately, and proposed corresponding improvement strategies for the refined protection of historic districts. In addition to the application Quanzhou *Xijie* Historic District, the indicator system can also be used for different types of historic districts, with adjustments to the weights based on actual conditions. Based on this, the innovations of this study are as follows: (1) In response to the abstract concept of resilience, the analytical and evaluation framework is improved to guide urban design and heritage protection; (2) The use of morphological multi-level diagram theory improves and supplements the integrity and operability of the morphological resilience evaluation at the meso-micro level; (3) By comprehensively considering spatial factors affected by social, a multi-scale unit division is proposed to implement targeted strategies based on local conditions; (4) The plot series is selected as the key analysis and operational level, and multi-indicator strategies are proposed to enhance overall resilience and adapt to tourism development.

Based on the adaptation between heritage values and the surrounding environment, coordinating historical districts conservation with urban development must be a multidimensional and holistic solution. Regarding the evaluation and cognitive, this study attempts to construct a more equitable and diverse evaluation method, maintain consistency and coordination between various resilience attributes, and obtain relatively scientific and comprehensive results. In terms of analysis and assessment, this study explores the synergistic relationship between indicators, proposing that historic districts' conservation and renewal should be based on tailored cognition. In terms of practice and operation, firstly, resilience enhancement requires not static conservation but a balanced co-development of community, tourism, commerce and other aspects of urban system. The proposed strategies, including division of plot series and streets, addition of character-defining public facilities, collectively promote heritage sustainability. Secondly, through targeted intervention in plot series and tailored governance strategies through morphological resilience assessment, this framework achieves integrated conservation at macro scales while enabling progressive revitalization at micro-meso scales.

This study remains some limitations. On the one hand, our research on the historic districts mainly focuses on factors of material space. In future studies, when the study area is expanded to a higher level, more attention should be given to macro-resilience regarding social, economic, and institutional aspects. On the other hand, there may be a certain degree of overlap and interaction between social and spatial resilience, requiring further research on adaptability at the sociological level. On the basis of classified conservation and renewal of physical space, it is necessary to provide institutional guarantees for the endogenous development of communities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foar.2025.05.003.

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