Heritage Science

RESEARCH **Open Access**

Quantitative research of street interface morphology in urban historic districts: a case study of west street historic district, Quanzhou

Kai Huang[1], Peiran Kang[1] and Yang Zhao[1*]

Abstract
Historical urban districts are imbued with a multitude of elements, including historical heritage, cultural significance, social relationships, and daily activities, making them of significant research value. Through a review of previous literature, it is evident that research on the protection and renewal of historical urban districts has mostly focused on macro-level planning and development. Addressing the lack of spatial morphology quantification research at the meso-level, this paper proposes a method suitable for quantifying interface morphology in historical streets. Using the historical cultural street district of Xijie in Quanzhou, Fujian Province as a case study, this research employs parameters such as Distance-Height Ratio, Interface Density, Build-To-Line Rate, and Near-Line Rate to quantify and summarize the morphology of street interfaces. It then proposes transformation strategies to guide the protection and renewal of streets in the future. The study validates the feasibility of this quantification method and provides valuable insights for the protection and renewal of historical urban districts.

Keywords Historic district, Street space, Interface morphology quantification, City planning, Architectural heritage, Conservation

Introduction
Urban historical and cultural districts serve as crucial repositories for preserving historical artifacts and embodying cultural evolution, representing invaluable cultural assets [1]. As urbanization progresses, there has been a transition from "incremental expansion" to "stock optimization" in land resource management [2]. Historical districts, as quintessential examples of culturally significant yet vulnerable areas within urban landscapes, are in dire need of protection and revitalization.

Since the twentieth century, the significance of historic districts in urban development has gradually gained recognition (see Table 1). The French "Historical Cultural Relics Law" (Loi du 31 décembre 1913 sur les monuments historiques) marked a milestone as the world's first heritage law, acknowledging cultural heritage as mankind's public wealth and pioneering the registration and protection of cultural artifacts [3]. The Athens Charter, adopted in August 1933, asserted that "buildings and districts with historical value should be properly preserved and not destroyed" [4]. The Venice Charter of 1964 brought public attention to the protection of Historic Districts [5], and the Nairobi Recommendations (Recommendation Concerning the Safeguarding and Contemporary Role of Historic Areas) of 1976 emphasized that "the preservation of historic areas and their integration into the lives of modern society are essential factors in urban planning and land development" [6]. The Washington Charter, also known as the "Charter for the Preservation of Historic Towns and Urban Areas," formally defined Historic Districts as "historic urban

*Correspondence:
Yang Zhao
13678@hqu.edu.cn
[1] School of Fine Arts, Huaqiao University, Quanzhou 362021, Fujian, China

Table 1 Documents related to the preservation and renewal of international historic and cultural districts

Time	Organisation	File	Content
1913	French	Historical Cultural Relics Lawcurriculum	Preservation of all or part of immovable property of public interest as historical monuments from the historical or artistic point of view
1933	C.I.A.M	The Athens Charter	All buildings and districts of historical value must be appropriately preserved to prevent damage, especially those representative of particular periods, of general interest for educational purposes, and not detrimental to inhabitants' health
1964	ICOMOS	The Venice Charter	Clarifies the concept of a historic heritage building, requiring that all scientific techniques must be utilized to protect and restore the heritage building, and that the layout or decoration of the building must not be altered
1976	UNESCO	Recommendation concerning the Safeguarding and Contemporary Role of Historic Areas	That historic areas provide the most accurate testimony to the diversity and wealth of cultural, religious and social activities, and that their preservation and integration into the life of modern societies is an essential factor in urban planning and land development
1987	ICOMOS	Charter for the Conservation of Historic Townsand Urban Areas	Historic urban areas, large and small, including cities, towns and historic centers or districts, and their natural and built environments
1999	UIA	The Beijing Charter	Summarizing the twentieth century's zeitgeist of great development and destruction, it states, "The destruction of cultural heritage has jeopardized humanity's own survival, and 'constructive' destruction is commonplace."

areas, large and small, including cities, towns, and historic centers or districts, and their natural and built environments," stressing the importance of spatial morphology in historic district studies [7]. The Beijing Charter, adopted at the 20th World Congress of Architects in Beijing in 1999, encapsulated the zeitgeist of the twentieth century, marked by significant development and destruction. It pointed out that "the destruction of cultural heritage has jeopardized the survival of mankind itself. 'Constructive' destruction is commonplace" [8]. Therefore, the preservation of the spatial form of the historic district is urgent.

The study of Spatial Morphology in Historic Districts can be categorized into three levels based on the forms of "point," "line," and "surface." This includes the microscopic point-like space of Historic Buildings, the mesoscopic linear space of Historic Streets, and the macroscopic surface-like space of Historical Districts. Currently, numerous scholars focus on the planning and development of the overall spatial layout of historical districts, while research on the Spatial Morphology of Historic Streets is relatively limited. Due to the lack of a theoretical basis for describing the spatial characteristics of streets, it is difficult to characterize the spatial differences in the morphology of historic streets. Therefore, the existing conservation of historic streets lacks clear spatial morphology control standards and often relies on the general expression "in harmony with the historical features." The renovation and renewal of street space in historic districts is in dire need of a methodology that can establish standards for spatial form control.

As a public space, a street is composed of a horizontal plane and two vertical planes serving as edges or boundaries. The term "Interface" is introduced in Architecture to describe the boundary sections that separate the internal space of a building from the external natural environment. The Street Interface is a physical entity generated by the interactions between Urban Morphological Elements (streets and buildings), and the attributes of the Interface constitute essential content in the Spatial Morphology of streets. As argued by Glaser et al. [10] who stated that "the ground floor may be only 10% of a building, but it determines 90% of the building's contribution to the experience of the environment." Numerous scholars have delved into the study of Street Interfaces [9, 11–13], but the application of street interface morphology theory to the spatial preservation and renewal of street space in historic districts has not yet been mentioned.

In view of this, this paper takes the West Street Historical and Cultural Neighborhood in Quanzhou City, Fujian Province, China, as a case study to conduct systematic research on the interface morphology of historical streets. It tries to explore a quantitative methodology applicable to the interface morphology of historical streets based on the theory of quantifying the interface morphology of urban streets. The aim is to establish a control standard applicable to the conservation and renewal of local historical streets through the quantitative characterization of the interface morphology. This method is based on actual data analysis, rather than only relying on the general expression of "harmonization with historical features." It can shift the protection and renewal of the spatial form of historic streets from traditional qualitative research to quantitative research, fill the gap in the field of quantitative research on the interface form of historic streets, and make the renewal of the interface form of the streets become evidence-based. It can provide a more objective reference sample for the protection and renewal of street space in future historic districts.

Literature review

The literature review in this document is organized into four sections. The first section offers a retrospective analysis of research on the preservation of historic districts. The second section delves into a review of Spatial Morphology Studies related to historic districts. The third section concentrates on a retrospective analysis of research on the renewal of historic districts. The fourth section delineates the distinctions between this study and prior research in the field.

Study on the preservation of historic districts

Currently, research on the conservation and utilization of Historic Districts can be broadly categorized into Qualitative and Quantitative studies. Qualitative research involves exploring the nature of historic district preservation issues, analyzing the current situation, and assessing their impacts. Quantitative research, on the other hand, utilizes various measurement models or mathematical languages to represent historic district preservation issues and phenomena with data. This allows for the analysis, evaluation, and interpretation of these issues using quantitative methods.

In qualitative research, scholars explore dimensions such as policy, ecology, sustainability, revitalization, tourism, economy, and culture, falling into three main categories. The first category discusses the current status and situation of historic districts. Chen et al. [14] summarized new trends in Chinese urban politics through redevelopment case studies. Similarly, Zhu and Martínez [15] investigated the impact of heritage-led redevelopment on the urban landscape and social structure in Chinese cities. Blum and Orbach [16] assess the link between activity and conflict in historic districts through public policy. The second category explores the impact aspects of historic districts, addressing cultural and economic factors. Wang [17] proposed strategies to stimulate cultural and economic revival, while Boussaa [18] discussed how cultural and economic forces integrate with a historical city or region. Jayantha and Yung [19] analyzed the social and economic impacts of historic districts on communities. The third group of scholars conducts research by combining historic districts with other fields. Some scholars explore the preservation methods of historic districts from an ecological and sustainable perspective [20–22]; others combine the preservation of historic heritage areas with tourism [23, 24]; while others try to combine transportation [25], revitalization of heritage [26], and other fields to achieve the purpose of revitalizing historic districts. Qualitative research on the conservation and utilization of Historic Districts largely focuses on discussing overall situations and impacts, as well as exploring interdisciplinary conservation concepts.

Quantitative research on historic districts can be categorized into four types. The first involves constructing evaluation systems for historical districts, utilizing perspectives such as conservation efforts [27], spatial activation [28], and public health [29]. Additionally, with the advent of the data era, some scholars have started utilizing big data, such as internet data [30], Internet of Things sensing [31], and network comment texts [32], for evaluation. The second type pertains to studies related to Historic District spaces. In this field, the application of spatial syntax is prevalent, mainly used for analyzing spatial topological structures [33–36]. Scholars using GIS for Spatial Morphology research are also numerous, focusing on spatial patterns and features [37–40]. Some scholars use GIS to assess the landscape sensitivity of historical districts, as seen in the works of Fang et al. [41] and Yang and Shen [42]. As the concept of a people-centered approach gradually takes hold, scholars are no longer confined to studying historical districts from an objective perspective. The third type explores the relationship between people and historic districts from a human perspective. Some scholars consider the relationship between historical districts and their residents from the perspective of residents' roles [43, 44]. Others explore heritage tourism in historical districts from the perspective of visitors [45, 46]. Some scholars study people's perceptions of historical districts [47–52]. Against the backdrop of the current energy crisis and climate change, the fourth type of research addresses energy issues in historic districts, by evaluating existing energy-saving measures [53, 54] and exploring new methods [55, 56]. Quantitative research mainly focuses on constructing evaluation systems and studying the space of historic districts. With technological advancements, there is a growing trend of cross-field and cross-perspective research, combining methodologies with big data, spatial syntax, GIS, eye-tracking devices, remote sensing, and exploring various perspectives such as cultural, tourist, social, perceptual, psychological, health, disaster, and energy.

Study on the spatial morphology of historic districts

Spatial morphology is a crucial component of the material environment in historical districts, consistently being a focal point of scholarly research. Research on the spatial morphology of historical districts can be divided into two categories: studying their spatial morphological features and examining the impacts of spatial morphology.

Firstly, regarding the research on the spatial morphological features of historical districts: Zhao [57] conducted research based on the "constructive authenticity" theory, consciously analyzing the authenticity of the spatial morphology of specific heritage by categorizing historical districts into three levels: (1) overall layout, (2) street landscapes, and (3) courtyard internal patterns; Zhang et al. [58] traced the temporal and spatial changes in street textures of historical districts at different periods, but primarily focusing on the overall structural analysis of the entire district; Both Teng et al. [59] and Zhou et al. [60] also analyzed the spatial morphological characteristics of the historic district. In addition to the analytical discussion of spatial morphological features, some scholars' studies have focused on quantifying morphological features: Yin et al. [61] propose a polarized attention-based landscape feature segmentation network (PALESNet), addressing limitations in automatically extracting landscape features; Zhang et al. [62] presented a method for the digital generation of heritage in historical areas; Zhang et al. [63] established a systematic 3D spatial diagnostic framework; and Wu et al. [64] explored the application of high-resolution remote sensing technology in the monitoring of historical urban conservation. However, research on Spatial Morphological Features has not deeply explored the spatial geometric Morphological at the street level.

Secondly, regarding research on the impacts of Spatial Morphology: Wang and Sun [65] developed a dynamic game model of traffic competition, starting from the impact of spatial form on traffic.Other scholars have focused on the effect of spatial form on perception: Xu et al. [66] investigated the relationship between street networks and tourists' spatial cognition; Mushayt et al. [67] used eye-tracking to evaluate the impact of street interface physical configurations on pedestrian visual perception; Moqadam and Nubani [68] explored the impact of changes in spatial patterns on perceived anti-social behavior (ASB). Besides, Xu et al. [69] analyzed cultural and urban landscapes from the perspective of spatial value; Huang et al. [70] studied the impact of diversity and accessibility on street vitality; Zhu et al. [71] explored the relationship between spatial morphology in severe cold historical districts and microclimates. While many studies in this category focus on the mid-level street aspects, most emphasize the impacts brought about by morphological features. Although Mushayt et al. [67] mentioned street interfaces, it primarily focused on the physical configurations of interfaces. Zhu et al. [71] in their study referenced quantifiable parameters for interface morphological features but delved more into the relationship between spatial morphology and climate.

Study on the regeneration and development of historic districts

As stated byWang et al. [26] in their article, historic districts are not static heritage that has lost its original and historical functions, but a part of the urban area that is still in use, and they should be regarded as living heritage, focusing on the continuation of its life and maintaining its vitality. Therefore, research on the renewal and development of historic districts is also a major focus of scholars. This kind of research focuses on the exploration of the development strategy of historic districts on the one hand, and on the renewal of the spatial form of historic districts on the other.

In the development strategy of historical districts, scholars have explored various perspectives, including machine learning, sense of place, sustainable renewal, and community governance: Gu et al. [72] discuss historical district renewal methods that simultaneously utilize feature space and culture from a machine learning perspective; Zhu and Chiou [73] Exploring the Sustainable Development of Historic Neighbourhoods from the Perspective of Place Attachment; Xia et al. [74] Integrating sustainability theory with the basic attributes of buildings to construct a dynamic monitoring and evaluation model for sustainable renewal; Also based on sustainability theory is Hassan et al. [75], proposing a framework for the application of historic districts based on sustainable mobility development. DING et al. [76] explore the research path of public space renewal in historic urban areas from the perspective of community governance.

In terms of spatial form renewal, scholars attempt to achieve intelligent spatial form generation using techniques such as parametric shape grammars and artificial intelligence: Yang et al. [77] establish a historical district urban spatial design method that includes morphological analysis, rule formulation, and scenario generation based on shape grammar and urban induction models; Chen et al. [78] generating urban spaces that meet contemporary needs through an intelligent generation program on a parametric platform. Chen et al. [79], also employing parametric shape grammar for spatial form renewal research, focus more on the automatic generation of building forms and facades. Lin [80] uses artificial intelligence technology to generate historical building facade decoration styles, attempting to address the conflict between historical and modern architectural styles. Most of these studies aim to intelligently generate spatial blocks based on existing spatial form data in historical districts for spatial form renewal. However, the authenticity of automatically generated spaces is closely related to quantifiable spatial form data, necessitating mature spatial form quantification methods to provide a reliable reference for renewal.

Research differences

Through a review of the literature, it can be observed that spatial morphology is a major focus of research on the preservation and renewal of historical districts. In these studies, scholars mostly focus more on overall spatial planning and development, employing quantitative research methods such as spatial syntax, GIS, remote sensing, parametric design, and morphology. Some scholars have consciously discussed the spatial aspects at macro, meso, and micro levels [57, 63]. However, the majority of researchers still concentrate on macro-level district studies, with limited exploration of meso and micro levels. A small number of scholars have conducted research on historical streets at the meso level, but it mostly revolves around traffic [65], climate [71], and streetscape [75], without in-depth quantitative studies on the morphological characteristics of street space.

Quantitative studies of spatial morphological features can usually be divided into quantitative studies of geometric morphology and quantitative studies of topological morphology. Topological morphology refers to the abstract structural features between graphic elements that are independent of the size, shape, scale, etc. of the graphic. Geometric morphological features of streets, on the other hand, refer to the features related to geometric shapes such as length, angle, shape, proportion, etc. It can be further divided into the geometric form of the street network at the macro level, and the geometric form as an individual street at the meso level. Most of the current quantitative studies on the spatial morphological characteristics of historic districts focus on the quantitative study of topological forms using methods such as spatial syntax [41], while some of the studies involving geometric forms tend to be the geometric forms of the street network at the macroscopic level [58], with few scholars focusing on the study of the geometric forms as individual streets. Mushayt et al. [67] mentioned the street interface, but mainly focused on the physical configuration of the interface rather than the interface geometry. It can be found that the quantification of geometric forms at the individual level of streets in historic districts is still a major gap in research.

In view of this, this paper introduces the quantitative theory of urban street interface morphology to quantify the interface morphology of street space within historic districts at the meso-level. The aim is to provide a method for quantifying the geometric morphology of street spaces, offering a rational standard for the protection of street spaces in historical districts and an objective reference for street space renewal.

Research methodology and study area

Study methodology

Empirical research served as the primary methodology in this paper. Grounded in logical induction from real cases, empirical research draws conclusions through the observation and analysis of actual instances. To conduct a specific case study, three methods were employed: literature review, Google Maps network research, and field surveys. The literature review delves into the theoretical underpinnings of relevant fields and synthesizes findings from previous researchers. Google Maps web research offers a comprehensive and efficient means to swiftly acquire detailed information about the case locations. In contrast, field surveys involve on-site visits to the case locations, facilitating the collection of authentic and precise data. The combined use of these three approaches ensures a comprehensive and accurate analysis and interpretation of the empirical research results.

Selection of research tools

The research tool used in this paper is Total Station. A total station, i.e., Electronic Total Station, is a kind of high-tech measuring instrument integrating light, machine, and electricity, and it is a surveying and mapping instrument system integrating the functions of horizontal angle, vertical angle, distance (slant distance, level distance), and height difference measurement [81]. Total Station has three measurement modes, among which the precision measurement mode can reach millimeter level. Compared with the optical latitude and longitude instruments, the total station instrument replaces the optical dial with the photoelectric scanning dial, and replaces the manual optical micrometer reading with automatic recording and display of readings, which simplifies the operation and avoids the generation of reading errors. It is called total station because it can complete all the measurement work on the station by placing the instrument once. In this study, the prism measurement mode and prism-free measurement mode are combined to carry out the survey, in which the horizontal dimension data collection is mainly in the form of setting up prism measurements, while in the vertical dimension data collection, the height of individual buildings is too high to set up prisms, so the prism-free mode of total station is used to carry out the measurements. All survey data are averaged by repeating the measurement three times and retaining three decimals to avoid measurement errors. Measurement with a total station can maximize the closeness to the true value of the data and control the error within a certain range.

Quantitative parameters of interface morphology

Regarding the street interface, many scholars have already conducted in-depth discussions on various factors such as urban environment, usage, and configuration, so we will not repeat them here. This paper is mainly based on the quantitative theory of urban street interface morphology, to sort out the quantitative parameters of street interface morphology applicable to historic districts in order to establish a suitable control index system.

Distance-Height Ratio(D/H)

The Distance-Height Ratio (D/H) delineates the correlation between street width and the height of buildings along both sides of the street. The concept of Distance-Height Ratio was initially introduced by Austrian architect and urban planner Camillo Sitte [82] in his research on architectural interfaces. Subsequently, Japanese architect Yoshinobu Ashihara [83] incorporated this parameter into the study of vertical-dimensional interfaces in street morphology. Here, D represents the distance between buildings, i.e., the street width, while H refers to the height of the building interfaces on both sides of the street (see Fig. 1). Different Distance-Height Ratios give different spatial perceptions, which are related to the characteristics of human visual perception. When D/H > 1, an increasing ratio tends to create a sense of distance, and when this ratio exceeds 2, a feeling of spaciousness emerges. Conversely, when D/H < 1, a decreasing ratio generates a sense of proximity. When D/H = 1, a symmetrical feeling exists between width and height, marking a turning point in people's perception of street space. According to studies by Yoshinobu Ashihara [83] and Jacobs [84], the interval 1 < D/H < 2 represents a moderately constrained perception of street space. In practical research, the Distance-Height Ratio can be further divided into an overall Distance-Height Ratio and a local Distance-Height Ratio. The parametric description method of street Distance-Height Ratio can effectively describe the street interface morphology, but it is only a characterization of the street interface in the vertical dimension and cannot reflect the continuity change of the street interface in the horizontal dimension, so it is also necessary to introduce quantitative parameters in the horizontal dimension. In this paper, the Distance-Height Ratio is introduced mainly to characterize the interface morphology of historical districts in the vertical dimension.

Width-Distance Ratio

The Width-Distance Ratio mainly intends to characterize the rhythmic change of the street interface in the horizontal dimension. In this case, W is the width of the storefront, and D is the width of the street (see Fig. 2). Yoshinobu Ashihara, in his book "The Aesthetics of Streets," argues that it is important that W/D ≤ 1 [83]. An excessively long interface makes the whole street look too monotonous and depressing, and only by dividing it into a suitable range of different widths can the eye be rested and diverted briefly without losing the pleasure of walking. Due to the recurrence of W, which is smaller than D, the street will appear to be alive. If the street is narrower and the face widths of the buildings along the street are large, the lively atmosphere of the street will be spoiled. When a building requires a large face width, the façade can be divided into small segments with W/D < 1, thus bringing change and rhythm to the street. However,

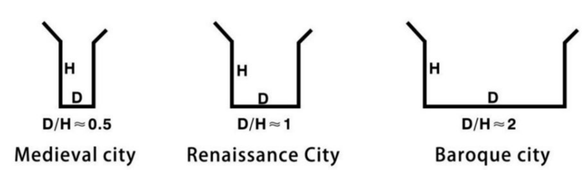

Fig. 1 D/H of Yoshinobu Ashihara

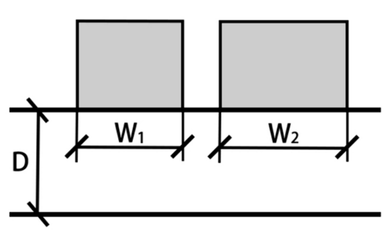

Fig. 2 W/D of Yoshinobu Ashihara

the W/D here is only for the façade division of the solid interface along the street, but in the actual situation, the buildings along the street may not be closely arranged, i.e., there may be gaps between the solid interfaces, in which case the W/D does not have an obvious effect on the characterization of the entire street interface form. In addition, when Yoshinobu Ashihara thought about the Width-Distance Ratio index, he mainly focused on the narrower traditional streets in Japan. In Chinese districts, the streets are generally wider, and the stores along the streets in historic districts seldom have large face widths, which are much smaller than the street widths, making the Width-Distance Ratio index less applicable to Chinese historic districts. Therefore, the practical application of this parameter is not considered in this study.

Interface density

Interface Density is a quantifiable parameter that examines the extent of density of street interfaces in the horizontal dimension, reflecting the pivotal role of building interface enclosures in shaping street space morphology. Generally speaking, the higher the interface density, the closer the arrangement of buildings along the street; that is, there is a positive correlation between street interface density and building density. At the same time, some scholars have shown that there is a negative correlation between neighborhood building density and street scale. Due to the influence of economy, function, and management, the larger the street scale, the lower the building density [85]. Therefore, the street scale will indirectly affect the street interface density through the neighborhood building density, and the larger the street scale, the lower the street interface density. Maintaining an interface density above 70% is deemed essential for creating an exemplary street space. The calculation method for interface density relies on the "ratio of the projected width of buildings (including maintenance structures such as walls and fences) along one side of the street to the length of the street" [86]. The formula for calculating interface density is given as:

$$De = \sum_{i=1}^{n} \frac{W_i}{L} \quad (1)$$

(where Wi denotes the projected width of buildings along the street in Section i). This method is still used in this paper for the calculation of the interface density of street space (see Fig. 3). The morphology of the street interface is complex and far from being accurately described by a single parameter. Theoretically, there are two different levels of morphological characteristics of the street interface: (1) the presence or absence of the street interface; and (2) the location of the street interface. Once the "presence" and "location" of the interface are determined, its morphology is also determined. The interface density parameter can only describe the presence or absence of the street interface, but it is also necessary to introduce a parameter that can characterize the positional relationship of the street interface. In this paper, the interface density is introduced into the spatial analysis of historical streets, which is mainly used to characterize the degree of interface enclosure in the horizontal dimension.

Build-To-Line Rate

The concept of "Build-To-Line Rate" originates from the notion of "Street Wall," proposed by the American architect William Atkinson [87]. The street wall refers to the continuous interface formed by buildings on both sides of the street, serving as a control method to ensure the coordinated form of street interfaces, while the Build-To-Line Rate is used to describe the continuity and regularity of building interfaces. Oliveira's development of Morpho simplifies the analysis of objects of urban form into streets, land units, and buildings, and based on this, develops seven quantitative indicators, aiming to measure the material form characteristics of the city systematically with the fewest variables possible [88]. Morpho, through

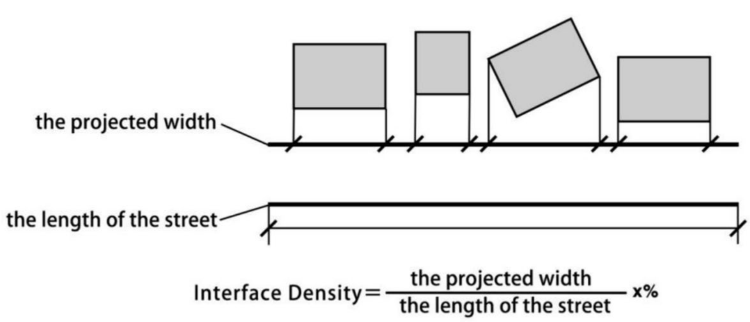

Fig. 3 Schematic diagram of interfacial density calculation

integrated analysis, can comprehensively characterize the "urbanity" of urban form—the urban form matrix that is more likely to promote the vitality of urban space, and a higher "Build-To-Line Rate" will lead to higher "urbanity." Generally, the higher the Build-To-Line Rate, the higher the regularity of the street interface. Currently, the calculation method of the Build-To-Line Rate in urban streets is mainly based on building setback lines and building control lines [89, 90], which to some extent reflect the morphological characteristics of street interfaces in the horizontal dimension. However, in China, street interface morphology is often related to regional cultural traditions. Many street interfaces are not uniform street walls, showing significant differences from streets with the Western tradition of "street walls." Due to the natural growth of historic districts, traditional streets may lack strict building setback lines and centerlines. There may be slight setbacks or protrusions between interface boundaries, resulting in occasional variations in street width and narrowness. Therefore, the Build-To-Line Rate of street space in historic districts formally refers to the ratio of the width of interfaces adjacent to the street boundary line to the total projected width of all interfaces (see Fig. 4). In addition, similar to street walls, the Build-To-Line Rate focuses on the ratio of interfaces "close to" the street boundary, lacking descriptive power for the concave and convex changes of interfaces. This paper introduces the Build-To-Line Rate primarily to characterize the continuity and regularity of streets in historic districts in the horizontal dimension.

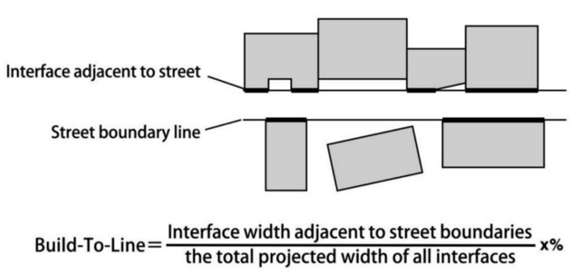

Fig. 4 Schematic diagram of Build-To-Line calculation

Near-Line Rate

Due to the varied and undulating morphology of many street interfaces in China, existing parameters such as "Interface Density" and "Build-To-Line Rate" fail to effectively describe this characteristic. Therefore, some Chinese scholars have proposed the parameter "Near-Line Rate" to characterize the degree to which street interfaces are close to or distant from the street boundary [91]. From a human-centered perspective, the degree of proximity or distance of street interfaces from the street boundary is related not only to their physical distance but also to human perception. The purely physical measurement of distance is inherently limited in its significance. As Kevin Lynch stated in "The Image of the City," the creation of environmental images is a reciprocal process between the observer and the observed [92]. What the observer sees originates from the external form of the environment, but the way they express and organize it, as well as the methods they use to guide their attention, will in turn influence what the observer sees.Therefore, when studying the morphological characteristics of street interfaces, it is essential to consider the influence of psychological cognitive mechanisms alongside their objective physical form. Human visual perception of objects is inversely proportional to distance, so the psychological cognition of the degree of proximity or distance of street interfaces can be described using an inverse proportion function in relation to interface distance. Additionally, under the condition of equal setback distance, the greater the street width, the less apparent the concave and convex changes of the interface; conversely, the narrower the street width, the more pronounced the concave and convex changes of the interface. Thus, it can be inferred that human perception of the degree of proximity or distance of street interfaces is directly proportional to street width.

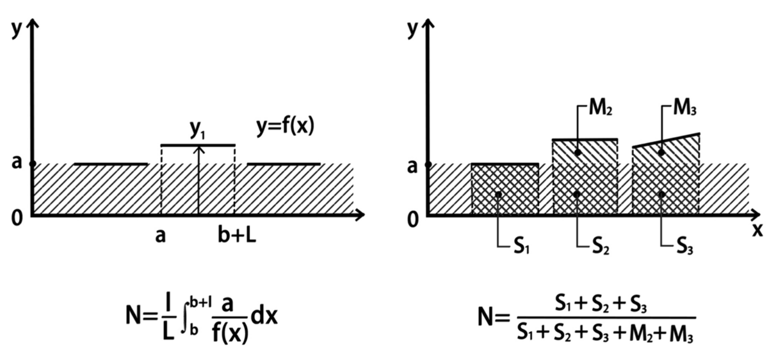

Fig. 5 Schematic diagram of Near-Line Rate calculation

The "Near-Line Rate" parameter introduces methods from psychophysics research, aiming to effectively characterize the physical morphological features of street interfaces' undulating nature while also reflecting human psychological cognition of them. The calculation formula is as follows:

$$N = \frac{1}{L}\int_{b}^{b+1}\frac{a}{f(x)}dx \quad (2)$$

In practical applications, the calculation of the Near-line Rate can also be performed using the method of area ratio instead of integral calculation, as shown in Fig. 5. The Near-Line Rate N for one side of the street is calculated as follows:

$$N = \frac{S_1 + S_2 + S_3}{S_1 + S_2 + S_3 + M_1 + M_2} \quad (3)$$

The introduction of the Near-Line Rate further reveals the diverse characteristics and rich connotations of street interface morphology, thereby bringing attention to the undulating nature of street interfaces in China. This paper introduces the Near-line Rate to characterize the degree of concave and convex changes in street interfaces within historical districts.

Summary

In the field of urban morphology, there exists a complex array of quantitative parameters concerning street interfaces. Among these, parameters such as Interface Density, Build-To-Line Rate, and Near-Line Rate are measurements of the horizontal dimension of street interface morphology. However, each parameter has its own distinct meaning, representing different aspects of street interface morphology, with varying applicability. Interface Density reflects the density of street interfaces and boasts a broad application scope, suitable for analyzing various types of street morphologies. The Build-To-Line Rate originates from the concept of "Street Wall" in American zoning laws, primarily indicating the continuity and regularity of street interfaces. A higher Build-To-Line Rate offers better control, yet it fails to capture the concavity and convexity of interfaces. The Near-Line Rate parameter, on the other hand, is proposed based on the irregular morphology of street interfaces in Chinese urban areas, making it unsuitable for straight and orderly street interfaces. It primarily serves as a complement to the Build-To-Line Rate, characterizing the proximity of street interfaces to the street boundary or the degree of interface concavity and convexity. Compared to the Near-Line Rate, the Build-To-Line Rate algorithm is more straightforward and practical for planning and control purposes. Therefore, when quantifying the morphology of the historic street interface, it is important to select the applicable parameters based on the specific street characteristics.

From existing research findings on prominent streets, it is generally understood that maintaining a high street interface density and Build-To-Line Rate are fundamental prerequisites for streets to exhibit prosperity and vitality. However, concerning Chinese urban areas, there are cases where streets exhibit high vitality despite having low Build-To-Line rates. Examples include the Kuanzhai Alley in Chengdu and Yujie Street in Hangzhou. This phenomenon can be attributed to the traditional irregular morphology of Chinese street interfaces, which differs significantly from the Western concept of street walls. Hence, it is evident that the numerical values of parameters such as Build-To-Line rate and Near-Line Rate do not directly correlate with the quality and vitality of street spaces. Quantitative methods for parameterization merely serve as representations of the differences in street interface morphology. These representations do not directly correspond to value judgments regarding the "good" or "bad" qualities of street interfaces. Quantitative methods themselves are akin to measuring tools, used to quantify various phenomena and illustrate their differences. However, determining what constitutes a "good" scale for various phenomena is not solely elucidated by the measuring tool itself. Establishing a control system for the morphology of historical street interfaces using quantitative parameters requires identifying reference standards suitable for historical districts.

Due to the diverse cultural backgrounds influencing the morphological characteristics of historical districts, there is no universal standard for street interface morphology. It is necessary to establish different street interface morphology control systems tailored to local conditions. The uniqueness of historical districts lies in their designation as protected areas, backed by legal enforceability. Therefore, once urban areas are legally designated as historical and cultural districts through proper procedures, their morphological characteristics are unquestionably protected by law, and any attempts to alter these characteristics are prohibited. As crucial public spaces within historical and cultural districts, the Interface morphological characteristics of streets are also legally protected. This resolves the issue of reference standards for quantitative methods, as the parameter characteristics of street interfaces in their original state serve as the benchmark for street renewal. Therefore, the application of such quantitative methods to the protection and renewal of street interfaces within historical and cultural districts is feasible.

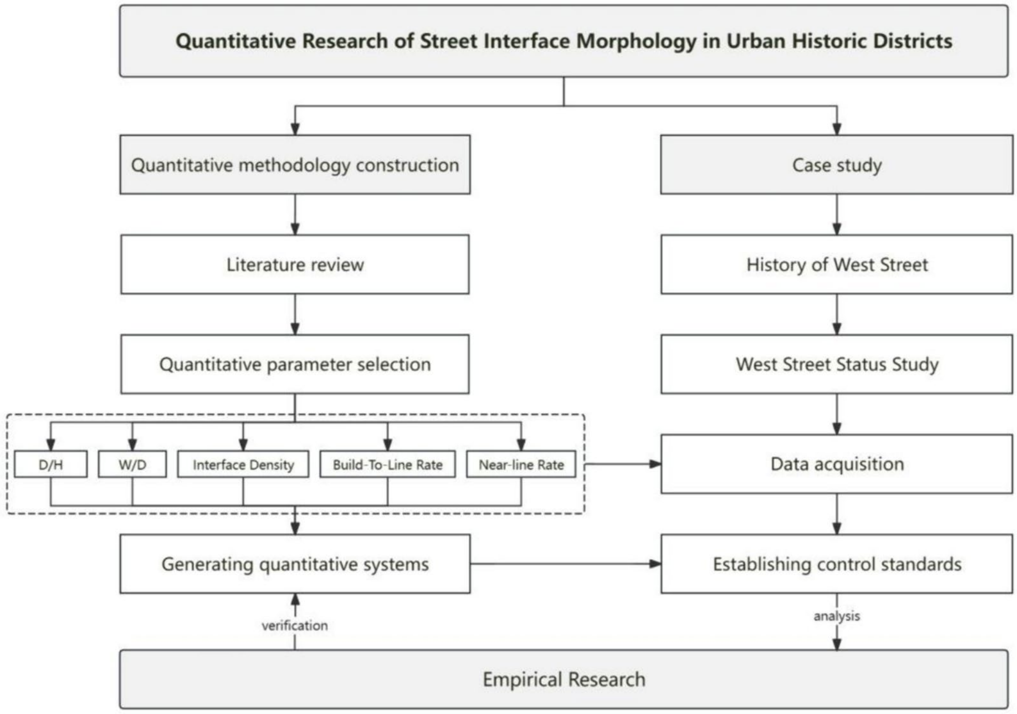

Fig. 6 Roadmap for research

Research process

This study can be broadly divided into two main parts: theoretical research and case studies. The method construction part primarily focuses on qualitative research, introducing the study of urban street interface morphology into the preservation of historical districts, and selecting appropriate quantitative parameters. The case study part mainly involves quantitative research, using the West Street historical district as a case study to test the feasibility of the quantitative method. Figure 6 shows the framework and process of the whole study.The specific research process is as follows:

(1) Literature review

Initially, relevant literature on historical districts is reviewed to identify gaps in previous research and determine the research direction of this study.

(2) Quantitative parameter selection

Based on previous studies on urban streets, discussions are conducted on the quantification indicators of street interface morphology, and suitable quantitative parameters applicable to historical district street interfaces are selected.

(3) Generating quantitative systems

A quantitative system for historical district street interfaces is constructed based on the selected indicators. This includes vertical dimensions such as overall distance-height ratio and cross-sectional distance-height ratio, and horizontal dimensions such as interface density, linearity rate, and near-line rate.

(4) West Street study

The West Street historical district is chosen as the research case. Surveys are conducted on the background, historical evolution, and current status of the West Street area. Segments with rich historical resources and well-preserved characteristics are selected as the study area.

(5) Data acquisition

Using the established interface morphology quantification system, data on both vertical and horizontal dimensions of West Street's morphology is measured, collected, and processed, including relevant parameter calculations.

(6) Empirical analysis

Fig. 7 Satellite view of West Street Historic District (1) and study area (2) Source: the authors/Google Maps

Fig. 8 West Street study area

The feasibility of the quantitative method is validated through empirical analysis. The morphological characteristics of West Street are summarized, and strategies for renovation and renewal are proposed to guide its sustainable development in the future.

Study area

This paper takes the West Street Historical and Cultural Districts of Quanzhou City as a case study (see Fig. 7) and selects the area from the Kaiyuan Temple to the Bell Tower in the eastern section of the district (see

Fig. 9 East and West Pagodas

Fig. 8), which is rich in historical and cultural resources, well-preserved in traditional features, and capable of embodying the traditional characteristics of Quanzhou, to carry out a quantitative study.

Background of the West Street historical and cultural district in Quanzhou City

Quanzhou City holds the distinction of being one of the 24 national-level historical and cultural cities, as first designated by the State Council of China in 1982 [93]. Among the initial nine provincial-level historical and cultural districts announced in Fujian Province, the West Street Historical and Cultural District stands out. Established over 1,300 years ago during the Tang Dynasty, this street has remained the vibrant heart of the ancient city of Quanzhou. The district boasts a wealth of historical and cultural treasures, embodying a distinctive historical area within the ancient city. According to statistics, there are more than 20 cultural relics protection units at all levels within the jurisdiction of the West Street, including the national key cultural relics protection unit Kaiyuan Temple, East and West Pagodas (see Fig. 9) [94]; the municipal key cultural relics protection unit Chengxin Pagoda; as well as numerous categories of ancient buildings, ruins, stone carvings, and so on. Furthermore, there are 12 well-preserved ancient buildings and residences, along with 34 ancient mansions, 3 western-style buildings, 1 ancestral hall, and over 20 ancient streets and lanes available for development. The abundance of cultural heritage in the area underscores its significant research value. This study selects the West Street Historical and Cultural District in Quanzhou City as a research case with the aim of exploring and analyzing its unique history, culture, and architecture. The goal is to provide valuable insights for the protection, development, and further exploration of its potential.

History of West Street morphology

West Street was established during the Tang Dynasty, between the years of Kaiyuan (714–741 AD). It extended from the east at Shuangmenqian (nowadays at the foot of the Bell Tower) to the west at the Sujing Gate, the west gate of the Tang Dynasty city (nowadays at the entrance of Xiaogan Alley). By the second year of the Guangqi era of the Tang Dynasty (886 AD), the brothers Wang Chao settled in Quanzhou and, in order to strengthen defense, built a sub-city within Quanzhou

Fig. 10 History of Quanzhou and West Street

and set up four major city gates: Xingchun Gate, Suqing Gate, Chongyang Gate, and Quanshan Gate. Among them, Suqing Gate was the west gate of the sub-city at that time, located between present-day New Street and Pei Alley. The site has now become Suqing Gate Square. In the second year of Tianyou (905 AD), when Wang Yanbin, the governor of Quanzhou, governed the city, the urban area was expanded, and West Street was extended to the current Gantang Alley. During the Southern Tang Dynasty in the Five Dynasties period (943–957 AD), due to trade expansion, Quanzhou expanded its city. The commander-in-chief of the Qingyuan Army, Liu Congxiao, strengthened the city walls and added a second wall around the city. Ximen Street, extending from the west gate of the sub-city, became the main thoroughfare for land transportation in Quanzhou. During the expansion of the city, it was incorporated into the second wall. The west gate (now called "Yicheng Gate") was moved to the intersection of West Street's west end and Xihuan Crossroads, and West Street was extended accordingly. Thus, the route of West Street was essentially determined (see Fig. 10).

During the Tang Dynasty, cities generally adopted the "li-fang system" layout, where continuous fang walls divided the city into a grid-like space, and rulers enforced strict military management within each fang. The main streets between the fangs were straight and wide, while the streets and alleys within the fangs, called "fangqu," were often narrow and winding, resembling free-flowing lanes. Some scholars argue that the main streets between fangs were not streets in the modern sense but rather buffer zones with semi-military control around each fang, lacking the urban life environment [95]. Consequently, the accessibility of urban pathways was much greater than their livability. Influenced by this, West Street, established during the Tang Dynasty, features a wide, straight main street with orderly buildings closely adhering to the road boundaries, while the side alleys vary in width and freely extend to both sides, resembling a fishbone pattern. This characteristic layout has been maintained to this day. Starting from the late Tang Dynasty, the enclosed li-fang system severely hindered commercial activities. People began to break free from

Fig. 11 Grid-like historic district

Fig. 12 Fishbone-like historic district

the constraints of the li-fang system, encroaching upon prohibited streets and alleys. The Tang Code, during the reign of Emperor Gaozong, stipulated punishments for those who encroached upon streets and alleys [96]. By the Five Dynasties period, the li-fang system was on the verge of disintegration, laying the foundation for the complete replacement of li-fangs with streets and alleys during the Northern Song Dynasty. After the Song Dynasty, fang walls were demolished, and opening shops along the streets became common practice, marking the emergence of streets in the modern sense. The transformation was also reflected in West Street: the eastern section from Kaiyuan Temple to the Bell Tower area has been a traditional commercial district since ancient times. The format of shops lining both sides of the main street has continued to this day. West Street is the most well-preserved ancient street area in Quanzhou City and a historical site with Quanzhou characteristics, symbolizing the prosperity of urban development in Quanzhou.

Status of the West Street historic district

Although street structures encompass various types, traditional historical street layouts in China are predominantly characterized by grid-like and fishbone-like arrangements, influenced by the ancient "li-fang system" and "street and alley system." Grid-like layouts feature interconnected alleys between buildings, forming a free grid structure, as seen in the historical Longwang Lane in Zhenjiang (see Fig. 11) [97]. Fishbone-like historical street areas typically have a main street as the axis, with supporting alleys branching out on both sides, forming a strip-like block, as exemplified by Taiping Street in Changsha (see Fig. 12) [98].

West Street exhibits a fishbone-like layout, with West Street Main Street as the backbone, and supporting alleys branching out on both sides. The western section of the block is primarily residential, while the eastern section serves as a traditional commercial and cultural display area, serving as an important window to showcase the history and culture of Quanzhou (see Fig. 7). Along the street, buildings consist of traditional one- to two-story pitched-roof houses and flat-roofed arcade buildings. These structures are primarily used for residential purposes, small-scale commercial activities, and cultural entertainment, making it a lively commercial street with multiple functions, including transportation and tourism. On both sides of West Street Main Street, the distinctive red-brick "dacuo" style, typical of southern Fujian, is prevalent, reflecting a unified approach to preserving the historical charm of West Street (see Fig. 13). Due to its unique geographical location, West Street faces many challenges in preservation and renovation, resulting in slow progress in recent years. Most preservation efforts have been passive repairs and maintenance, leaving a series of technical challenges for systematic preservation and renovation. The weak foundations of West Street buildings, coupled with aging wooden structures and inadequate maintenance, exacerbate existing safety hazards, with many buildings at risk due to compromised

Fig. 13 West Street style status

structural integrity. Furthermore, rampant unauthorized construction and alterations significantly deviate from the traditional architectural style, causing obvious damage to the overall historical charm of West Street. The preservation and renovation of West Street's street space urgently require a control standard. This study selected this historical street block as a case study due to its exemplary nature.

Data acquisition and interpretation

Data acquisition and analysis are key components of quantitative research. This study summarizes the street interface morphology features of West Street using quantitative parameters for both horizontal and vertical dimensions. The vertical dimension parameter is the "Distance-Height Ratio," while the horizontal dimension parameters include "Interface Density," "Build-To-Line Rate," and "Near-Line Rate." The measurement method using a total station is the primary approach for collecting data on street interface morphology features.

West Street vertical dimension data acquisition

Based on the survey, the east section of West Street is primarily occupied by commercial structures, mostly 1–2-story buildings. Due to variations in building heights on both sides, this paper initially calculates the north–south Distance-Height Ratios using D/HN and D/H_S, respectively. Subsequently, the Distance-Height Ratio is computed based on the average height of the buildings on both sides. It's important to highlight that the interval near Kaiyuan Temple is excluded from this stage due to the temple's boundary on the north side, where building interfaces are non-existent (see Fig. 13). Recognizing the dynamic changes in building heights along West Street, simply calculating the overall Distance-Height Ratio or local Distance-Height Ratios might not holistically and objectively characterize the vertical dimension morphology of West Street's street interface. To address this, the paper proposes that the collection of Distance-Height Ratio data be divided into two parts: the Overall Distance-Height Ratio and the Local Distance-Height Ratio.

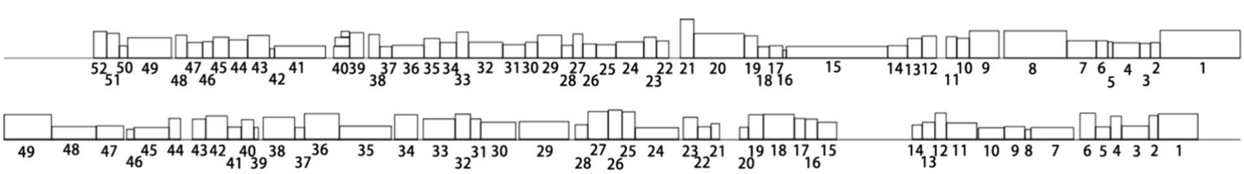

Fig. 14 the vertical dimension morphology of West Street's street interface

Table 2 Weighted average height of buildings on the north side of West Street

Number	Heights (M)	Lengths (M)	Weights	Weighted height (M)
1	8.230	23.887	0.073	0.597
2	4.546	2.892	0.009	0.040
3	4.336	3.206	0.010	0.042
4	4.508	8.065	0.025	0.110
5	4.825	1.438	0.004	0.021
6	5.129	3.395	0.010	0.053
7	5.120	8.835	0.027	0.137
8	8.027	18.684	0.057	0.456
9	8.031	8.884	0.027	0.217
10	5.874	3.718	0.011	0.066
11	6.339	3.200	0.010	0.062
12	6.535	4.361	0.013	0.087
13	5.822	4.317	0.013	0.076
14	3.704	5.923	0.018	0.067
15	3.486	30.210	0.092	0.320
16	2.398	1.039	0.003	0.008
17	3.684	3.987	0.012	0.045
18	3.589	3.488	0.011	0.038
19	6.577	4.010	0.012	0.080
20	7.245	14.984	0.046	0.330
21	11.466	4.079	0.012	0.142
22	5.064	3.771	0.011	0.058
23	6.174	3.727	0.011	0.070
24	4.772	8.343	0.025	0.121
25	4.016	5.845	0.018	0.071
26	4.212	4.021	0.012	0.051
27	7.094	2.977	0.009	0.064
28	3.796	3.329	0.010	0.038
29	6.795	7.213	0.022	0.149
30	4.723	3.605	0.011	0.052
31	4.026	6.699	0.020	0.082
32	4.726	10.238	0.031	0.147
33	7.712	3.635	0.011	0.085
34	4.598	4.908	0.015	0.069
35	5.792	4.723	0.014	0.083
36	3.819	9.536	0.029	0.111
37	3.412	3.700	0.011	0.038
38	7.064	3.237	0.010	0.069
39	7.503	4.229	0.013	0.096
40	7.931	4.809	0.015	0.116
41	3.604	15.26	0.046	0.167
42	2.795	1.472	0.004	0.013
43	6.716	6.494	0.020	0.133
44	5.405	5.615	0.017	0.092
45	6.213	4.732	0.014	0.089
46	4.895	3.051	0.009	0.045
47	4.609	4.702	0.014	0.066
48	6.803	3.411	0.010	0.071
49	6.029	13.093	0.040	0.240
50	3.603	2.459	0.007	0.027
51	7.344	3.733	0.011	0.083
52	7.836	3.945	0.012	0.094
Total	288.552	329.114	1	5.685

Overal Distance-Height Ratio

In the initial phase, the entire street section from East Tower to Quanzhou Cinema Theater is treated as a unit for collecting overall Distance-Height Ratio data. While computing the average height, considering variations in building units' heights and the distinct proportion each height building contributes to the overall street (see Fig. 14), this paper employs a weighted average calculation for building height. The weighted average is determined by the proportional weight of each building height to ensure an objective and accurate representation of building heights (see Tables 2, 3). The formula for the height-weighted average is:

$$\overline{x} = \frac{x_1\omega_1 + x_2\omega_2 + \ldots\ldots + x_n\omega_n}{\omega_1 + \omega_2 + \ldots\ldots + \omega_n} \tag{4}$$

where $\omega_1, \omega_2, \ldots\ldots, \omega_n$ is the weight of $x_1, x_2, \ldots\ldots, x_n$.

This results in a weighted average building height of 5.685 m on the north side and an overall Distance-Height Ratio D/H_N of 1.784 on the north side; a weighted average building height of 5.412 m on the south side and an overall Distance-Height Ratio D/H_S of 1.874 on the south side; and an average building height of 5.549 m on the north and south sides, with an overall Distance-Height Ratio of 1.828 in the entire section.

Local Distance-Height Ratio

Next, the data collection for the local Distance-Height Ratio along West Street was conducted. Similarly, the area with the densest concentration of historically protected buildings between Kaiyuan Temple and the Bell Tower was selected for the calculation of the local Distance-Height Ratio. This study employed a combination of equidistant uniform sampling and node-based supplementary sampling to select street section samples. Initially, street facade samples were taken at intervals of ten meters, with 35 sections sampled in total. Subsequently, an additional 13 sections were sampled based on changes in building height as the criterion. Specifically, these additional sections were sampled at nodes where there was a significant variation in building

Table 3 Weighted average height of buildings on the south side of West Street

Number	Heights (M)	Lengths (M)	Weights	Weighted height (M)
1	7.518	11.926	0.038	0.286
2	7.028	2.676	0.009	0.060
3	3.933	8.171	0.026	0.103
4	6.867	3.287	0.010	0.072
5	3.690	4.441	0.014	0.052
6	7.719	4.698	0.015	0.116
7	3.518	12.787	0.041	0.144
8	2.912	1.773	0.006	0.016
9	3.762	6.196	0.020	0.074
10	3.402	7.668	0.024	0.083
11	4.827	9.098	0.029	0.140
12	7.790	3.375	0.011	0.084
13	5.010	3.782	0.012	0.060
14	4.234	3.013	0.010	0.041
15	5.013	5.768	0.018	0.092
16	5.954	3.694	0.012	0.070
17	6.156	3.235	0.010	0.064
18	7.365	9.288	0.030	0.218
19	7.257	4.456	0.014	0.103
20	3.590	2.610	0.008	0.030
21	4.587	2.606	0.008	0.038
22	3.714	3.950	0.013	0.047
23	6.465	4.323	0.014	0.089
24	3.440	12.98	0.041	0.142
25	8.095	3.927	0.013	0.101
26	8.596	4.081	0.013	0.112
27	8.180	6.105	0.019	0.159
28	4.297	3.836	0.012	0.053
29	5.215	14.780	0.047	0.246
30	5.020	10.448	0.033	0.167
31	6.018	3.608	0.012	0.069
32	7.411	4.596	0.015	0.109
33	6.038	9.557	0.030	0.184
34	7.253	6.913	0.022	0.160
35	3.889	15.579	0.050	0.193
36	7.563	10.384	0.033	0.251
37	3.546	2.853	0.009	0.032
38	6.512	9.465	0.030	0.197
39	3.597	1.363	0.004	0.016
40	5.819	3.726	0.012	0.069
41	3.603	4.153	0.013	0.048
42	6.913	6.445	0.021	0.142
43	5.956	4.048	0.013	0.077
44	6.185	3.490	0.011	0.069
45	3.517	10.409	0.033	0.117
46	2.970	2.196	0.007	0.021
47	4.005	8.141	0.026	0.104
48	3.765	13.363	0.043	0.161
49	7.329	14.157	0.045	0.331
Total	267.043	313.424	1	5.412

height along the street. The specific sectional sampling process is illustrated in Fig. 15. For each of the 48 selected street sections, the width of the street and the height of the buildings were measured (see Table 4), and vertical section diagrams of the street were drawn (see Fig. 16). These diagrams served as the basis for analyzing the variations in the street interface morphology features along the vertical dimension of West Street.

West Street horizontal dimension data acquisition

Interface density

Considering the influence of street sections on the calculation of Interface Density, West Street is now divided into several units based on the positions of the side alleys (see Fig. 17). It is divided into units using two methods: dividing along the alley centerline and dividing along the alley width boundary. Dividing along the alley centerline is more representative of pedestrians' actual perception along the street and facilitates comparison with other streets. On the other hand, dividing along the alley width boundary helps eliminate the influence of the width of side alleys on interface density. Since the number and positions of side alleys are different on the north and south sides of West Street, each side is independently divided into units, and horizontal dimension data are calculated separately for each side before computing the average data. Specific statistical data are presented in Tables 5 and 6.

Build-To-Line Rate

The Build-To-Line Rate is not influenced by the sections of side alleys. Therefore, for the calculation of the Build-To-Line Rate, the street is not divided into units based on side alleys' sections. Instead, the Build-To-Line Rate is calculated separately for the north and south sides of West Street, and then the arithmetic mean is used to calculate the overall Build-To-Line Rate of West Street. Through the collection of interface projection widths on both the north and south sides, it is determined that the total projected width of interfaces on the north side is 624.575 m, with the portion built to the line being 498.259 m, resulting in a Build-To-Line Rate of 79.8% for the north side. Similarly, the total projected width of interfaces on the south side is 633.691 m, with the portion built to the line being 503.560 m, leading to

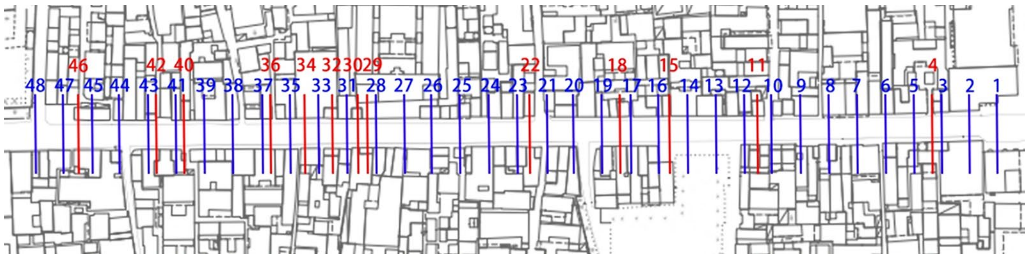

Fig. 15 Schematic of street vertical section sampling

a Build-To-Line Rate of 79.5% for the south side. The average Build-To-Line Rate of West Street is calculated to be 79.7%.

Near-Line Rate

The calculation of Near-Line Rate involves complex integral operations. Therefore, this paper adopts the calculation method of area ratio instead. In the calculation process, Near-Line Rates are calculated separately for the north and south sides, and then the arithmetic mean is used to calculate the overall Near-Line Rate of West Street. For the north side, the total area of street interfaces S_N is 6257.75 m^2, and the area M_N enclosed by the north side interfaces and the street boundary is 6898.545 m^2. Thus, the Near-Line Rate for the north side is 90.7%. For the south side, the total area of street interfaces S_S is 6496.921 m^2, and the area M_S enclosed by the south side interfaces and the street boundary is 7042.618 m^2. Consequently, the Near-Line Rate for the south side is 92.3%. The average Near-Line Rate of West Street is calculated to be 91.5%.

Result and discussion

In historical urban areas, the apparent disorderliness in the morphology and scale of street spaces conceals inherent patterns. Sustaining traditional street forms and dimensions to preserve the lifestyle and culture of the lanes and alleys is the ultimate goal of street space conservation in historic districts. This study conducts a detailed statistical analysis of the street interface morphology parameters of West Street, yielding specific parameter ranges. These findings lay the groundwork for inferring the street interface morphology characteristics of West Street. In-depth analysis of these morphology features aids in a more comprehensive understanding of West Street's spatial morphology and facilitates the formulation of effective strategies for preserving historical street morphology characteristics. Furthermore, these research results can serve as a reference for the planning and updating of West Street to ensure the continued inheritance of its unique historical value.

Vertical dimension interface analysis

Overal Distance-Height Ratio analysis

The analysis of the street distance-height ratio data for West Street reveals the following results: The average height on the north side is 5.685 m, while on the south side, it is 5.412 m. The overall average width is 10.144 m, leading to an overall average distance-height ratio of 1.828. The average height of buildings on both sides falls within the range of 5 to 6 m, indicating that the majority of structures on West Street consist of one- to two-story buildings, with a prevalence of two-story buildings. This characteristic is attributed to West Street's preservation of its historical character, with many buildings being of historical significance and lacking modern high-rise structures. The average width of approximately 10 m also reflects its unique historical background. During the Tang and Song dynasties, urban roads gradually transitioned from reflecting hierarchical concepts of etiquette to meeting the practical needs of the urban economy. At that time, horse-drawn carriages were the primary mode of transportation, and a width of ten meters was sufficient to accommodate the traffic demands of West Street. The overall distance-height ratio falling between 1 and 2 indicates that West Street's main thoroughfare maintains a balanced proportion, offering a relatively spacious environment. The enclosure of the interfaces contributes to a distinct sense of spatial definition without inducing a feeling of oppression. At this juncture, buildings manifest as self-contained microcosms, with surrounding elements serving as mere stage scenery.

Local Distance-Height Ratio analysis

The slight discrepancy between the average value of the local distance-height ratio and the overall

Table 4 West Street localized Distance-Height Ratio

Number	North (M)	South (M)	Widths (M)	D/H_N	D/H_S	D/H
1	8.230	7.230	16.443	1.998	2.274	2.136
2	8.230	7.518	10.177	1.237	1.354	1.295
3	4.546	7.028	10.114	2.225	1.439	1.832
4	4.336	3.933	10.029	2.313	2.550	2.431
5	4.508	6.867	9.733	2.159	1.417	1.788
6	5.120	7.719	9.665	1.888	1.252	1.570
7	8.027	3.518	9.814	1.223	2.790	2.006
8	8.027	3.762	9.513	1.185	2.529	1.857
9	8.031	3.402	9.742	1.213	2.864	2.038
10	6.339	4.827	10.171	1.605	2.107	1.856
11	6.535	7.790	9.762	1.494	1.253	1.373
12	5.822	4.234	9.678	1.662	2.286	1.974
13	3.486	0.000	9.901	2.840	/	2.840
14	3.486	0.000	10.094	2.896	/	2.896
15	3.486	5.013	11.453	3.285	2.285	2.785
16	3.486	5.954	9.942	2.852	1.670	2.261
17	2.398	7.365	9.757	4.069	1.325	2.697
18	3.684	7.365	9.761	2.650	1.325	1.987
19	6.577	7.257	10.184	1.548	1.403	1.476
20	7.245	4.587	10.542	1.455	2.298	1.877
21	11.446	6.465	10.267	0.897	1.588	1.243
22	5.064	3.440	9.646	1.905	2.804	2.354
23	6.174	3.440	9.783	1.585	2.844	2.214
24	4.772	8.596	9.737	2.040	1.133	1.587
25	7.094	4.297	9.435	1.330	2.196	1.763
26	6.795	5.215	9.698	1.427	1.860	1.643
27	4.026	5.020	10.127	2.515	2.017	2.266
28	4.725	5.020	9.555	2.022	1.903	1.963
29	4.725	6.018	9.673	2.047	1.607	1.827
30	7.712	7.441	9.760	1.266	1.312	1.289
31	4.598	6.038	9.665	2.102	1.601	1.851
32	5.792	6.038	9.673	1.670	1.602	1.636
33	3.819	7.253	9.512	2.491	1.311	1.901
34	3.819	7.253	9.586	2.510	1.322	1.916
35	3.412	3.889	10.162	2.978	2.613	2.796
36	7.503	3.889	9.503	1.267	2.444	1.855
37	7.931	3.889	9.882	1.246	2.541	1.894
38	3.604	7.563	9.534	2.645	1.261	1.953
39	3.604	6.512	9.679	2.686	1.486	2.086
40	6.716	3.597	11.127	1.657	3.093	2.375
41	5.405	5.819	9.705	1.796	1.668	1.732
42	6.213	6.913	10.164	1.636	1.470	1.553
43	6.213	6.913	9.620	1.548	1.392	1.470
44	6.803	6.185	9.836	1.446	1.590	1.518
45	6.029	3.517	9.694	1.608	2.756	2.182
46	6.029	2.970	9.669	1.604	3.256	2.430
47	7.344	4.005	15.724	2.141	3.926	3.034
48	0.000	3.765	10.013	/	2.659	2.659
49	0.000	7.328	10.131	/	1.383	1.383

Table 4 (continued)

Number	North (M)	South (M)	Widths (M)	D/H_N	D/H_S	D/H
Average	5.723	5.381	10.144	1.954	1.980	1.987

Fig. 16 vertical section diagrams of the street

distance-height ratio indicates that the heights of buildings on West Street vary rhythmically rather than uniformly. Examination of the column chart (see Fig. 18) depicting the distance-height ratios of the cross-sections reveals fluctuations within a certain range on both sides, suggesting a continuous variation in building heights. Excessively long interfaces may render the street monotonous and oppressive, whereas a diversity of vertical forms allows the eye to rest and shift momentarily during traversal, preventing a loss of interest during pedestrian activities. This dynamic

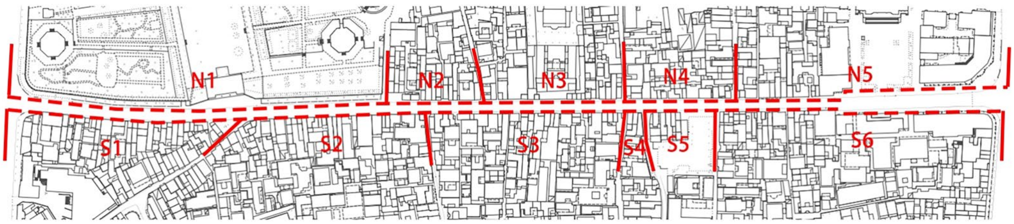

Fig. 17 Schematic diagram of the division of interfacial density units

Table 5 North side interface density statistics

Number	Based on the alley centerline (%)	Based on the alley boundary (%)
N1	94.9	100
N2	93.3	98.3
N3	95.8	98.5
N4	96.1	100
N5	69.4	71.9

Table 6 South side interface density statistics

Number	Based on the alley centerline (%)	Based on the alley boundary (%)
S1	90.4	100
S2	93.8	99.3
S3	93.8	95.4
S4	74.9	100
S5	74.6	77.5
S6	96.0	100

interplay imbues the street space of West Street with vitality.

Overlaying the data from the 49 sampled cross-sections reveals that while buildings on both sides exhibit varied heights, the undulations are not drastic, with the majority of structures ranging from 3 to 8.5 m in height (see Fig. 19). There is a notable concentration of building heights around the values of 7 m and 3.4 m on both the north and south sides, further corroborating the prevalence of one- to two-story buildings along West Street. Additionally, the average street width of 10 m is distinctly evident in the overlay analysis graph.

Horizontal dimension interface analysis

Analysis of interface sparseness

The statistical analysis of the interface density data for West Street reveals the following results: Without considering the influence of street width, the interface density range on the north side falls between 71.9 and 100% (see Fig. 20), while on the south side, it ranges from 77.5 to 100% (see Fig. 21). The overall average interface density on West Street is 94.6%. This indicates that the buildings along West Street are densely arranged, with minimal gaps between solid interfaces, presenting a state of dense distribution. After accounting for the impact of street width, the average interface density on both sides of West Street remains above 85%. This suggests that the presence of interfaces on both sides of West Street is clearly perceptible, and the high continuity of the interfaces provides a sense of enclosure for the street space. Notably, in Unit N5, where the Quanzhou Film and Drama Theater is located, and Unit S5, where the site of the Suqing Gate is situated, the interface density significantly decreases due to the influence of the two squares. Additionally, in Unit S4, the narrow interface projection width and the wide cross-section of the side lanes prevent the formation of a cohesive interface, resulting in an interface density of less than 80%. During on-site investigations, the lack of spatial enclosure in

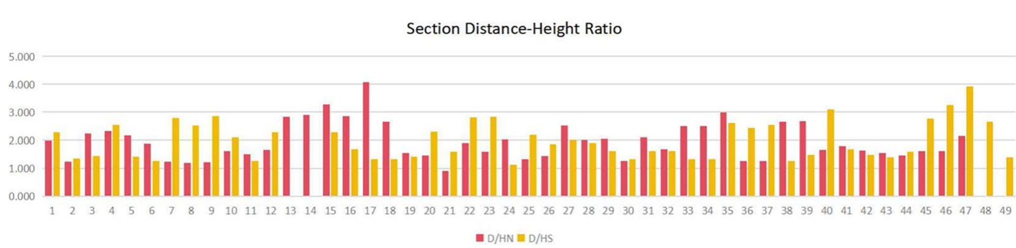

Fig. 18 West Street section distance-height ratio

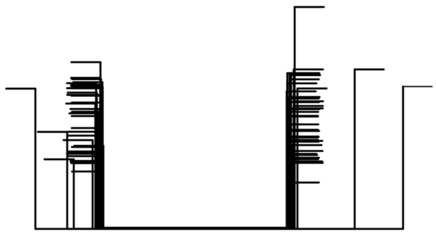

Fig. 19 Cross-section overlay analysis chart

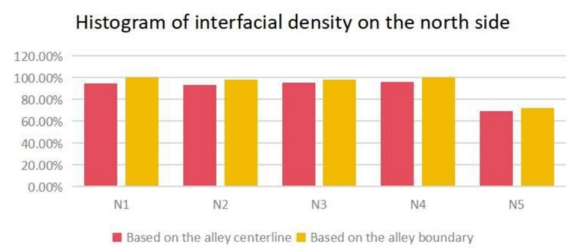

Fig. 20 Histogram of interfacial density on the north side

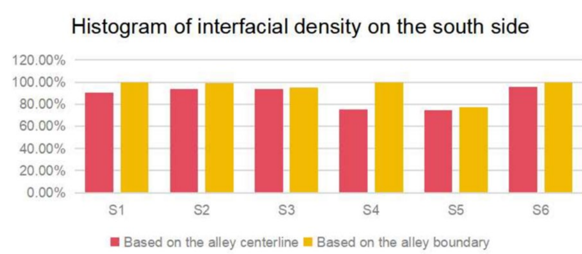

Fig. 21 Histogram of interfacial density on the south side

these three areas can be felt, aligning with the data feedback. However, in the unit where the Kaiyuan Temple is situated, although the north side of the street lacks enclosed building interfaces, the clear railings and orderly roadside trees provide spatial enclosure. On the south side of the street, despite the inward inclination of both sides of the buildings due to the slanted entrance of Xiangfeng Alley, the establishment of the Ziyun Screen effectively blocks the entrance of Xiangfeng Alley, compensating for the impact of the side lane cross-sections and providing clear enclosure for the street space. During field investigations, the sense of enclosure in these areas can still be perceived, consistent with the data feedback.

Analysis of interface convexity changes

The statistical analysis of the Build-To-Line rate data for West Street reveals the following results: The Build-To-Line rate on the north side is 79.8%, while on the south side, it is 79.5%, resulting in an average Build-To-Line rate of 79.7%. A higher Build-To-Line rate indicates stronger continuity and higher regularity along West Street (see Fig. 22). However, the Build-To-Line rate only describes the proportion of setback interfaces and does not provide detailed descriptions of all morphological features, including concavity and convexity. Through the analysis of street interface receding line overlay (see Fig. 23), it is observed that the setback range of the street interfaces is $[-6.12\ \text{m}, +0\ \text{m}]$. This range indicates that the maximum setback distance is approximately 6.12 m, and the maximum protrusion distance is 0 m. Regarding street width, except for individual sections affected by building setbacks, most sections fall within the range of

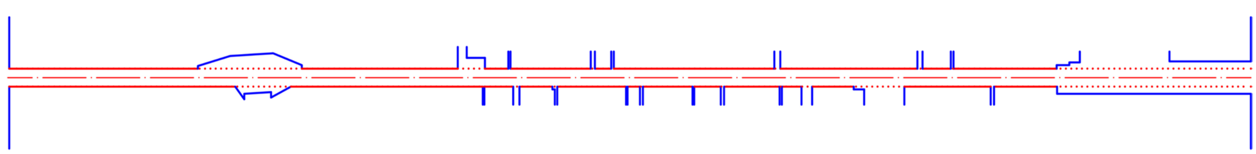

Fig. 22 Schematic of street interface setbacks

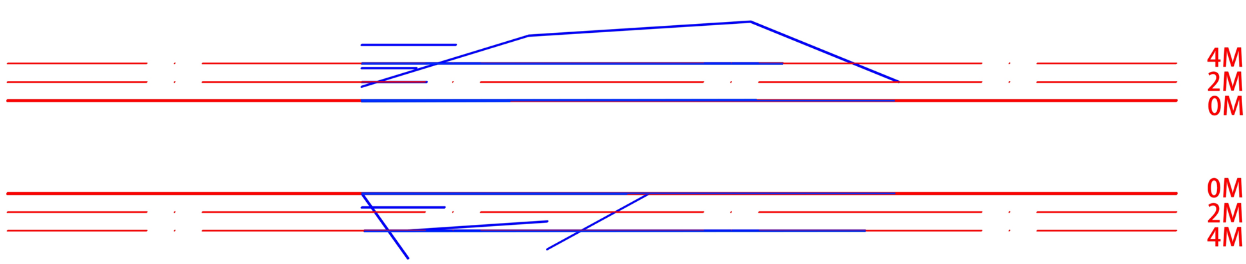

Fig. 23 Street interface receding line overlay

9.5–10 m. This suggests that the majority of shops along West Street are closely aligned with the street, with minimal fluctuations in setbacks. The degree of concavity and convexity of interfaces is not only related to setback distance but also to human perceptual distance. Regarding the analysis of the near-line rate data for West Street, the results indicate that the near-line rate on the north side is 90.7%, while on the south side, it is 92.3%, resulting in an average near-line rate of 91.5%. This suggests that, within the perceptual scale of a street with an average width of 10 m, the degree of concavity and convexity along West Street is not significant. Therefore, it can be inferred that the overall interfaces of West Street are relatively flat.

Summary of morphological characteristics of the West Street interface

Analysis of the quantified results reveals the following characteristics of the streetscape on West Street:

(1) Horizontally, West Street, influenced by its historical background, exhibits a uniform and densely packed arrangement of buildings along both sides of the street, with minimal undulations. Consequently, the interface density, build-to-line rate, and near-line rate are all relatively high, contributing to a strong sense of enclosure and definition of space, thus ensuring a high degree of spatial continuity along the street.

(2) Vertically, the buildings along West Street have modest heights, primarily consisting of one- to two-story commercial structures. Although there are no significant height differentials, there is frequent fluctuation in height. This variability enriches the vertical interface morphology of West Street, effectively mitigating the rigidity associated with high build-to-line rates and interface densities, thereby providing visitors to the street with a sense of freshness and dynamism.

West Street morphological character control strategy

In the practical implementation of historical street area renovations, conflicts may arise between the requirements depicted in illustrations and building regulations. Scholars have pointed out that historical street areas generally exhibit high building density and small inter-building spacing [99]. Evaluating these areas based on existing urban development regulations often necessitates extensive modifications, contradicting the goal of preserving the original urban fabric. Therefore, allowances should be made for historical street areas to deviate from conventional construction standards. Instead, locally applicable control standards should be formulated based on the original spatial morphology of the street area. Quantitative summaries of interface morphology characteristics can provide clear and precise control standards for street space morphology during renovation and redevelopment projects. Based on the quantified parameter ranges summarized earlier, the following standards should be adhered to when conserving and renovating West Street's historical and cultural district:

(1) Maintain an overall Distance-Height Ratio of 1.8, with section Distance-Height Ratios controlled within the range of 0.9 to 3.3, implying building heights should be maintained between 3 and 11 m. The predominant building types should be one to two-story structures, with a maximum height of three stories, ensuring consistency with adjacent buildings to maintain the continuity of street interfaces. Additionally, during the renovation process, ensure a certain degree of height variation to avoid large segments of uniformly tall buildings, preserving a diverse vertical interface morphology overall.

(2) Interface Density, delineated by street width boundaries, should range from 70 to 100%, ensuring that over 70% of the interface length along the street is maintained during the renovation of each street segment. Unrestricted demolition of street-facing buildings, which disrupts the spatial enclosure of the street, should be avoided. If it becomes necessary to remove street-facing buildings, reference can be made to the Kaiyuan Temple Street section to re-provide a sense of spatial limitation to the street space through maintenance structures such as walls and fences.

(3) Maintain a Build-To-Line Rate of 80% (± 5%). Ensure that at least 80% of the total interface length within each renovated street segment is adjacent to the street boundary. The distribution pattern of buildings along the street should be preserved, avoiding unnecessary setbacks of buildings from the street, which could compromise the continuity and regularity of the street.

(4) Maintain a Near-Line Rate of 90% (± 5%). Given the ideal street width of 10 m, the average setback distance can be calculated as 1.1 m based on the near-line rate formula. The maximum setback distance for interfaces should be within 6 m, with no allowance for buildings encroaching onto the street, signifying a 0-m setback allowance.

Research implications and limitations

Urban historical districts possess unique historical rhythms in their spatial morphology, and maintaining the traditional spatial form of streets to continue the historical cultural atmosphere is the significance of spatial morphology quantification research. Through empirical research on specific cases, this study verifies the feasibility of quantitative analysis in the protection of spatial forms in historical districts. The data and features obtained from the research have important value for the protection and planning of street spaces within historical districts. Due to the lack of effective technical means for the protection of street interfaces in historical districts, this parameter quantification method has positive application prospects in the protection of historical and cultural streets. This method provides a clear and precise standard for controlling street space morphology, laying a solid foundation for updating the architectural interface form in historical districts. In the updating process, the architectural interface form along the streets can no longer rely on subjective judgments such as whether it is "harmonious with the historical style," but can be based on quantitative method analysis to derive control standards as design guidelines. This is significant for promoting the legalization of historical and cultural district protection. Moreover, its updating mode is neither arbitrary, entirely based on old building boundaries as reference criteria, nor laissez-faire, but based on the characteristics of street interfaces, providing a certain "self-growth" space to facilitate resource integration and architectural innovation, and truly achieve the purpose of "gradual and organic renewal" of historical districts. This approach is no longer results-oriented but forms an effective measure of process control to promote the organic renewal of street interfaces. The quantification method of street interfaces as a research method and technical means is reflected in the preparation process of protection planning rather than directly in the planning text as a result. Therefore, participants involved in the implementation of protection planning, such as government officials, developers, constructors, and social groups, do not need to understand the professional quantification process, ensuring the practicality of this quantification method to a certain extent.

Although this study has reviewed a large amount of literature and documents, there are still limitations. This empirical study has certain reference value for the protection of street interfaces in historical and cultural districts within artificially planned urban textures. However, historical districts, which have diverse characteristics, especially the interface forms of naturally grown historical districts are relatively complex, and the quantification methods proposed in this study may not be effectively applicable. The quantification parameter framework developed in this study cannot form a one-to-one correspondence with street interface forms, as quantification parameters are only necessary but not sufficient conditions for street interface forms. That is, a specific street interface form will only have a specific parameter set corresponding to it, but a specific parameter set corresponding to street interface forms does not have uniqueness. Therefore, how to control the differences in morphological characteristics under the same parameters to ensure the effectiveness of quantification methods requires further research. Moreover, the case study only attempts to control the architectural interface, and does not provide a comprehensive solution to all problems of block renewal, such as determining building density, floor area ratio, and architectural color control, which require further research to address the complexities in practice. The protection of historical and cultural districts involves not only physical buildings and streets but also complex factors such as district culture, economic structure, and residents' lifestyles. Therefore, more research is needed for specific historical and cultural district cases to explore corresponding protection methods.

Conclusion

After reviewing the relevant studies on historical urban districts, this research points out that scholars have mainly focused on macro-planning and development of the regions, with limited in-depth quantitative research on street-level spatial morphology. Therefore, based on the theory of interface morphology quantification, this paper proposes a geometric morphology quantification method for the street space in historical urban districts, using five quantitative parameters including "Distance-Height Ratio," "Interface Density," "Build-To-Line Rate," "Near-Line Rate," and "Width-Distance Ratio" to construct a system for controlling street interface morphology characteristics. These parameters comprehensively analyze the morphological characteristics of street interfaces from both longitudinal and transverse dimensions, quantifying abstract interface morphology into specific parameter ranges. This quantification method not only describes the continuous characteristics of the overall street morphology but also includes segmental characteristics of street cross-section morphology. Through the data and features obtained from the research, it is possible to effectively control the impact of reconstruction and redevelopment of historical urban districts on street space morphology, guiding the future updating of architectural interface morphology in historical urban districts. In practical implementation, interface updates are neither solely based on old buildings nor arbitrarily demolished and constructed. Instead, they should be based on the numerical ranges and rules obtained from quantitative parameter analysis, following the reference criteria while adhering to the characteristics of street interface morphology and preserving the overall integrity of street space, thereby conducting a gradual and "organic renewal."

Author contributions
Conceptualization, Y.Z. and K.H. methodology, K.H.; resources, K.H. and Y.Z.; investigation, K.H. and P.K.; Data Curation, K.H., Y.Z. and P.K.; formal analysis, K.H.; writing—original draft preparation, K.H.; writing—review and editing, K.H. and Y.Z. supervision, Y.Z.; All authors have read and agreed to the published version of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding
This study was not funded.

Availability of data and materials
All data generated or analysed during this study are included in this published article.

Declarations

Competing interests
The authors declare they have no competing interests.

Received: 10 February 2024 Accepted: 27 June 2024
Published online: 04 July 2024

References

1. Jones GA, Bromley RD. The relationship between urban conservation programmes and property renovation: evidence from Quito, Ecuador. Cities. 1996;13(6):373–85.
2. Oliver G. The limitlessness city: a primer on the urban sprawl debate. Beijing: China Architecture & Building Press; 2007.
3. Poincaré R. Loi sur les monuments historiques. Bibliothèque de l'École des chartes. 1914;75:211–20.
4. CIAM, IV. The Athens Charter. The 4th congress of Congress International Architecture Modern. Athens. 1933.
5. ICOMOS, UK. The venice charter. London: ICOMOS; 1964.
6. Unesco R. Concerning the safeguarding and contemporary role of historic areas. Nairobi. 1976;11:26.
7. Charter, Washington. Charter for the conservation of historic towns and urban areas. Adopted by ICOMOS General Assembly. 1987.
8. Wu L. The Beijing charter. Urban Stud. 1999;4:1–4.
9. Dovey K, Wood S. Public/private urban interfaces: type, adaptation, assemblage. J Urban. 2015;8(1):1–16.
10. Glaser M, van Hoff M, Karssenberg H, Laven J, Van Teeffelen J. The city at eye level: lessons for street plinths. Delft: Eburon Uitgeverij BV; 2012.
11. Sitte C. City planning according to artistic principles. (No Title). 1965.
12. Hillier B, Hanson J. The social logic of space. Cambridge: Cambridge University Press; 1989.
13. Sayegh A, Andreani S, Kalchschmidt M. Responsive environments. Oxfordshire: Routledge; 2013.
14. Chen H, Wang L, Waley P. The right to envision the city? The emerging vision conflicts in redeveloping historic Nanjing, China. Urban Aff Rev. 2020;56(6):1746–78.
15. Zhu Y, González Martínez P. Heritage, values and gentrification: the redevelopment of historic areas in China. Int J Herit Stud. 2022;28(4):476–94.
16. Blum ML, Orbach MK. First steps at first point: protecting California surf breaks and the Malibu historic district. Coast Manag. 2021;49(2):201–14.
17. Wang Z. Remodeling and reflection historic district-taking Qianmen Street as an example. IOP Conf Ser Earth Environ Sci. 2017. https://doi.org/10.1088/1755-1315/86/1/012001.
18. Boussaa D. The past as a catalyst for cultural sustainability in historic cities; the case of Doha, Qatar. Int J Herit Stud. 2021;27(5):470–86.
19. Jayantha WM, Yung EHK. Effect of revitalisation of historic buildings on retail shop values in urban renewal: an empirical analysis. Sustainability. 2018;10(5):1418.
20. Hu C, Gong C. Exploring the creation of ecological historic district through comparing and analyzing four typical revitalized historic districts. Energy Procedia. 2017;115:308–20.
21. Masuwan K, Lertwattanaruk P. Incorporating form-based codes into the design-based approach to historic building conservation in Phuket, Thailand. Sustainability. 2020;12(9):3859.
22. Wang H, Yan Z, He X, Song Y, Huang Y, Zhang J, Jiang X. Research on architectural art and sustainable design of ginling college historic district (Nanjing, China). Buildings. 2023;13(7):1725.
23. Dai L, Wang S, Xu J, Wan L, Wu B. Qualitative analysis of residents' perceptions of tourism impacts on historic districts: a case study of nanluoguxiang in Beijing, China. J Asian Archit Build Eng. 2017;16(1):107–14.
24. Pezeshki F, Khodadadi M, Bagheri M. Investigating community support for sustainable tourism development in small heritage sites in Iran: a grounded theory approach. Int J Heritage Stud. 2023. https://doi.org/10.1080/13527258.2023.2220316.
25. Zhang N. A preliminary study of slow traffic system to activate the vitality of historic districts take Wuhan Tanhualin historic district as an example. IOP Conf Ser Earth Environ Sci. 2021;647(1):012206.
26. Wang S, Guo Q, Yuan J, Li H, Fu B. Research on the conservation methods of Qu Street's Living heritage from the perspective of life continuity. Buildings. 2023;13(6):1562.
27. Kou H, Zhou J, Chen J, Zhang S. Conservation for sustainable development: the sustainability evaluation of the Xijie historic district, Dujiangyan city, China. Sustainability. 2018;10(12):4645.
28. Wu F, Qin S, Su C, Chen M, Wang Q, Zhang Q. Development of evaluation index model for activation and promotion of public space in the historic district based on AHP/DEA. Math Probl Eng. 2021;2021:1–17.
29. Gai Q, Li Z, Hu H. Strategies for china's historic districts regeneration in responding to public health emergencies. Sustainability. 2022;14(21):14020.
30. Zhang J, Huo X, Zheng W, Zheng X, Zhang M. Research on the positioning of protection and utilization of historic districts under big data analysis. Int Arch Photogramm Remote Sens Spat Inf Sci. 2017;42:731–5.
31. Zhao Q, Ren Y. Protection and planning of historic districts based on internet of things perception. Comput Intell Neurosci. 2022. https://doi.org/10.1155/2022/1325381.
32. Skotis A, Livas C. A data-driven analysis of experience in urban historic districts. Ann Tour Res Empir Insights. 2022;3(2):100052.
33. Wang M, Yang J, Hsu WL, Zhang C, Liu HL. Service facilities in heritage tourism: Identification and planning based on space syntax. Information. 2021;12(12):504.
34. Tutuko P, Bonifacius N, Yuniawan D, Aini N, Shen Z, Bin Mohamad E, Sulaksono AG. The pattern of land use integration in historic areas in the CBD zone: comparative study of space syntax attributes of Malang, Melaka, and Kanazawa. Int Rev Sp Plan Sustain Dev. 2022;10(3):148–69.
35. Liang W, Ahmad Y, Mohidin HHB. Spatial form and conservation strategy of Sishengci historic district in Chengdu, China. Heritage. 2023;6(2):891–903.
36. Lyu Y, Abd Malek MI, Jaafar NH, Sima Y, Han Z, Liu Z. Unveiling the potential of space syntax approach for revitalizing historic urban areas: a case study of Yushan Historic District, China. Front Archit Res. 2023;12(6):1144–56.
37. Wang F, Mao W, Dong Y, Zhu X. Implications for cultural landscape in a Chinese context: geo-analysis of spatial distribution of historic sites. Chin Geogra Sci. 2018;28:167–82.
38. Merciu C, Ianos I, Merciu GL, Jones R, Pomeroy G. Mapping accessibility for earthquake hazard response in the historic urban centre of Bucharest. Nat Hazard. 2018;18(7):2011–26.

39. Chen Z, Liu S, Liao W, Zhang J. Construction of security pattern for historical districts in cultural landscape based on MCR model: a case study of Chaozong Street, Changsha City. Sustainability. 2023;15(13):10619.
40. Deng Z, Chen D, Qin X, Wang S. Comprehensive assessment to residents' perceptions to historic urban center in megacity: a case study of Yuexiu District, Guangzhou, China. J Asian Archit Build Eng. 2021;20(5):566–80.
41. Fang YN, Zeng J, Namaiti A. Landscape visual sensitivity assessment of historic districts—a case study of Wudadao historic district in Tianjin, China. ISPRS Int J Geo Inf. 2021;10(3):175.
42. Yang X, Shen J. Landscape sensitivity assessment of historic districts using a GIS-based method: a case study of beishan street in Hangzhou, China. ISPRS Int J Geo Inf. 2023;12(11):462.
43. Jiang Y, Chen L, Xie Y, Li Y, Li T. subjective well-being of historical neighborhood residents in Beijing: the impact on the residential environment. Sustainability. 2023;15(3):1847.
44. García-Esparza JA, Altaba P, Huerta J. Examining urban polarization in five Spanish historic cities through online datasets and onsite perceptions. Habitat Int. 2023;139:102900.
45. Liang F, Pan Y, Gu M, Liu Y, Lei L. Research on the paths and strategies of the integrated development of culture and tourism industry in urban historical blocks. Front Public Health. 2022;10:1016801.
46. Li J, Luo J, Deng T, Tian J, Wang H. Exploring perceived restoration, landscape perception, and place attachment in historical districts: insights from diverse visitors. Front Psychol. 2023. https://doi.org/10.3389/fpsyg.2023.1156207.
47. Liu T, Butler RJ, Zhang C. Evaluation of public perceptions of authenticity of urban heritage under the conservation paradigm of Historic Urban Landscape—a case study of the Five Avenues Historic District in Tianjin, China. J Archit Conserv. 2019;25(3):228–51.
48. Li X, Jia T, Lusk A, Larkham P. Rethinking place-making: Aligning placeness factors with perceived urban design qualities (PUDQs) to improve the built environment in historical districts. Urban Des Int. 2020;25:338–56.
49. Wang Z, Sun H, Li J. Research on architectural color and visual comfort in historic landscape areas. Buildings. 2023;13(4):1004.
50. Taysun B, Bayram Ş, Oktay HE, Danaci HM. Preferences for facades of historic building: example of Gevaş, Turkey. Environ –Behav Proc J. 2023;8(23):281–6.
51. Jiang N, Li X, Peng Z, Ban Q, Feng Y. Assessing distributional and perceived equity of urban green spaces in Qingdao's historic urban area. Buildings. 2023;13(11):2822.
52. Hosseini A, Kowkabi L. Measuring the soundscape quality in urban spaces: a case study of historic urban area. Sustainability. 2023;15(5):4255.
53. Egusquiza A, Prieto I, Izkara JL, Béjar R. Multi-scale urban data models for early-stage suitability assessment of energy conservation measures in historic urban areas. Energy Build. 2018;164:87–98.
54. Mukhopadhyay J, Ore J, Amende K. Assessing housing retrofits in historic districts in Havre Montana. Energy Rep. 2019;5:489–500.
55. Cantatore E, Fatiguso F. An energy-resilient retrofit methodology to climate change for historic districts. Application in the mediterranean area. Sustainability. 2021;13(3):1422.
56. Hubinský T, Hajtmanek R, Šeligová A, Legény J, Špaček R. Potentials and limits of photovoltaic systems integration in historic urban structures: the case study of monument reserve in Bratislava, Slovakia. Sustainability. 2023;15(3):2299.
57. Zhao H. How can it be more real? A case study to present the authenticity of a local heritage district from the perspective of regional spatial morphology. Sustainability. 2018;10(6):1715.
58. Zhang J, Zhang J, Yu S, Zhou J. The Sustainable development of street texture of historic and cultural districts-a case study in Shichahai District, Beijing. Sustainability. 2018;10(7):2343.
59. Teng Y, Yang S, Huang Y, Barker N. Research on space optimization of historic blocks on Jiangnan from the perspective of place construction. Appl Math Nonlinear Sci. 2021;6(1):201–10.
60. Zhou X, Zhang X, Dai Z, Hermaputi RL, Hua C, Li Y. Spatial layout and coupling of urban cultural relics: analyzing historical sites and commercial facilities in district iii of Shaoxing. Sustainability. 2021;13(12):6877.
61. Yin S, Guo X, Jiang J. Extracting the urban landscape features of the historic district from street view images based on deep learning: a case study in the Beijing core area. ISPRS Int J Geo Inf. 2022;11(6):326.
62. Zhang K, Zhang N, Quan F, Li Y, Wang S. Digital form generation of heritages in historical district based on plan typology and shape grammar: case study on Kulangsu Islet. Buildings. 2023;13(1):229.
63. Zhang M, Zhang Y, Fang X, Wang X. A 3D spatial diagnostic framework of sustainable historic and cultural district preservation: a case study in Henan, China. Buildings. 2023;13(5):1344.
64. Wu G, Dang A, Chen M, Li X. Study on historical cities conservation monitoring supported by high-resolution remote sensing. Int Rev Sp Plan Sustain Dev. 2023;11(2):240–58.
65. Wang Q, Sun H. Traffic structure optimization in historic districts based on green transportation and sustainable development concept. Adv Civ Eng. 2019;2019:1–18.
66. Xu Y, Rollo J, Jones DS, Esteban Y, Tong H, Mu Q. Towards sustainable heritage tourism: a space syntax-based analysis method to improve tourists' spatial cognition in Chinese historic districts. Buildings. 2020;10(2):29.
67. Al Mushayt NS, Dal Cin F, Barreiros Proença S. New lens to reveal the street interface. A morphological-visual perception methodological contribution for decoding the public/private edge of arterial streets. Sustainability. 2021;13(20):11442.
68. Moqadam S, Nubani L. The impact of spatial changes of Shiraz's historic district on perceived anti-social behavior. Sustainability. 2022;14(14):8446.
69. Xu Y, Tong H, Chen M, Rollo J, Zhang R. Examining the urban regeneration of public cultural space using multi-scale geospatial data: a case study of the historic district in Jinan, China.". Front Built Environ. 2023;9:1328157.
70. Huang J, Hu X, Wang J, Lu A. How diversity and accessibility affect street vitality in historic districts? Land. 2023;12(1):219.
71. Zhu G, Chen Y, Wu W, Liu R, Tang Y, Li P, Xu A. Coupling relationships between urban block spatial morphology and microclimate in severe cold regions. Iscience. 2023;26(11):108313.
72. Gu H, Wei Y, Zhao H. Designing a renewal approach of rejuvenating historic districts: taking nantong temple street as an example. Mob Inform Syst. 2022. https://doi.org/10.1155/2022/2957757.
73. Zhu X, Chiou SC. A study on the sustainable development of historic district landscapes based on place attachment among tourists: a case study of Taiping old street, Taiwan. Sustainability. 2022;14(18):11755.
74. Xia S, Liu B, Wang H. Construction of a sustainability-based building attribute conservation assessment model in historic areas. Buildings. 2022;12(9):1346.
75. Hassan O, Mohamed EA, Hassan A, Shaheen M, Bekeet W. Sustainable urban development of mobility and streetscape in historic city quarters, an ancient street in Alexandria-Egypt, as a case study. Alex Eng J. 2023;78:378–89.
76. Ding F, Ren Y, Goudos S, Zhao Y. Analysis of public space in historic districts based on community governance and neural networks. IEEE Access. 2023. https://doi.org/10.1109/ACCESS.2023.3297507.
77. Yang L, Li J, Chang HT, Zhao Z, Ma H, Zhou L. A generative urban space design method based on shape grammar and urban induction patterns. Land. 2023;12(6):1167.
78. Chen Y, Zheng L, Yan L. Research on the intelligent generation of the spatial form of the island city historic district Based on parameterization: Taking Macau Taipa Village as an example. J Asian Archit Build Eng. 2023. https://doi.org/10.1080/13467581.2023.2257274.
79. Chen YX, Shu B, Chang HT. Exploring architectural shapes based on parametric shape grammars: a case study of the "three lanes and seven alleys" historic district in Fuzhou City, China. Buildings. 2023;13(8):2063.
80. Lin H, Huang L, Chen Y, Zheng L, Huang M, Chen Y. Research on the application of CGAN in the design of historic building facades in urban renewal—taking Fujian Putian historic districts as an example. Buildings. 2023;13(6):1478.
81. Xia L, Li J, Hu Y, Sun H. Testing and accuracy analysis of prism-free total station ranging performance. Geospatial Information. 2008;6(2):133–5.
82. Sitte C. The art of building cities: city building according to its artistic fundamentals. Odessa: Ravenio Books; 1979.
83. Ashihara Y. The aesthetic townscape. J Aesthet Art Crit. 1986. https://doi.org/10.2307/429797.
84. Jacobs AB. Great streets. No. qt3t62h1fv. University of California Transportation Center, 1993.
85. Zhou Y, Zhao JB, Zhang YK. Planning control of street interface density and urban form. Urban Plan. 2012;6:28–32.

86. Sun H, Shen L. Efficiency and vitality: modern urban street structure. Beijing: China Building Industry Press; 2007.
87. Zhou Y. Exploration on "Build-To-Line Rate" in urban planning control on street interface. Urban Plan. 2016;40(08):25–9.
88. Oliveira V, Medeiros V. Morpho: combining morphological measures. Environ Plan B Plan Des. 2016;5:805–25.
89. SMAPLR. Technical Guidelines for Shanghai Municipality's Detailed Control Planning (2016 Revision). 2016; 73–76.
90. JPDC. Guidelines for the Preparation of Detailed Control Planning in Jiangsu Province (revised in 2012). 2012; 23
91. Zhou Y, Wang Z. A study on the "Near Line Rate" for quantitative measurement of street interface morphology. New Archit. 2018;36(5):150–4.
92. Lynch K. The image of the city. Cambridge: MIT press; 1964.
93. China State Council. Circular of the State Council Approving the Petition of the State Capital Construction Committee and Other Departments on the Protection of China's Famous Historical and Cultural Cities. Bull State Counc PR China. 1982;04:137–42.
94. China State Council. State Council on the announcement of the first batch of national key cultural relics protection unit list notice. Bull State Counc PR China. 1961;04:79–89.
95. Jiang L, Sun H. A new interpretation of urban layout and fangli formation in Chang'an, Tang. Urban Plan. 2003;27(1):77–82.
96. Changsun W. Tang law review. Vol. 61. artchina.com, 2000.
97. Huo J, Zou Y, Zhu Z. Research on the design of street space renewal in Zhenjiang historical style district based on spatial syntax analysis. Design. 2018;31(5):20–2.
98. Xu C, Guo S. A study on the characteristics of historical and cultural neighborhood business and its influencing factors-taking Changsha Taiping street as an example. Ecotour China. 2023;13(1):152–68.
99. Zhang K. Study on the preparation of control detailed planning for urban historic landscape area-taking "control detailed planning for Zhenjiang Ancient City landscape area" as an example. Urban Plan. 2003;27(11):93–6.

Publisher's Note