Identification, Spatial Characteristics, and Planning Discussion of Urban Nighttime Vitality Centers: A Case Study of Central Shanghai

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Abstract: Urban nighttime vitality is closely linked to urban consumption, employment, and the quality of residents' everyday life. Taking central Shanghai as the case, this study integrates mobile-phone signaling data and points of interest (POI) from a human activity-spatial environment perspective. A locally decaying model is used to identify nighttime vitality centers and to summarize their spatial distribution and functional characteristics. The results show that nighttime vitality is centrally agglomerated. Nighttime vitality centers are strongly associated with basic urban functions and comprehensive functions, and tend to cluster around commercial and business centers, transport nodes, and several specific areas. A planning-matching assessment indicates that most planned centers can be identified at night, although some are not; meanwhile, the planned nighttime economy agglomeration areas do not fully cover the broader peripheral vitality centers. On this basis, the paper proposes planning suggestions concerning spatial layout, functional allocation, characteristic cultivation, and institutional safeguards for enhancing nighttime vitality.

Keywords: urban vitality; nighttime vitality center; spatial planning; locally decaying model; Shanghai.

The nighttime economy and nighttime vitality are important expressions of diversified urban life in the process of modernization. Nighttime vitality has both social and economic attributes [1]. Improving it is not only related to enhancing residents' everyday quality of life and meeting their needs for social interaction, but also to expanding urban consumption and employment, advancing the renewal of built-up areas, and cultivating urban cultural atmosphere. It is therefore significant for strengthening a city's overall competitiveness [2]. To promote nighttime cultural and tourism consumption, China's Ministry of Culture and Tourism has announced three batches of national nighttime cultural and tourism consumption clusters and issued construction guidelines. As China's megacities and large cities shift from expansion-oriented growth to connotative development, research on nighttime vitality is both a socioeconomic need and an issue of spatial planning and governance. Against the background of identifying redevelopment potential in built-up areas and regenerating vitality in central districts [3], it is practically important to analyze differences between nighttime and daytime urban spatial vitality and to discuss how planning can promote diversified nighttime development and urban competitiveness.

At present, spatial planning research and practice generally rely on daytime or all-day activity patterns and pay limited attention to the spatial patterns and needs that differ sharply between night and day [4]. Studies of urban vitality based on spatial big data such as mobile-phone signaling have the advantages of extremely large samples, fine granularity, and all-day coverage, but they have difficulty in directly identifying trip purposes and functional attributes or in representing the carrying role of the physical spatial environment. Nighttime planning therefore needs to address two questions: given the differences between daytime and nighttime vitality distribution, how can the spatial characteristics and day-night differences of nighttime vitality be understood? Technically, how can multiple data sources be used to identify nighttime vitality centers with different functional types?

This paper takes central Shanghai as the study area. It combines mobile-phone signaling data with nighttime-function POI data to identify urban nighttime vitality centers, analyzes their spatial distribution and functional characteristics, evaluates their matching relationship with existing plans, and proposes recommendations for enhancing nighttime vitality.

1 Literature Review and Research Approach

1.1 Studies on Urban Nighttime Vitality

1.1.1 Conceptual Interpretation

Jane Jacobs argued that urban vitality originates from the diverse lifestyles of urban residents [4]. Tong Ming regarded urban vitality as a dimension for measuring citizens' behavioral activities in the city and emphasized the particular importance of the physical carrier as a relatively stable factor in the generation of vitality [5]. Both views indicate that the physical spatial environment, as the material container of urban vitality, works together with human activities to influence the identification and evaluation of vitality spaces and vitality centers (Figure 1).

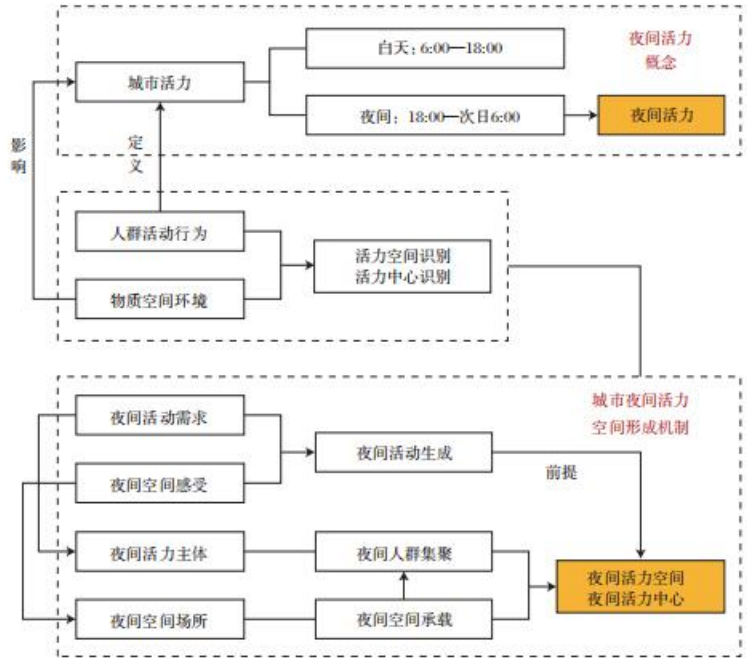

Fig.1 The conceptual explanation and spatial formation mechanism of urban night vitality

In temporal terms, urban vitality can be divided into daytime vitality (6:00-18:00) and nighttime vitality (18:00-6:00 the following day). Nighttime vitality is the component of urban vitality occurring from 18:00 to 6:00 the next day.

1.1.2 Typical Characteristics of Nighttime Vitality

(1) Typical nighttime activities and spatial heterogeneity. Compared with daytime, the urban night often forms distinctive social spaces and different affective characteristics [6], making people feel freer and less constrained [7]. Nighttime urban behavior is therefore dominated by leisure and free-time activities such as cultural exchange and entertainment. These activities generate formats such as night markets, bars, convenience stores, restaurants, and cultural venues, which may further develop into nighttime vitality centers such as urban complexes and pedestrian districts. They show locational clustering around commercial and business facilities. Nighttime vitality centers also tend to cluster along rail transit. Renewed historic districts and former industrial areas, as well as urban fringes, residential areas, and universities, can also become nighttime vitality clusters [8]. The heterogeneous spatial distribution of nighttime vitality centers has been confirmed by relevant studies [9-10].

(2) Social and economic attributes of nighttime vitality. Urban nighttime vitality is generally understood as having both social and economic attributes. Its social attribute emphasizes social interaction and everyday activity in nighttime spaces, whereas the nighttime economy, which reflects its economic attribute, is a service-

oriented consumption economy occurring at night and supported by urban space [1]. Research on nighttime vitality must therefore address both the social attribute represented by people and the economic attribute represented by functions.

(3) Spatial types of nighttime vitality. According to the concentration of active populations, nighttime space can be divided into active, transitional, quiet, and silent spaces. Active spaces are areas with large flows, high density, and long duration of nighttime crowds, and they play a core and catalytic role in nightlife [8]. Thus, studies of nighttime vitality space should focus primarily on nighttime vitality clusters and centers represented by active spaces.

1.1.3 Spatial Formation Mechanism of Nighttime Vitality

Previous studies show that the spatial production of urban vitality involves three processes: activity generation, activity carrying, and activity agglomeration. Its external expression is human activity, and its internal mechanism is spatial characteristics [11-12]. Urban nighttime vitality can likewise be summarized as three steps: generation of nighttime activities, agglomeration of nighttime crowds, and carrying of nighttime space [13] (Figure 1). Nighttime activity generation consists of residents' demand for nighttime activities and their perceptions of nighttime activity space, and forms the premise for the production of nighttime vitality spaces. The agglomeration of nighttime crowds is the main body of nighttime vitality, while the carrying of nighttime space provides the physical setting.

Therefore, identifying nighttime vitality centers requires combining the spatial concentration of people with the physical spatial environment that carries nighttime activities. In addition, typical nighttime venues such as bars are difficult to capture fully with population activity data of insufficient spatial resolution. Their identification should be supplemented by venue-distribution data such as POI, so as to better serve planning needs.

1.1.4 Studies on Measuring and Analyzing Nighttime Vitality

Nighttime light data are widely used to measure the intensity and spatial change of nighttime activity and thereby nighttime vitality [14]. For the economic attribute of nighttime vitality, previous studies often use transaction data, economic statistics, consumption data, and other economic datasets to examine nighttime economic vitality [1,9,15]. Other studies use open online data and other multi-source big data [13]. In contrast, high-precision and fine-grained data such as mobile-phone signaling and location-based services, which are grounded in a people-oriented perspective and human activity behavior, can better measure urban nighttime vitality [10,16].

However, vitality measurement based on mobile-phone signaling often gives insufficient consideration to facilities and functional elements, and it is difficult to classify different behavioral choices accurately. This affects the identification of nighttime vitality spaces that depend on the physical environment. Therefore, in identifying vitality centers, the twofold definition of urban vitality should be superimposed to identify vitality clusters and centers more accurately, as used in previous research [17].

1.2 Explorations in Nighttime Spatial Planning

Many Chinese cities have already explored nighttime spatial planning. Shanghai, for example, has proposed the layout of nighttime economy agglomeration areas in its special commercial-space layout plan [18]. Relevant schemes issued by Huadu District in Guangzhou [19], Gulou District in Nanjing [20], and other localities also discuss spatial planning for the nighttime economy. These explorations have three characteristics.

First, they mainly target the construction of agglomeration areas, which demonstrates the importance of identifying nighttime vitality centers and their characteristics from the perspective of human activity and spatial environment in supporting nighttime planning. Second, they are generally part of cultural-tourism or commercial schemes to develop the nighttime economy and promote nighttime consumption. Policy support is mostly textual and often provides only the names of agglomeration areas, with insufficient spatial guidance and

mapping, making it difficult to link directly to concrete spaces. Third, they are typically designed for specific areas and lack nighttime-oriented spatial analysis.

1.3 Research Approach

In summary, this study takes central Shanghai as the case, identifies nighttime vitality centers from a human activity-spatial environment perspective, analyzes their spatial distribution and functional characteristics, evaluates the matching relationship between the identification results and planned centers and agglomeration areas, and proposes planning suggestions for enhancing nighttime vitality.

2 Study Area and Methods

2.1 Study Area and Scope

The study focuses on central Shanghai. Following previous research [21], the research boundary is set as the central Shanghai area identified using mobile-phone data, including 125 subdistricts and towns and covering approximately 1,180 km2. A 500 m x 500 m grid is established over this area for data analysis. This scope largely covers the main urban area defined in the Shanghai Master Plan (2017-2035), and includes all municipal- and district-level centers planned within the main urban area in the relevant plan [18]. It is therefore suitable for identifying and evaluating nighttime vitality centers.

2.2 Data

Mobile-phone signaling is typical big data on population activity, with a large sample size and full coverage, and can reflect individual activities [22]. Given the non-work nature of nighttime leisure and entertainment, the study uses the advantage of mobile-phone signaling in representing origin-destination (OD) connections to exclude commuting as far as possible. The data used are China Unicom mobile-phone signaling data for Shanghai during nighttime (18:00-6:00 the next day) over one continuous week in early November 2019. The collection range covers the study area. Frequently connected base stations on weekdays at the place of residence (nighttime) and workplace (daytime), already included in the dataset, were used to identify and exclude home-work commuting effects [23]. The final grid-level dataset contains 6.6005 million population activity records.

In terms of reliability, China Unicom's market share in Shanghai was approximately 30%, which is equivalent to a large-sample survey [21]. Residential locations were identified by subdistrict and compared with the Seventh National Population Census; the correlation coefficient exceeded 0.9, indicating high reliability.

POI data record various facilities related to daily life and are valuable for identifying urban vitality characteristics. This study mainly uses categorized POI data from Amap for autumn 2018, which is temporally close to the mobile-phone signaling data.

2.3 Method for Identifying Nighttime Vitality Centers from a Human Activity-Spatial Environment Perspective

(1) Measuring nighttime population activity. With grids as spatial units, after excluding commuting effects the study first selects OD trips whose origins and destinations are both within the study area. It then aggregates flows by spatial unit, constructs a connection matrix and connection network [24], and calculates the average total inflow attraction for each grid.

(2) Screening through center association. The association between nighttime population activity and the physical spatial environment is calculated with a coupling coordination model (Note 1). This step is equivalent to introducing POI data for secondary screening on the basis of mobile-phone signaling data that represent nighttime population activity. It removes invalid identification results in which nighttime crowds are clustered but spatial-functional carrying capacity is lacking, thereby supporting the identification of genuine nighttime vitality centers.

(3) Center identification. McMillen et al. define an urban center as a spatial unit in which the density of elements is significantly higher than in surrounding areas and has a certain influence on the distribution of

surrounding elements [27]. To meet the need to identify local and relative centers in urban-center-system identification and planning-matching evaluation, this study draws on center identification methods based on a locally decaying model used in previous studies [28-30]. Combined with the coupling coordination results, it identifies statistically tested local high-value areas whose spatial distribution declines significantly with distance. The result is a set of local and relative nighttime vitality centers that can reflect the actual spatial pattern of nighttime vitality. Details are provided in Note 2, and the identification logic is illustrated in Figure 2.

(4) Classification of centers. The study selects POI of three representative categories of nighttime venues (see Section 4.1), applies the same method to calculate the coupling coordination between each category and the mobile-phone signaling data, and identifies local and relative nighttime vitality centers by category, revealing the spatial distribution of different nighttime functions.

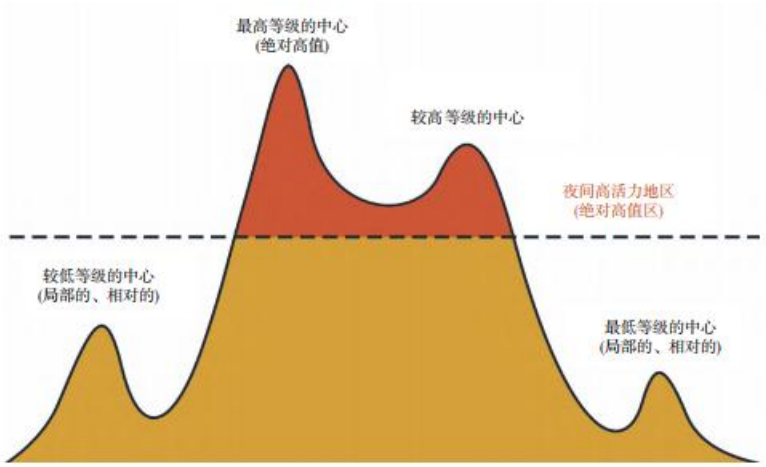

Figure 2. Cross-sectional illustration of nighttime vitality center identification.

3 Spatial Distribution Characteristics of Nighttime Vitality Centers

The method described in Section 2.3 was used to identify nighttime vitality centers in central Shanghai; the results are shown in Figure 3(a) (for naming rules, see Note 3). Daytime vitality centers were identified using the same method and compared with the nighttime results (Figure 3). Overall, daytime and nighttime vitality centers show strong consistency. However, work-oriented daytime vitality centers such as Caohejing Development Zone and southern Gaoqiao are not identified at night, whereas leisure activity areas such as northern Disney, which are not identified in daytime, become nighttime vitality centers. This reflects the spatial differences between nighttime and daytime vitality.

High-value nighttime vitality areas in central Shanghai are concentrated mainly in the city center, showing a pattern of central agglomeration. This is consistent with previous findings on Shanghai's urban vitality, especially its nighttime vitality [13,16,31]. Represented by the Bund and Nanjing Road, central Shanghai has a prosperous nighttime economy, diverse business formats, convenient transport, and a long history of active nighttime space formation, continuously attracting nighttime vitality. Compared with daytime, nighttime vitality centers show stronger leisure and daily-life attributes.

Figure 3. Identification results for nighttime and daytime vitality centers. Note: red text indicates centers identified during daytime but not at night; green text indicates centers identified at night but not during daytime.

4 Functional Characteristics of Nighttime Vitality Centers

4.1 Functional Types of Nighttime Vitality

4.1.1 Functional Identification Results

Shanghai's policy guidance on promoting the nighttime economy calls for enriching nighttime dining such as late-night snacks, as well as nighttime cultural and entertainment formats such as cinemas and bars [32]. Following previous research [8], this study selects three functional categories: distinctive venues with obvious nighttime attributes, including bars, nightclubs, KTVs, discos, cinemas, and theaters; dining venues representative of nighttime activity; and leisure venues including shopping and other leisure-entertainment sites. POI data for each category were extracted, and the method in Section 2.3 was applied together with mobile-phone signaling data to identify and compare functional types of nighttime vitality centers (Figure 4).

Figure 4. Functional identification results of nighttime vitality centers: (a) dining; (b) leisure; (c) distinctive functions.

4.1.2 Summary of Functional Types

Based on the functional identification results, nighttime vitality can be summarized into the following types.

(1) Basic functions. Nighttime business formats represented by dining functions, such as hotpot and barbecue, are closely related to nighttime vitality. Dining can therefore represent the basic function of nighttime vitality. Among the 47 identified nighttime vitality centers, 30 are identified as nighttime dining vitality centers (another

center is not among the identified nighttime vitality centers), indicating a strong association between dining vitality and overall nighttime vitality. Dining is an important component and basic function of nighttime vitality.

(2) Comprehensive functions. Given the recreational nature of nighttime activities and the composite nature of leisure behavior, leisure venues can represent the comprehensive function of nighttime vitality. Among the 47 identified nighttime vitality centers, 21 are identified as nighttime leisure vitality centers, accounting for nearly half. This demonstrates the association between leisure vitality and overall nighttime vitality and reflects the comprehensive function of nighttime vitality.

(3) Distinctive functions. Bars, nightclubs, and similar venues are typical nighttime business formats and distinctive formats that differ from daytime activities. They are closely related to nighttime vitality and can represent distinctive nighttime functions. The six identified distinctive-function centers are all located in the city center, and their small number indicates that distinctive functions need to be cultivated in highly active city-center areas. This also reflects the agglomeration characteristic of nighttime vitality.

4.2 Location-Functional Agglomeration Characteristics of Nighttime Vitality

4.2.1 Location-Functional Classification

Nighttime activities often cluster around commercial and business districts, transport hubs (including rail-transit corridors), historic districts, former industrial areas, natural scenic sites, urban fringe areas, residential areas, and universities [8]. The identified nighttime vitality centers can therefore be classified into four categories: (1) commercial and business centers, meaning nighttime vitality centers that overlap with traditional commercial and business centers; (2) transport nodes, meaning nighttime vitality centers with rail-transit stations during the data collection period, representing population activity nodes nearby; (3) historical and cultural areas, meaning nighttime vitality centers overlapping or associated with historical districts, historic conservation areas, industrial heritage, and other historical-cultural resources; and (4) other specific areas, such as centers related to universities, open spaces, and special facilities. The classification draws on previous literature on Shanghai's urban-center classification and identification [33] and the authors' field investigations. The results are shown in Table 1.

Table 1. Location classification of nighttime vitality centers in central Shanghai.

Location	Center names	Commercial/business	Transport node	Historical/cultural	Other specific area
Central city (within the Outer Ring)	Nanjing East Road; Nanjing West Road	Yes	Yes	Yes	Yes
	Xiaolujiazui-Zhangyang Road (Xiaolujiazui*); Wujiaochang; Hongqiao-Gubei / Zhongshan Park; Baoshan Nanda; Zhangjiang (along Metro	Yes	Yes		Yes

	Line 2); Kongjiang Road / Yangpu Riverside				
	Xujiahui; Wuzhong Road; Central Ring (Zhenbei); Gongkang; Nanfang Mall; Yuqiao; Jinqiao; Yangjing; Songhong Road; Dahua; Expo; Beicai; Sanlin; Gaoqiao; Songnan (around Songfa Road Station); Longyang Road; Jinqiao East	Yes	Yes		
	Changfeng; Donglu Road		Yes		Yes
	Waigaoqiao; Shenjiang				Yes
Main-city clusters	Baoshan Cruise Riverside (Wusongkou International Cruise Terminal*)	Yes	Yes	Yes	Yes
	Qibao	Yes	Yes	Yes	
	International Tourism Resort (Disneytown*); Gucun	Yes	Yes		Yes
	Hongqiao International Central Business District; Songbao;	Yes	Yes		

	Zhuanqiao; Chuansha; Xinzhuang (around Xinzhuang Station); Yanghang; Jiangqiao (around Jinyun Road Station)				
	Wujing			Yes	Yes
	Gucun East	Yes			
	North Disney; Shanghai Jiao Tong University Minhang Campus				Yes
	South Hongqiao; Zhoupu East; North Xinchang				

* In the naming rule in Note 3, some centers have different names in the plan. The table uses their names as municipal-level commercial centers and lists in parentheses their names as international-level consumption agglomeration areas or international consumption gateways.

4.2.2 Summary of Location-Functional Agglomeration Characteristics

Following previous research [8] on the classification and analysis of nighttime urban functions, the location-functional agglomeration characteristics of nighttime vitality centers are summarized below.

(1) Nighttime vitality centers clustered around commercial and business centers. This is the main spatial agglomeration type of nighttime vitality centers. Among the 47 nighttime vitality centers, 37 show clustering around commercial and business centers. Such centers derive from typical nighttime activities of urban residents, meet the demand for nighttime vitality agglomeration, and reflect the economic attribute of nighttime vitality. The agglomeration of commercial and business centers strongly supports the basic, comprehensive, and distinctive functions of nighttime vitality. Of the 21 nighttime comprehensive-function vitality centers, 20 are commercial and business center types, while all nighttime basic-function and distinctive-function vitality centers are commercial and business center types.

(2) Nighttime vitality centers clustered around transport nodes. This is also a major spatial agglomeration type. Among the 47 nighttime vitality centers, 38 cluster around rail-transit stations and other transport nodes. These centers often develop nighttime vitality along transport hubs and rail-transit stations, reflecting their relationship with the urban transport system. Location-functional agglomeration around transport nodes strongly supports basic, comprehensive, and distinctive nighttime functions. Of the 30 nighttime basic-function vitality centers, 29 are transport-node types; of the 21 nighttime comprehensive-function centers, 19 are transport-node types; and all distinctive-function centers are transport-node types.

(3) Nighttime vitality centers clustered around historical and cultural resources. This is a distinctive spatial agglomeration type, often formed through the renewal of historic districts and old factories. The spatial scale of historic buildings and districts is often suitable for nighttime formats such as bars and dining, which do not require large building areas and can connect with outdoor environments. Historic conservation areas in city centers also need nighttime economic returns to pay high rents, jointly promoting the formation of nighttime vitality centers. Some old factories, because of their cultural character and the flexibility created by larger spatial scales, are suitable for conversion into cultural and creative industry districts, thereby forming nighttime vitality centers [8].

(4) Nighttime vitality centers clustered around other specific areas. Beyond the above locations, other specific areas in central Shanghai also produce distinctive spatial agglomeration types, such as open spaces, universities, and special facilities. Open spaces such as parks and green spaces have both natural and urban leisure attributes; their function as leisure venues can extend into the night and form vitality centers [8], such as Zhongshan Park. Universities contain large stable nighttime populations, and nearby areas are likely to form nighttime vitality centers to meet strong nighttime demand [8], as in Wujiaochang.

Location-functional agglomeration around specific areas, including historical-cultural resources, open spaces, and universities, strongly supports the distinctive functions of urban nighttime vitality and also provides some support for basic and comprehensive functions. Among the 30 nighttime basic-function centers, 10 are other-specific-area types and 4 are historical-cultural types. Among the 21 comprehensive-function centers, 7 are other-specific-area types and 3 are historical-cultural types. Among the 6 distinctive-function centers, 5 are other-specific-area types and 2 are historical-cultural types.

5 Planning-Matching Assessment of Nighttime Vitality

Shanghai's planning for its urban center system and nighttime agglomeration areas is mainly reflected in the master plan and commercial-space layout plan. Referring to previous studies on the identification and evaluation of Shanghai's urban center system [30], this paper compares the identified nighttime vitality centers with the plan [18] to analyze the matching relationship between nighttime vitality centers and planning. The results (Figure 5) indicate the following.

First, among 54 municipal- and district-level centers, 41 match either the identified nighttime vitality centers or high-value nighttime vitality areas (Note 2). This shows a high degree of overlap between nighttime vitality centers in central Shanghai and planned centers, and also demonstrates the effectiveness of the method used here to identify local and relative nighttime vitality centers. Second, 19 identified nighttime vitality centers do not match planned centers; five of them are close to planned centers although they do not overlap, and future planning can focus on these spontaneously formed centers. Third, 13 planned centers are neither identified as nighttime vitality centers nor located in high-value areas of nighttime vitality coupling coordination, suggesting that their planning should be strengthened or adjusted. Fourth, five planned municipal centers are not identified, and four of six long-term planned municipal centers are also not identified, indicating possible weaknesses in these centers. Drawing on previous research [16], planned centers that are not identified often suffer from operational problems such as insufficient nighttime formats and single land-use or functional structures. Fifth, one planned center is identified in daytime but not at night, indicating that the area's nighttime vitality is weaker than its daytime vitality and may require targeted improvement.

Comparison with the nighttime agglomeration area plan [18] further shows that, except for Daning and part of the waterfront nightlife experience areas, the planned nighttime agglomeration areas are generally identified as nighttime vitality centers or high-vitality areas, which is broadly consistent with current conditions. Subsequent work can focus on supporting the few areas not identified. Existing nighttime agglomeration areas are mostly concentrated in the city center inside the Inner Ring and mostly correspond to identified high-vitality areas, indicating that the plan emphasizes the cultivation of municipal nighttime centers and agglomeration areas, while paying less attention to broader district-level centers and municipal centers outside the Inner Ring. Since Shanghai's nighttime spatial layout planning is still at an early stage, the scope of future nighttime spatial planning can be expanded.

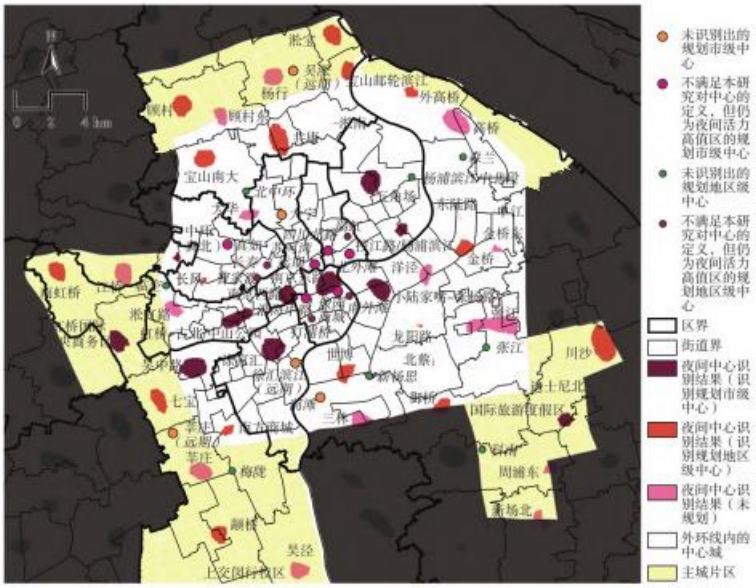

Figure 5. Comparison of identified nighttime centers and planned centers. Note: the municipal- and district-level centers in Plan [18] already include international-level consumption agglomeration areas and international consumption gateways; the comparison therefore mainly refers to municipal- and district-level centers.

6 Nighttime Vitality and Planning Support Suggestions

Spatial layout. (1) Nighttime vitality shows a very clear pattern of central agglomeration. It is therefore consistent with spatial regularities for current planning to consolidate key city-center areas. In the future, planning can selectively develop core nighttime vitality agglomeration areas represented by central vitality districts. (2) The nighttime transport system should be improved, especially the match between rail transit and nighttime vitality centers. Planning can promote the coverage of existing and emerging nighttime centers by rail-transit stations and urban expressways, and can guide rail lines in different directions and major urban roads to serve nighttime centers with strong service capacity. (3) Nighttime vitality construction should be strengthened in planned commercial centers that are not identified at night. These centers are often at an early stage of nighttime agglomeration and can be targeted for renewal and improvement through built-up-area regeneration. (4) Attention to broader district-level centers and municipal centers outside the core area can help improve the city's overall nighttime vitality.

Functional allocation. (1) Planning should address different nighttime functions represented by basic functions such as dining and comprehensive functions such as shopping and leisure. (2) Nighttime formats should be enriched. Incremental cultivation and existing-format optimization should be promoted according to local conditions, and spontaneous renewal in the nighttime economy should be encouraged. (3) Nighttime transport

supply should be improved, for example by opening more night-bus routes, guiding taxi and ride-hailing nighttime services, encouraging nighttime opening of parking facilities, and improving supporting systems. (4) Mixed land use promotes nighttime vitality [16,31], and land-use mixing and functional integration in agglomeration areas can be further improved.

Characteristic cultivation. Location agglomeration around specific areas such as historical-cultural resources, open spaces, and universities often forms distinctive nighttime vitality centers. Therefore: (1) the distinctive resources of nighttime vitality can be further explored and distinctive functions cultivated. For example, the renewal of historic districts and industrial heritage can promote the cultivation and development of nighttime vitality centers; in built-up-area renewal, historic buildings can be converted into nighttime formats such as bars and restaurants, and larger-scale old factories can be transformed into nighttime vitality spaces characterized by culture and creativity, thereby exploring the potential value of historical-cultural resources. (2) Compared with the era of incremental development, urban operation capacity is increasingly important in the era of stock-based development [34]. Operational models can be adjusted and optimized according to nighttime characteristics to enhance nighttime vitality.

Institutional safeguards. (1) Nighttime vitality has both social and economic attributes [1], and its economic model is dominated by services. A market operation and social participation mechanism involving multiple nighttime actors can therefore be established to respond to the characteristics and differentiated needs of nighttime activities. (2) The authors' field interviews indicate that nighttime-related plans and policies issued by a single department, such as commerce or planning, may conflict with other departments. A coordination mechanism can therefore be established to promote the joint participation of commerce, planning, culture and tourism, market regulation, and other departments in compiling plans, issuing policies, and improving supporting safeguards. For example, multiple departments can jointly improve nighttime lighting, signage, and supporting facilities; improve public security, fire safety, and other functional arrangements; and strengthen refined nighttime governance and rapid emergency response capacity.

7 Conclusion

Taking central Shanghai as the case, this paper identifies nighttime vitality centers, analyzes their characteristics, evaluates planning-matching relationships, and proposes suggestions. The main conclusions are as follows. (1) In terms of spatial distribution, nighttime vitality shows central agglomeration and differs from daytime vitality. (2) In terms of functional characteristics, basic and comprehensive functions are strongly associated with nighttime vitality centers, whereas distinctive functions can be cultivated only in highly active city-center areas. Regarding location-functional agglomeration, clustering around commercial and business centers and transport nodes is the main nighttime agglomeration type, strongly supporting basic, comprehensive, and distinctive functions. Clustering around specific areas such as historical-cultural resources, open spaces, and universities is a distinctive nighttime spatial agglomeration type and provides strong support for distinctive nighttime functions. (3) In terms of planning matching, most planned centers basically match nighttime vitality centers, but some planned centers are not identified. Planned nighttime agglomeration areas are broadly consistent with the identification results, but the plan has not yet covered broader peripheral nighttime vitality centers. (4) Future planning should consolidate existing centers while also paying attention to a broader set of centers; address basic and comprehensive functions, enrich nighttime formats, and promote functional integration; use stock renewal to explore nighttime characteristics and improve nighttime operation; establish market operation and social participation mechanisms involving multiple actors; and promote interdepartmental coordination.

This study also has limitations. The motivations, needs, and potential problems behind nighttime activities require further investigation. Nighttime vitality is often related to local culture, and social habits and lifestyles differ across regions [8], so cross-regional generalization should be treated cautiously. Quantitative indicators

for nighttime business formats are still insufficient. Future research can combine questionnaire surveys, in-depth interviews, and behavioral observation to reveal residents' nighttime needs, motivations, and sociocultural contexts more deeply, and can further improve data collection by integrating the distribution of nighttime formats and consumption data. Such work will provide a stronger basis for improving the quality of nighttime human settlements.

Notes

1. Calculation of coupling coordination. Following relevant literature [25], after standardization to reduce data differences, the coupling degree is calculated as: C = 2[(B_i H_i)/(B_i + H_i)^2]^(1/2). Here C is the coupling degree; the larger it is, the stronger the interaction and mutual influence between indicators. B_i and H_i are respectively the positively standardized average nighttime vitality and the POI count; if both are 0, C is 0. The coupling coordination degree is then calculated as: G = (C K)^(1/2), K = alpha B + beta H. Here C is the coupling degree, G is the coupling coordination degree, B and H are the standardized average nighttime vitality and POI count, and alpha and beta are undetermined coefficients for the two indicators. Following previous studies [26], both are set to 0.5, indicating that nighttime population activity and the carrying capacity of the physical spatial environment are equally important for identifying nighttime vitality centers.

2. Identification of nighttime vitality centers based on the locally decaying model. y_j = beta(i)d_ij + b(i) + epsilon_j(i). Here y_j represents the logarithm of the nighttime vitality coupling coordination degree of other grids around grid i; d_ij is the distance from surrounding grids to grid i; beta_i is the regression coefficient of this distance; b(i) is the constant term; and epsilon_j(i) is the error term. For each grid i, if the nighttime vitality coupling coordination degree of surrounding grids is negatively correlated with their distance to grid i, the grid can be regarded as a nighttime vitality center within a certain range, that is, beta(i) is significantly negative. Following the steps and parameter values in previous studies [28-29], this study sets a local search radius of 3,000 m, calculates the weight of each sample, calibrates coefficients using weighted least squares, records beta(i) and its standard error, conducts a one-tailed t-test, and, following previous analytical tests [28-30], sets the p-value threshold at 0.1. Eligible grids are then selected and combined with vector boundary areas to identify nighttime vitality centers. It should be noted that this method may lead to some traditionally recognized high-vitality nighttime areas not being identified as centers because they are not significantly higher than their surroundings and therefore do not meet this paper's definition of a center (Figure 2). The paper therefore adds a classification of high-vitality areas and evaluates it as well (Figure 5). Drawing on similar studies on Shanghai, the nighttime vitality coupling coordination degree is divided into five classes using natural breaks. Clear differentiation appears between classes, and the two highest classes generally correspond to municipal centers and subcenters, conforming to practical experience and previous judgment [29-30]. This classification is used only to assist in judging the relationship between nighttime vitality centers and planned centers.

3. Naming of centers. Following naming methods used in previous studies identifying centers in Shanghai [29-30], nighttime vitality centers within the study area that match the plan [18] are named using their planned names. Other centers are named by reference to widely used names and to the names of their areas, nearby transport stations, universities, industrial parks, or communities. This naming method is intended only to ensure readability and comparability; it does not imply that the identified results are primarily commercial centers.

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