

Identifying industry structure and industrial relevance of commercial historic cultural districts using functional co-location networks

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Article

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Abstract

Commercial functions are widely regarded as a key instrument for revitalizing historic cultural districts, yet functional mix decisions are often made on experiential grounds, resulting in heritage erosion, homogenized retail, and weakened district identity. This study develops a data-informed analytical framework to identify industry structure typologies and to uncover the industrial relevance mechanisms that shape functional co-location in commercial historic cultural districts. Drawing on 2023 Point-of-Interest data from Gaode Map for 50 well-performing commercial historic cultural districts across 29 cities in China, the study integrates industry structure indicators, hierarchical cluster analysis, and functional co-location network analysis. Four steps are undertaken: case selection, industry structure evaluation and classification, functional co-location network cluster identification, and abstraction of common industrial relevance mechanisms. The results identify seven industry structure types that each exhibiting a distinct functional-structural profile: balanced development, shopping and leisure dominant, overnight accommodation ancient town, specialty catering dominant, scenic attractions pulling, business and living services, and administrative and cultural services. Functional co-location network analysis further reveals eight characteristic clusters whose compositions and interrelations vary systematically across the seven types: shopping and leisure, catering and entertainment, culture and art, holiday accommodation, scenic sightseeing, local life, corporate business, and administrative office. Four recurring industrial relevance mechanisms are distilled: consumption behaviour relevance, environmental quality relevance, planning and administrative relevance, and production chain relevance. The framework extends industrial relevance analysis from macro-regional to neighbourhood micro-scales, offers a typological reference for benchmarking district positioning, and provides actionable guidance for fine-grained business mix regulation in heritage revitalization practice.

Keywords: commercial historic cultural districts; industry structure; functional co-location networks; industrial relevance

Introduction

Historic cultural districts constitute a vital component of urban cultural heritage, carrying irreplaceable historical information and collective memory^{[1][2]}. Their conservation and adaptive reuse have become a global priority in the pursuit of sustainable urban development^[3]. In recent years, China has issued a series of policy documents, including the Opinions on Strengthening the Protection and Inheritance of Historical and Cultural Heritage in Urban and Rural Development^[4] and the 14th Five-Year Plan for Cultural Development^[5], which explicitly call for integrating cultural heritage protection into territorial spatial planning and encouraging the use of idle facilities and revitalization of underutilized land for cultural and tourism industries. Within this policy context, commercial functions have been widely recognized as a core instrument for injecting vitality into historic quarters and achieving the effective utilization of cultural heritage^{[6][7]}. However, a large body of practice has revealed a host of emerging problems: large-scale commercial development has displaced indigenous residents and eroded traditional ways of life^[8]; inappropriate business mix configurations have blurred the distinctive identities of

historic quarters and rigidified their operational models^{[9][10]}; and the proliferation of homogenized Internet-famous retail formats has progressively diluted the historical legibility and cultural authenticity of these places^[11]. At the root of these problems lies the fact that current business mix decisions rely predominantly on experiential judgment and qualitative analysis, lacking a systematic scientific understanding of the typological diversity of business mix compositions and the inherent laws governing inter-industry relationships^[12].

The international academic community has accumulated substantial knowledge on the conservation and development of historic quarters. Early research primarily focused on the cultural, aesthetic, and historical values of historic quarters, with evaluation methods largely based on qualitative description and expert scoring^[13]. As the research frontier advanced, scholars began to explore the economic value and industrial potential of historic quarters, investigating tourism-led and creative-industry-led regeneration strategies^{[14][15]}. In terms of planning techniques, quantitative tools such as GIS, fuzzy comprehensive evaluation models, and the Analytic Hierarchy Process (AHP) have been progressively introduced into conservation planning for purposes of condition survey, value assessment, and performance evaluation^{[16][17][18]}. With specific reference to commercial historic quarters, existing studies have conducted valuable explorations from perspectives including commercial attractiveness, functional density, customer satisfaction, and spatial morphology^{[19][20]}, drawing on cases such as Beijing's Qianmen^{[21][22]}, Shanghai's Yuyuan Road^[23], and Tunxi Old Street in Anhui^[24]. These studies have revealed the influences of locational conditions, historical context, and government behavior on the commercial evolution of historic quarters, providing preliminary empirical guidance for business mix configuration^[25].

Nevertheless, a critical examination of the existing literature reveals three significant gaps. First, the majority of studies are confined to qualitative descriptions and strategy recommendations for single or few cases, lacking systematic quantitative comparisons based on large and diverse samples, and thus failing to generate a generally applicable typology of business mix compositions^{[26][27]}. Second, existing quantitative research tends to focus on macroeconomic benefits or macroscopic spatial morphological characteristics, with insufficient attention to inter-industry correlations at the micro-scale^{[28][29]}. Industrial economics theory has long established that inter-industry relevance is a key factor shaping industrial agglomeration and regional economic evolution^{[30][31][32]}. Yet this perspective has not been adequately mobilized in urban planning research at the neighborhood scale^{[33][34][35]}. Third, with respect to analytical methods, while some studies have begun to employ POI data and spatial analysis techniques^[36], the technical challenge of how to effectively extract industrial cluster characteristics from massive spatial point data, identify positive and negative inter-industry associations, and translate these findings into actionable planning strategies remains largely unresolved^[37]. In recent years, the functional co-location network approach, grounded in co-location pattern mining, has offered a promising solution to this challenge^{[38][39]}. By calculating the conditional probability of different functions co-occurring within the same spatial unit, this method constructs networks of functional associations and has demonstrated robust analytical capacity in studies of urban functional structure and mixed-use intensity^{[40][41]}. Its application to commercial historic quarters holds the potential to reveal the intrinsic logic of business mix configuration from a spatial-association perspective^[42].

In response to the gaps identified above, this study poses three core research questions. First, can

the business mix compositions of typical commercial historic quarters in China be classified into identifiable typologies, and what are the functional-structural differences among these types? Second, what cluster characteristics do the business activities of each type exhibit in space? Which business categories tend to co-locate, and what patterns can be discerned in their combinations? Third, what are the underlying industrial mechanisms that drive spatial co-location, and how do these mechanisms shape the functional organization and developmental trajectories of these quarters? To address these questions, this study selects 50 well-performing commercial historic quarters across China as cases, draws on Gaode Map POI data, and employs hierarchical clustering and functional co-location network methods in combination. The objective is to establish a complete analytical framework encompassing business mix typology identification, functional cluster characterization, and industrial relevance mechanism distillation. The findings are expected to provide a scientific basis for functional positioning, business mix regulation, and fine-grained management of commercial historic quarters, thereby facilitating a transition from experience-driven to data-informed decision-making in heritage revitalization practice.

Methods

Research framework

The research methodology comprised four primary steps (Fig. 1):

1. 50 typical commercial historic cultural districts in good operating condition nationwide were selected as the study cases.
2. Indicators of industry structure were calculated to evaluate the study cases, and seven types of industry structure of commercial historic cultural districts were identified by using the sample clustering method in SPSS hierarchical cluster analysis^{[43][44]}.
3. Functional co-location network method was conducted to identify eight functional co-location network characteristic clusters⁴⁰³⁸³⁹.
4. Finally, analyzing industrial relevance between and within the clusters, and abstracting common industrial relevance mechanisms of commercial historic cultural districts in China.

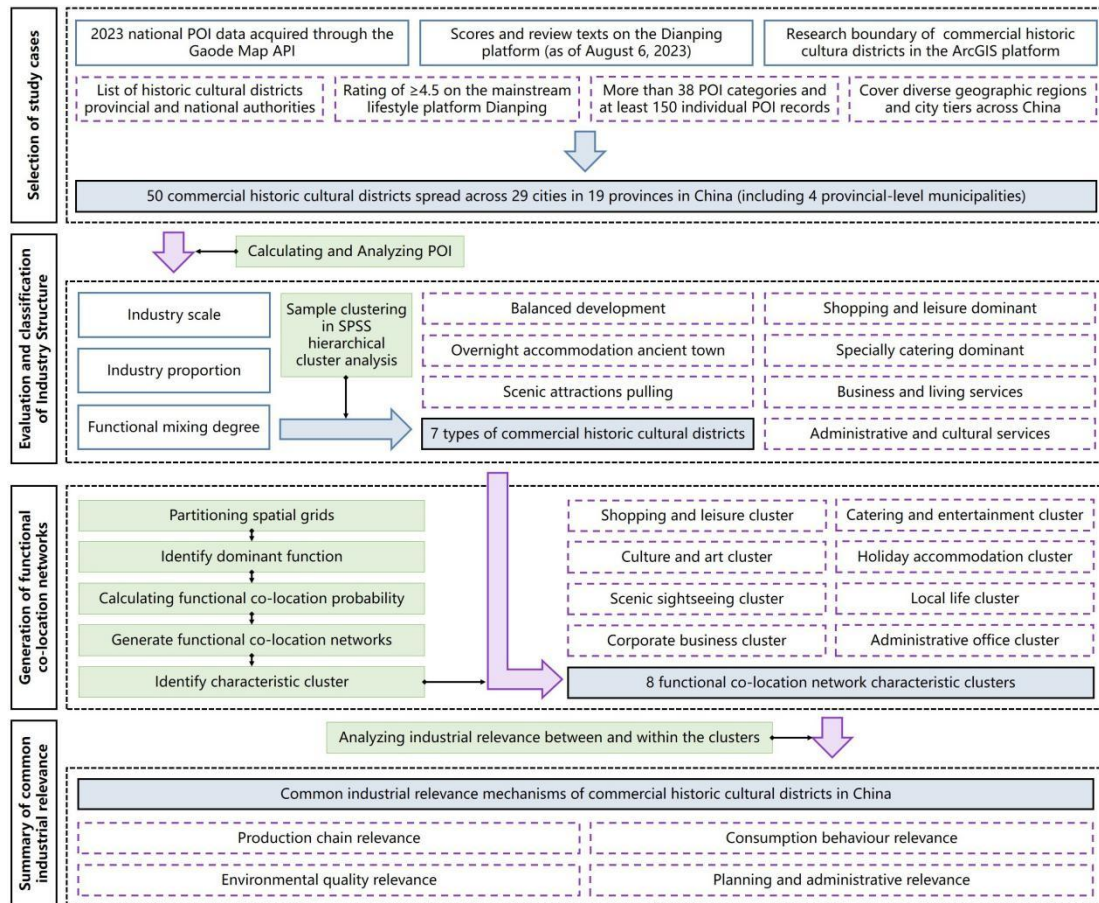


Fig. 1 | Research framework. The workflow integrates study cases selection, industry structure evaluation and classification, functional co-location network characteristic clusters identification, and common industrial relevance mechanisms of commercial historic cultural districts abstraction.

Data sources

The core dataset used in this study is the 2023 national POI (Point of Interest) data acquired through the Gaode Map API(<https://lbs.amap.com/>). The dataset contains facility names, addresses, geographic coordinates, and a three-tier classification system (20 major categories and 134 intermediate categories), characterized by comprehensive coverage, high positional accuracy, and timely updates. In the ArcGIS platform, the research boundary for each case was first delineated by integrating the officially designated conservation area with the actual visitor activity range inferred from social media check-in and review geographies. The raw POI data were then spatially clipped and filtered against these boundaries, with irrelevant or duplicate records removed. The final compiled dataset comprises 77,389 valid POI records across all 50 cases, covering all major business categories including catering, shopping, accommodation, cultural-educational services, and scenic attractions. In addition, rating scores (ranging from 4.5 to 4.9) and review texts were scraped from the Dianping platform for each district, serving as qualitative reference data for case validation and result interpretation.

Study cases

Commercial historic cultural districts are urban neighborhoods that possess both cultural heritage attributes and commercial service functions. To ensure case representativeness and the

generalizability of findings, a systematic case selection protocol was established:

1. The site must be officially designated as a historic cultural district by provincial or national authorities.

2. It must achieve a rating of ≥ 4.5 (out of 5) on the mainstream lifestyle platform Dianping (the Chinese equivalent of Yelp), accompanied by a substantial number of user reviews, indicating high public recognition and market vitality.

3. The district must contain no fewer than 38 POI categories and at least 150 individual POI records to ensure sufficient data richness for subsequent network analysis.

4. Cases were selected to cover diverse geographic regions and city tiers across China, accommodating variations between northern and southern cities and across different scales.

The final dataset comprised 50 qualified commercial historic cultural districts (Fig. 2). These cases range from small neighborhoods of less than 10 hectares to large ancient towns approaching 1000 hectares, with industry categories varying from 38 to 114 types, collectively capturing the full spectrum of commercial historic cultural district diversity in China.

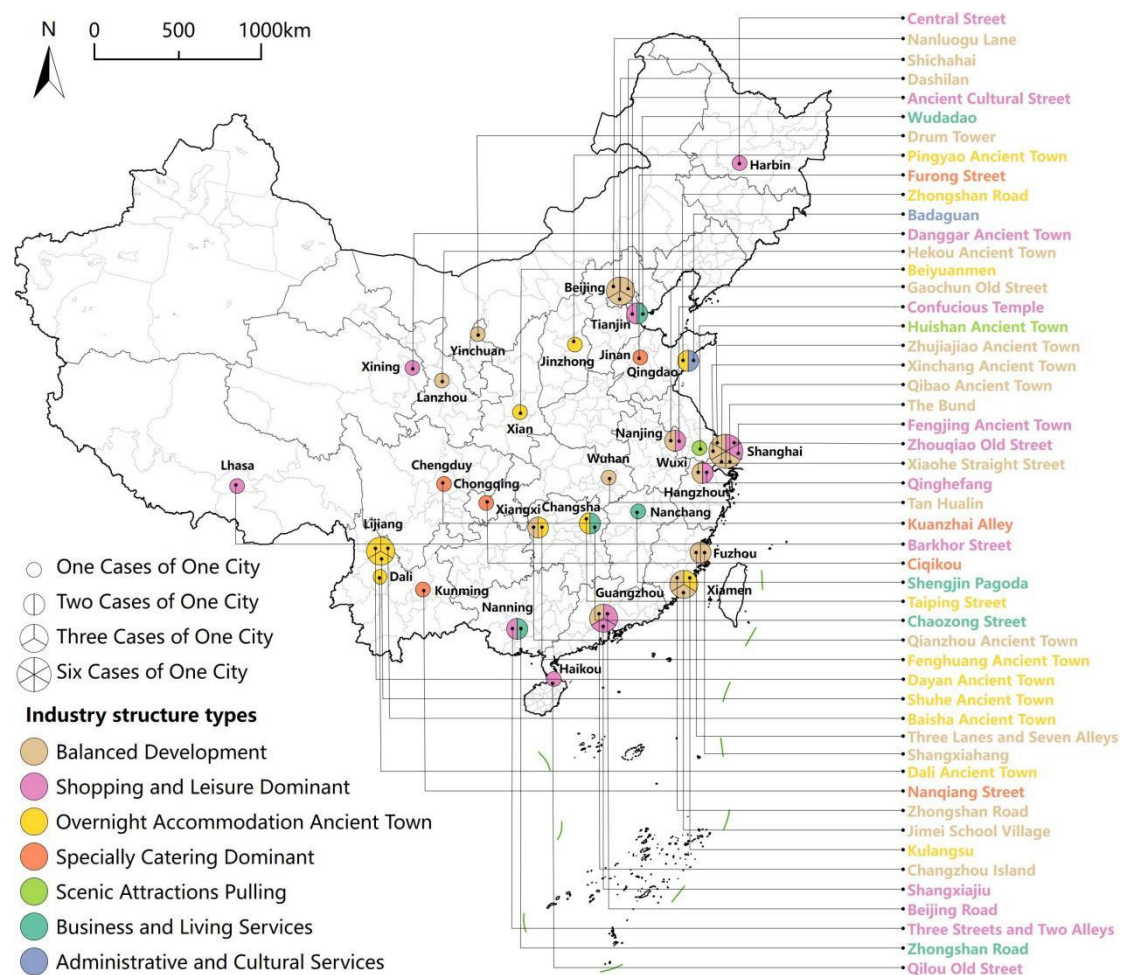


Fig. 2 | Spatial distribution of the 50 commercial historic cultural districts. The cases are spread across 29 cities in 19 provinces in China (including 4 provincial-level municipalities).

Industry structure evaluation and classification

For each case, descriptive statistics on industry structure were first computed. Three basic

indicators were calculated:

1. Industry scale:

Assessed jointly by total POI count and POI density (POIs per hectare), reflecting absolute industry volume and spatial compactness²⁹.

2. Industry proportion:

The ratio of POI count of a given business category to the total POI count within the district, reflecting the relative scale of that category. The formula is as follows^[45]:

$$pi=POI_num/sum(POI_num) \quad (1)$$

Where pi represents the relative proportion of a certain type of POI to the total number of POIs in the district, POI_num is the number of that type of POI in the district, and sum(POI_num) is the total number of POIs in the district.

3. Functional mixing degree:

Calculated using the concept of locational entropy, according to the following formula³⁶:

$$H=-sum(pi \times \ln pi), (i=1, \dots, n) \quad (2)$$

Where H represents the functional mixing degree for a given district, n represents the number of POI categories in that district, and pi represents the relative proportion of POIs of a given category to the total number of POIs in the district.

Subsequently, sample clustering method in SPSS hierarchical cluster analysis was performed using the proportion of 20 major industry categories for each district as the input variable⁴³. The optimal number of clusters was determined by inspecting the dendrogram. The 50 cases were partitioned into seven industry structure typologies, and each type was named and qualitatively characterized based on its distinctive functional-structural profile.

Functional co-location network characteristic clusters identification

Functional co-location network analysis is a method for analyzing urban functional structures based on co-location pattern mining technology³⁹. It applies the concept of locational entropy to spatial grids of varying granularity, with the aim of quantitatively characterizing the spatial proximity relationships among business types^[46]. The conditional probability of two functions appearing as dominant functions in the same spatial grid is calculated³⁸³⁷. A functional co-occurrence matrix is constructed using the resulting functional co-occurrence probabilities. In Gephi, the complex network calculation tool is used to generate a functional co-occurrence network by connecting nodes based on these probability values^[47]. Typical node clusters with high internal connectivity are identified within the network to analyze industrial interconnections^{[48][49]}. The core logic is as follows: if two business types tend to co-occur frequently in space, a positive co-location relationship exists between them, which may be driven by common locational factors or functional linkages⁴¹. The specific procedure consists of the following four steps:

1. Partitioning spatial grids:

To investigate the scale at which functional mixing occurs, it is necessary to identify several spatially representative scales. Research indicates that the vast majority of urban functions exhibit the highest degree of mixing at the mesoscale (1 km), while the clustering characteristics of functional networks are most evident at the small scale (below 200m); therefore, the spatial grid resolution should be selected appropriately based on research needs and data characteristics. This study area of each quarter was divided into regular fishing-net grids of 50m×50m, facilitating the identification of micro-level industry agglomerations. Grids containing no POI records were

excluded from subsequent analysis⁴⁰³⁸.

2. Identify dominant function:

Use the locational entropy formula to calculate and determine the dominant functional type of each grid⁴⁶. The ratio of the number of POIs of a certain type in a grid to the total number of POIs in that grid, divided by the ratio of the number of POIs of that type across all grids to the total number of POIs across all grids³⁶. The calculation formula is:

$$LQ_i^{(m)} = \frac{(x_i^{(m)} / \sum_i x_i^{(m)})}{(\sum_m x_i^{(m)} / \sum_m \sum_i x_i^{(m)})} \quad (3)$$

Where $x_i^{(m)}$ is the number of POIs for function i in grid m, and $LQ_i^{(m)}$ is the locational index of function i in grid m. When the locational index is greater than 1, it indicates that function i is a dominant function in grid m³⁸³⁹.

3. Calculating functional co-location probability:

After determining in which spatial grids each type of function exists as a dominant function, the conditional probability that any two industry categories are both dominant functions in the same grid is calculated as their co-location probability³⁷³⁹. The calculation formula is:

$$\zeta_{ij} = \frac{P[LQ_i^{(M)} > 1, LQ_j^{(M)} > 1]}{P[LQ_i^{(M)} > 1]P[LQ_j^{(M)} > 1]} \quad (4)$$

Where $LQ_i^{(M)}$ represents the locational degree of function i in any spatial grid M. The co-occurrence probability between two functions ranges from 0 (if the two functions are completely independent and uncorrelated) to 1; the larger the value, the higher the co-occurrence probability, and the more likely it is that the two functions will appear together as dominant functions in the same grid⁴⁰³⁸.

4. Generate functional co-location networks:

A functional co-location network was constructed for each quarter with industry categories as nodes and pairwise co-location probabilities as edge weights³⁹. The network data were imported into Gephi and visualized using the “Fruchterman-Reingold” and “ForceAtlas 2” layout algorithm, which simulate attractive and repulsive forces between nodes so that closely associated nodes cluster together in the visual space, facilitating the identification of community structures⁴⁷. Modularity indices were computed, and the built-in cluster detection algorithm in Gephi was applied to partition each network into clusters, characterized by dense internal connections and sparse external connections⁴⁹. Each functional co-location network characteristic cluster represents a group of industry categories that tend to be spatially proximate³⁸⁴¹. To focus on strong associations and enhance visual clarity, only edges with co-location probabilities greater than 8 were retained for display and subsequent analysis.

Common industrial relevance mechanisms abstraction

After network construction and cluster identification, the internal composition of each functional cluster was deconstructed to examine which specific intermediate categories it contained. The cluster profiles of different types of districts were then compared cross-sectionally. Combined with planning background documents and visitor review texts from the Dianping platform, qualitative

interpretation was conducted to identify the underlying reasons for cluster formation. By generalizing the recurring logics of association observed across multiple cluster cases, a set of common industrial relevance mechanisms that drive spatial co-location in commercial historic districts was distilled.

Results

Industry structure evaluation and classification

In terms of industry scale, POI counts and densities are generally higher in southern districts than in their northern counterparts (Fig. 3). This disparity may be jointly attributable to climatic conditions, urban street network density, levels of economic development, and varying states of historic quarter preservation^[50]. Descriptive statistics on industry proportions and functional mixing degrees across the 50 cases show that all districts have functional mix degrees greater than 1.5, indicating considerable business diversity in each. Meanwhile, the proportional structures of industry categories differ markedly across districts. Hierarchical cluster analysis partitioned the 50 cases into seven distinct types, each exhibiting a recognizable functional-structural profile (Fig. 4).



Fig. 3 | POI kernel densities and spatial grid distribution of the 50 commercial historic cultural districts.

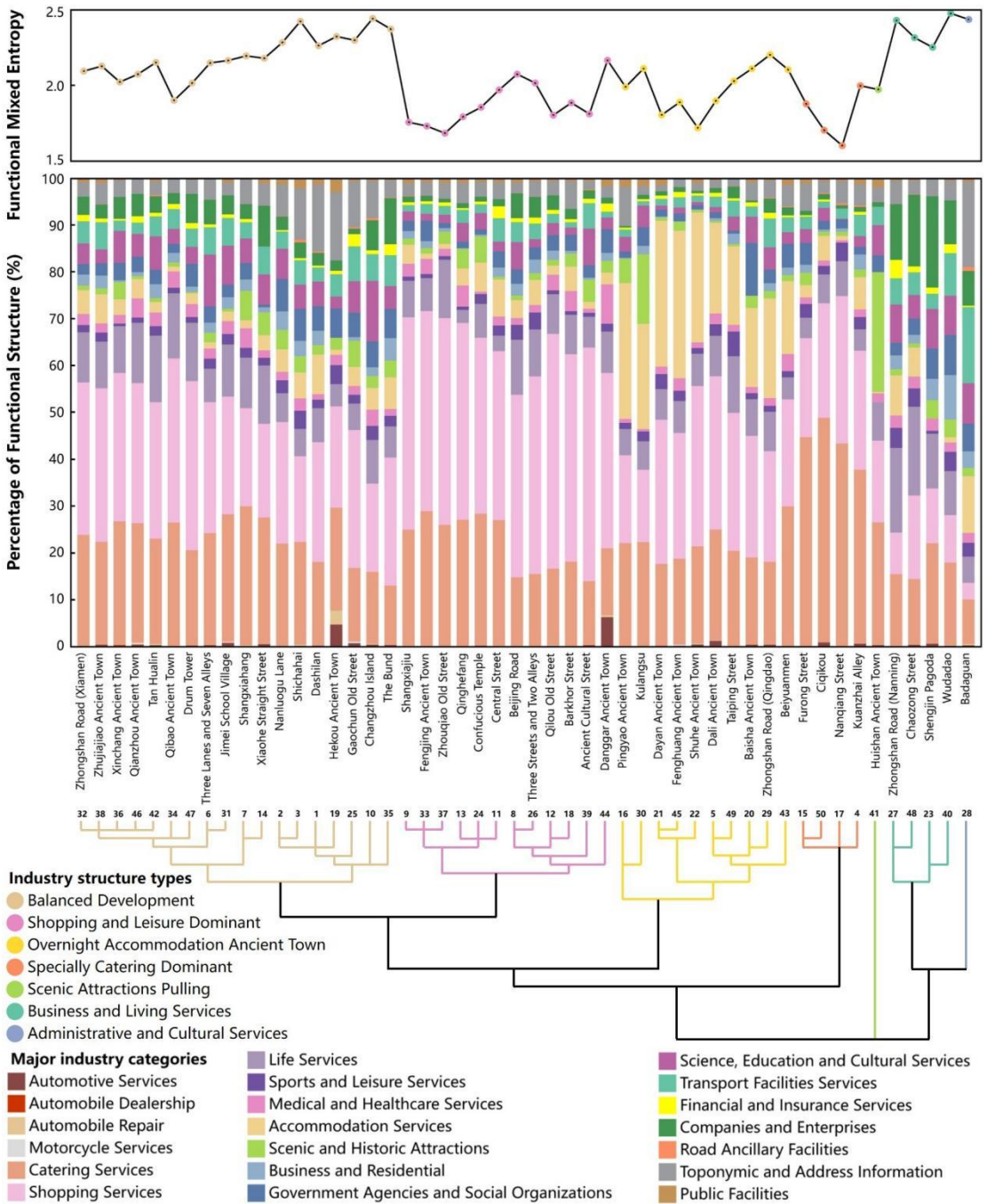


Fig. 4 | Classification of seven industry structure types of commercial historic cultural districts. Based on the seven types derived from hierarchical clustering analysis, the bar chart showing the industry structure reveals significant differences.

Balanced development type, represented by Beijing Nanluogu Lane, Xiamen Zhongshan Road, and Shanghai The Bund. The defining feature is the combined proportion of shopping and catering services approximately 50%, with shopping slightly exceeding catering. Life services (~10%), cultural-educational services (~8%), and accommodation services (~6%) all account for notable shares, while corporate enterprises and transport facilities are also present. Functional mix degrees

are consistently above 2.0. This balanced proportional structure suggests that these quarters have developed a relatively complete commercial-culture-service industrial chain, capable of simultaneously meeting visitors' needs for shopping, dining, cultural experiences, and short-term accommodation. They typically serve as national demonstration cases for historic cultural district revitalization^[51].

Shopping and leisure dominant type, represented by Harbin Central Street, Guangzhou Beijing Road, and Tianjin Ancient Cultural Street. The most salient feature is the overwhelming dominance of shopping services approximately 40%. Combined with catering at ~25%, the two total approximately 65%. In contrast, cultural-educational and accommodation services are comparatively underrepresented, and functional mix degrees mostly range between 1.5 and 2.0. These districts are characterized by strong commercial orientation and consumption clarity, catering primarily to mass tourists seeking shopping and casual leisure experiences.

Overnight accommodation ancient town type, represented by Lijiang Dayan Ancient Town, Pingyao Ancient Town in Shanxi, and Fenghuang Ancient Town in Hunan. The signature characteristic is the remarkably high proportion of accommodation services, ranging from 20% to 30%, far exceeding that of other types (typically below 5%). Catering and shopping still account for approximately 50% combined, but with catering slightly surpassing shopping. Life services and cultural-educational services are present at levels comparable to the balanced development type. Functional mix degrees are around 2.0. This type typically occupies extensive contiguous historic urban fabric, capable of offering immersive in-depth cultural experiences, and the abundance of accommodation distinguishes it from other types^[52].

Specially catering dominant type, represented by Chengdu Kuanzhai Alley, Chongqing Ciqikou, and Jinan Furong Street. Catering services account for approximately 40%, the highest of all types, shopping for about 30%, and the two together total ~70%. Supporting categories such as cultural-educational, accommodation, and life services occupy notably lower proportions than in preceding types. Functional mix degrees range from 1.5 to 2.0. These districts typically revolve around a signature local cuisine as the primary tourism attraction, where the high concentration of catering directly drives visitor footfall and consumption, though the service chain remains relatively short.

Scenic attractions pulling type, namely Wuxi Huishan Ancient Town. Catering and shopping together account for approximately 40%, similar to the overnight-stay type, but scenic-attraction POIs constitute ~25%, and cultural-educational services are also above average. The commercial value of this type is heavily contingent upon natural landscapes and historic architectural resources, with cultural immersion and tourism-recreation as the dominant functional orientation.

Business and living services type, represented by Tianjin Wudadao and Changsha Chaozong Street. Unlike the preceding types, catering and shopping together account for only ~30%, but life services and corporate enterprises each occupy between 10% and 20%, far exceeding other types. Business-residential, transport facilities, and cultural-educational services are also disproportionately represented. These districts, while serving tourism functions, continue to sustain active local business office activities and residential life, presenting a distinctive hybrid atmosphere of cultural experience, tourism, business, and daily living^[53].

Administrative and cultural services type, namely Qingdao Badaguan. The proportional structure is most distinctive that transport facilities and accommodation account for relatively high shares, while catering and shopping combined are significantly lower than in other types. Government

agencies, cultural-educational services, and toponymic-address information are notably prominent. This type exhibits the lowest degree of commercialization, serving primarily administrative, cultural-educational, and public open-space functions^[54].

Functional Co-location Network Cluster Characterization

Deconstructing the functional co-location networks of each type reveals the core and auxiliary functional clusters, with systematic differences in cluster composition and internal business configurations across types (Fig. 5, Table 1).

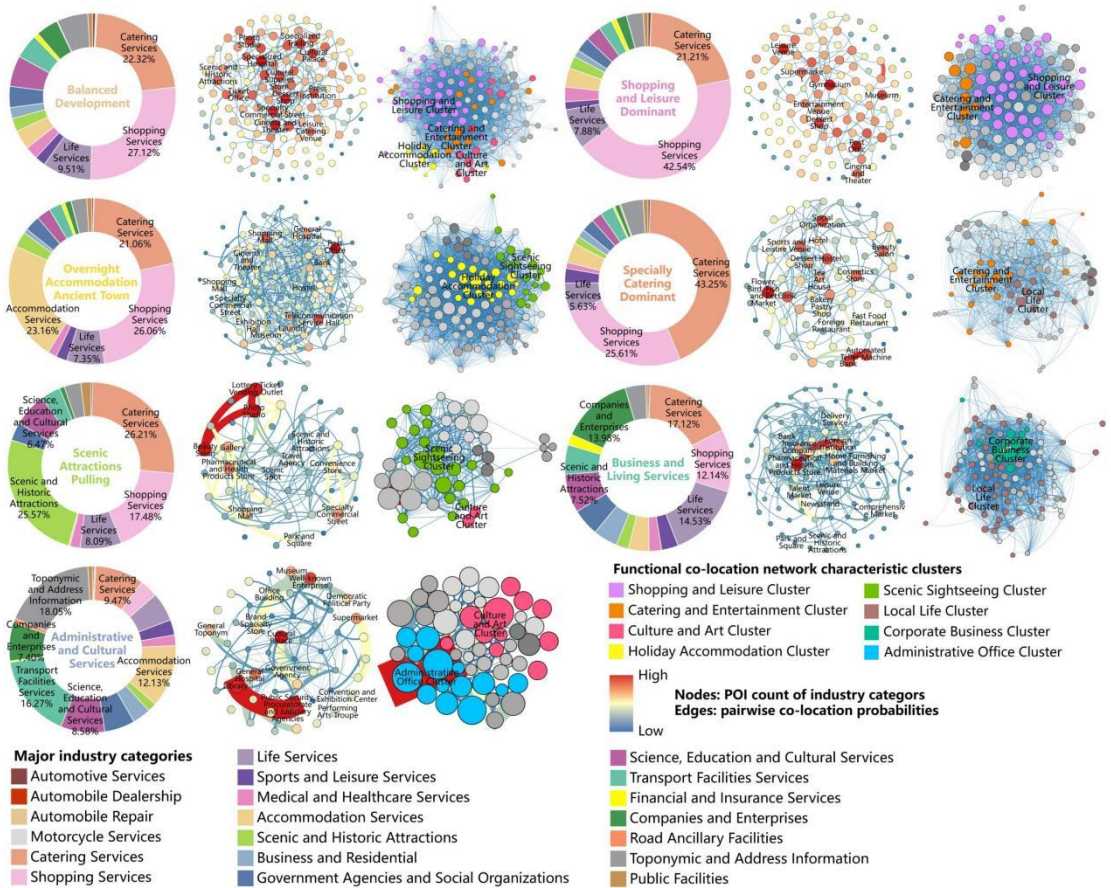


Fig. 5 | Average industrial structure of the seven types and functional co-location network cluster characterization. (Industrial structure data from cases in the same type are averaged and used to generate functional isomorphic networks. When generating a functional co-location network in Gephi, first apply the “Fruchterman-Reingold” layout to analyze the cold spots and hot spots of functional co-location probabilities. Then, using the results of the modularity coefficient calculation, apply the “ForceAtlas 2” layout; nodes of the same color are considered to be in the same cluster if they are deemed to be closer to each other in the complex network.)

Table 1 | Seven industry structure types and average functional co-location network cluster characterization. (Supplementary Table 1 | Detailed basic information and functional co-location network characteristic indicators of 50 cases)

Industry structure types	Functional co-location network characteristic clusters	Basic information		Functional co-location network characteristic indicators					
		No. of POI	POI density(units /hectare)	Avg. degree	Avg. weighted degree	Graph density	Modularity	Avg. Clustering coefficient	Avg. path length
Balanced development type	Shopping and leisure cluster								
	Catering and entertainment cluster	1704	15.356	64.894	290.892	0.495	0.172	0.821	1.522
	Culture and art cluster								
	Holiday accommodation Cluster								
Shopping and leisure dominant type	Shopping and leisure cluster	1528	34.228	60.627	201.743	0.518	0.168	0.840	1.479
Overnight accommodation ancient town type	Catering and entertainment cluster								
	Holiday accommodation cluster	2298	20.527	56.926	362.523	0.474	0.221	0.818	1.539
Specially catering dominant type	Scenic sightseeing cluster								
	Catering and entertainment cluster	455	29.630	28.000	178.354	0.364	0.324	0.741	1.774
Scenic attractions pulling type	Local life cluster								
	Scenic sightseeing cluster	309	9.990	15.750	225.425	0.335	0.438	0.717	1.888
	Culture and art cluster								
Business and living services type	Corporate business cluster	737	23.268	39.220	305.909	0.396	0.266	0.768	1.658
	Local life cluster								
Administrative and cultural service type	Administrative office cluster	338	4.430	7.127	334.337	0.132	0.715	0.532	2.385
	Culture and art cluster								

Balanced development type exhibits a multi-core network structure. The shopping and leisure cluster encompasses diverse retail categories including shopping-related venues, specialty stores, general markets, convenience stores, specialty commercial streets, apparel and leather goods shops, cosmetics stores, and sporting goods stores, reflecting supply-side diversity anchored in merchandise retail^[55]. The catering and entertainment cluster incorporates Chinese restaurants, fast-food outlets, cafés, tea houses, dessert shops, cold beverage shops, and entertainment venues, catering to immediate consumption of dining and recreation. The culture and art cluster comprises museums, art galleries, exhibition halls, libraries, cultural palaces, theaters, and cultural-educational venues, constituting the tangible infrastructure of cultural experience. The high edge weights and dense interconnections among these three core clusters indicate that shopping, dining, and cultural functions are not spatially segregated but rather deeply integrated, jointly shaping the overall ambiance of a comprehensive tourist destination. The auxiliary holiday accommodation cluster (hotels, guesthouses, spa and massage venues) exists to accommodate

overnight visitors and extend the consumption chain. In the case of Beijing Nanluogu Lane, the modularity coefficient of 0.491 suggests that cluster boundaries are reasonably clear, with shopping, dining, and cultural activities clusters occupying partially overlapping but distinguishable spatial territories.

Shopping and leisure dominant type displays a simpler network architecture with the shopping and leisure cluster as the undisputed core and the catering and entertainment cluster as auxiliary. Within the shopping cluster, cultural-products stores, specialty commercial streets, and flower-bird-fish-insect markets feature prominently alongside general retail, indicating that these quarters leverage historical and cultural elements to enhance the consumption experience. In the case of Guangzhou Beijing Road, the average degree reaches 55.5 (the highest among all cases) and the graph density is 0.544, suggesting exceptionally dense spatial associations among business categories, consistent with its status as a city-level commercial hub. The catering cluster in this type leans toward light refreshments such as fast-food outlets, cafés, and dessert shops, serving rest and replenishment needs during shopping excursions rather than functioning as independent dining destinations.

Overnight accommodation ancient town type is organized around the holiday accommodation cluster as its core. Beyond hotels and guesthouses, this cluster incorporates holiday resorts, leisure venues, and spa-massage establishments, indicating that the accommodation function extends beyond overnight stays to encompass comprehensive relaxation experiences. The auxiliary scenic sightseeing cluster comprises scenic spots, exhibition halls, theaters, museums, ticket offices, and travel agencies, providing the content for visitors' daytime activities. The strong inter-cluster association forms a closed functional loop of daytime sightseeing-nighttime lodging. Notably, the average weighted degree of this type is consistently high (e.g., Pingyao at 537.4, Lijiang Dayan at 443.7), indicating that the overall co-location probability and mixing intensity among business categories rank highest among all types. This reflects the systemic nature of ancient town operations, where the quality of the visitor's full-journey experience depends on highly coordinated services across all sectors^{[56][57]}.

Specially catering dominant type centers on the catering and entertainment cluster, which, in addition to conventional dining establishments, incorporates tea houses, cafés, and foreign restaurants, alongside spa-massage and beauty services. This suggests an upgrade trajectory from mere eating one's fill to quality dining plus leisure. The auxiliary local life cluster includes life-service venues, convenience stores, logistics and delivery outlets, residential areas, and lottery sales points, industry directly serving the daily needs of local residents. This reveals a critical feature: local residents are not displaced by commercial development in these quarters. Rather, they maintain substantial residency and employment through participation in catering operations and support services, and visitors precisely value this authentic exposure to local life. However, the limited number of POI secondary categories (averaging 58) and the relatively low average weighted degree (approximately 155.5) suggest a short service chain, carrying potential risks of short visitor dwell times and undiversified consumption scenarios.

Scenic attractions pulling type is anchored by the scenic sightseeing cluster that, in addition to scenic spots and public parks, incorporates shopping-related venues, specialty stores, and convenience stores, indicating that sightseeing circuits and consumption routes heavily overlap. The auxiliary culture and art cluster includes art galleries, museums, exhibition halls, tea houses, and research institutions, offering visitors deeper interpretive engagement with the site. This

combination forms a mutually reinforcing cycle of scenery driving commerce, commerce sustaining scenery. Nevertheless, the POI density of this type is only 9.99 per hectare and the functional mix degree is around 2.0, suggesting that commercialization intensity remains relatively restrained, with revenue depending more on ticket sales and word-of-mouth reputation than on the scale of internal consumption.

Business and living services type features the corporate business cluster as its core, comprising corporate enterprises, financial companies, insurance firms, banks, industrial parks, professional offices, and talent agencies. The concentration of these businesses reflects the historical continuity of these quarters as continuing loci of urban commercial and office functions^[58]. The auxiliary local life cluster encompasses life-service venues, convenience stores, shopping-related venues, beauty salons, laundries, and car rental agencies, serving the daily needs of office workers and residents. The connection between the two clusters is primarily mediated by mid-to-high-end catering (Chinese restaurants, cafés), entertainment venues, and accommodation services, indicating that these businesses simultaneously serve business banquets, social gatherings, and tourist experiences. In the case of Tianjin Five Avenues, the average weighted degree reaches 542.6 indicating that despite the wide variety of business categories, functional co-location associations remain tightly integrated, reflecting the temporal and spatial overlap of business professionals' and tourists' activity patterns.

Administrative and cultural service type presents a distinctive dual-cluster structure. The administrative office cluster covers government agencies, public security and judicial institutions, well-known enterprises, social organizations, and democratic parties, while the culture and art cluster encompasses cultural-educational venues, arts organizations, convention centers, museums, libraries, schools, and sports facilities. The connection between the two clusters is primarily mediated by public facilities, public parks, and a limited number of high-end dining establishments^[59]. This type exhibits the higher modularity coefficient among all cases at 0.710 and the longest average path length at 2.385, indicating pronounced functional differentiation within the network, relatively large spatial distances between clusters, and comparatively weak commercial interconnections. The Badaguan case demonstrates that when administrative and cultural functions become the dominant orientation, commercial activities are more ancillary than driving in nature, and commercial spaces are correspondingly more dispersed^[60].

Industrial Relevance Mechanisms

Synthesizing the cluster characteristics identified across the seven types and comparing inter-type variations, this study distills four recurring industrial relevance mechanisms that collectively drive the spatial co-location of business activities in commercial historic quarters: consumption behaviour relevance, environmental quality relevance, planning and administrative relevance, production chain relevance.

Consumption behaviour relevance is the most prevalent and directly influential mechanism shaping business spatial distribution. It refers to the phenomenon whereby certain consumption activities are routinely planned along the same activity routes or within the same spatial range in visitors' habitual behavioral patterns, thereby spontaneously inducing the businesses serving these activities to locate in geographical proximity. In commercial historic quarters, the typical consumption sequence is "strolling (shopping)-dining-entertainment," and the corresponding

shopping, catering, and entertainment categories consequently exhibit high spatial co-location probabilities across all types. In specialty-catering dominant quarters, for instance, the co-location probability between catering and entertainment venues is substantially higher than that between catering and administrative offices. This mechanism suggests that business mix configuration should follow rather than violate visitors' behavioral regularities; inserting businesses without relational support is unlikely to succeed and may disrupt existing functional networks.

Environmental quality relevance refers to the tendency of businesses with particular requirements for spatial environmental quality, such as boutique cafés, cultural-creative retail, and art exhibitions, to cluster in areas where historic architectural fabric is well preserved, natural landscapes are aesthetically pleasing, or streetscapes are tidy and elegant, while businesses that may negatively impact the environment are repelled from these areas. This mechanism operates most prominently in scenic-attraction driven and administrative-cultural service types, where high-quality landscape and heritage resources are themselves the core assets attracting visitors, and businesses positioned around these resources typically target mid-to-high-end market segments to match the environmental quality, thereby generating an environmental premium. In the functional co-location networks, this manifests as strong associations between scenic spots, public parks, and art galleries, tea houses, and research institutions, and weak or negative associations with fast-food outlets and low-end retail.

Planning and administrative relevance refers to business spatial associations shaped by governmental administrative power, public policy, and urban planning controls. Historic quarters are typically subject to special conservation plans that impose controls on building use, business licensing, and streetscape appearance. Furthermore, the presence of government agencies and cultural institutions within a quarter influences the composition of surrounding businesses, the administrative-office cluster in Badaguan spatially precludes large-scale commercial development, whereas the proximity of cultural-arts clusters to government agencies in Three Lanes and Seven Alleys reflects policy-level support for culturally oriented businesses. This mechanism endows planning authorities with the potential to actively shape business mix structures through policy instruments, but it also implies that inappropriately introducing businesses mismatched with the administrative atmosphere may encounter market resistance.

Production chain relevance derives from the upstream-downstream relationships in industrial economics, where the products or services of one business category serve as inputs for another, creating techno-economic linkages in their production or operational processes. At the neighborhood scale, this mechanism manifests as forward and backward linkages along the tourism industry chain: travel agencies and ticketing offices channel visitors to accommodation and scenic areas; accommodation provides consumption scenarios for dining and shopping; and scenic areas create sales opportunities for cultural-creative products. The strong association between the holiday accommodation cluster and the sightseeing cluster in the overnight-stay ancient town type, together with the embedding of tourism-service categories (ticket offices, travel agencies, car rentals) within these clusters, exemplifies production-chain relevance^[61]. Although this mechanism operates less directly than the preceding three at the micro-neighborhood scale, its role is non-negligible in more systematically organized ancient town operations^{[62][63]}.

Discussion

This study establishes a sequential analytical framework that encompassing business mix typology

identification, functional cluster characterization, and industrial relevance mechanism distillation through a large-N analysis of 50 commercial historic quarters across China. The framework offers both theoretical and practical contributions to the field of heritage planning and management.

At the theoretical level, this study represents the first systematic application of the functional co-location network method to historic quarter research, providing an operational analytical tool for understanding the organizational logic of business mixes from a spatial-association perspective. While existing research on industrial relevance has largely been confined to macro-regional or city-wide scales, this study extends the analytical lens to the neighborhood micro-scale and empirically validates that consumption behaviour, environmental quality, planning and administrative, production chain mechanisms are equally explanatory at this scale. Meanwhile, the seven business mix typologies distilled through cluster analysis transcend the limitations of single-case studies, offering a typological reference system for understanding functional differentiation among commercial historic quarters in China. These seven types do not constitute a hierarchy of quality but rather reflect divergent choices shaped by differential resource endowments, developmental trajectories, and market positioning. Planners can perform benchmarking analyses by comparing the empirical data of a target quarter against the prototypical profiles of these types.

At the practical level, the findings yield actionable strategies for business mix planning and regulation in commercial historic cultural districts. First, the identification of business mix typology should be prioritized. Functional structures differ substantially across quarters, and imitative replication of so-called Internet-famous models often leads to homogenization and loss of distinctiveness. Operators should diagnose their own district's typology through quantitative assessment and then formulate tailored strategies aligned with the developmental patterns and latent risks of that type. For example, the specially catering dominant type should enrich leisure and entertainment businesses to extend visitor dwell time, while the overnight accommodation ancient town type must strengthen quality control across all service sectors to sustain overall reputation. Second, industrial relevance mechanisms should be leveraged to guide spatial design. Functional co-location network analysis can precisely identify which business categories tend to cluster spatially, providing scientific support for grouping commercial units and organizing visitor circulation in business planning. Planners could use co-location probability calculations to combine strongly associated business modules into integrated functional zones, and complete fine-grained spatial layout in conjunction with pedestrian flow simulations. Third, the central driving role of cultural-heritage value should be consistently emphasized. Regardless of typology, cultural businesses (museums, art galleries, cultural-creative retail) exhibit stable positive associations with core commercial categories, indicating that cultural interpretation and commercial monetization are not oppositional but mutually reinforcing that the former supplies content and depth, while the latter provides funding and dissemination channels.

Several limitations of this study should be acknowledged, pointing toward avenues for future research. First, POI data characterize the quantitative distribution of business establishments but do not capture economic attributes critical for assessing business significance such as operational scale, turnover, or average spending. Future studies could integrate business registration data, tax records, or mobile signaling data to develop a more multidimensional portrait of business vitality. Second, the choice of 50 m grid size, while suitable for revealing micro-level clusters, may obscure cross-neighborhood functional relationships at larger scales. Subsequent research could

construct co-location networks at multiple grid scales to compare how cluster characteristics vary with analytical granularity and to identify the optimal scale for different research questions. Third, the application of social media texts in this study has been confined to auxiliary interpretation, without fully exploiting their quantitative analytical potential. Future studies could employ natural language processing techniques for sentiment analysis and topic modeling of large-scale visitor review corpora, linking subjective satisfaction evaluations with objective business mix data to provide more publicly grounded guidance for business mix regulation.

Data availability

All data from the research institute's computational processes is deposited into the Science Data Bank and is available at the following URL: <https://www.scidb.cn/anonymous/eVFyNm5x>.

Code availability

Not applicable.

Reference

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Ethical Approval and Informed Consent

This article does not contain any studies with human participants performed by any of the authors

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