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MDPI

https://doi.org/10.3390/su16198290

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Multidimensional Evaluation of the Quality of Socio-Spatial Environments in Inner-City Transitional Edges: A Case Study of Chongqing's Yuzhong District

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Abstract: In rapid urbanization, the socio-spatial environment between inner-city functional areas faces numerous challenges. Assessing and enhancing the environmental quality of these areas has become an urgent research issue. This study quantitatively evaluates the social-spatial environment of inner-city transitional edges, selecting Chongqing's Yuzhong District as the case study area. It explores the relationship between spatial environmental factors and social activities. Integrating spatial data, internet "big" data, and field survey data, a multidimensional evaluation of the quality of the social-spatial environment framework is constructed, encompassing four dimensions: connectivity, social function, comfort, and conviviality. Subsequently, a multiple linear regression model is used to explore the main environmental factors influencing social activities on transitional edges. The results show that the density of street trees, lighting facilities, functional density, and functional diversity significantly impact social activities, demonstrating the correlation between the spatial environment of inner-city transitional edges and social activities. Corresponding optimization strategies for each dimension in transitional edges are then summarized. This study provides references for coordinating inner-city functional areas, optimizing urban environments, and promoting sustainability. It can also be applied to a broader range of transitional edge evaluation studies.

Keywords: transitional edge; urban environment; quantitative evaluation

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Citation: He, X.; Kozlowski, M.; Ujang, N.B.; Ma, Y. Multidimensional Evaluation of the Quality of Socio-Spatial Environments in Inner-City Transitional Edges: A Case Study of Chongqing's Yuzhong District. *Sustainability* **2024**, *16*, 8290. https://doi.org/10.3390/su16198290

Academic Editor: Beniamino Murgante

Received: 9 August 2024
Revised: 7 September 2024
Accepted: 18 September 2024
Published: 24 September 2024

1. Introduction

With the rapid advancement of urbanization, the quality of the socio-spatial environment in inner-city transitional edges not only influences the functional transition between central business districts (CBDs) and residential areas but also directly impacts the environmental sustainability of cities [1]. These transitional edges, located between the CBD and inner-city residential areas, serve as vital links for functional transitions and are crucial for fostering social interaction and urban vitality [2]. Improving the environmental quality of these areas can alleviate social isolation, promote effective integration of urban functions, and enhance the radiative effect of CBDs, thereby stimulating social activities and extending their functional advantages to surrounding residential areas, ultimately enhancing the overall sustainability of urban development [3–5]. Although existing studies have explored the space between CBDs and inner-city residential areas as an independent transitional region [6], there remains a gap in understanding how to optimize the quality of these transitional edges to enhance the radiative effect of CBDs. This challenge is particularly pronounced in mountainous cities, where complex topographical conditions and diverse social needs increase the difficulty of design and coordination, resulting in a CBD's favorable socio-spatial environment being less able to permeate nearby residential areas and insufficiently promoting the development of adjacent functional zones.

This study aimed to develop a multidimensional evaluation framework for evaluating the quality of the socio-spatial environment, focusing on the spatial environmental quality of inner-city transitional edges in Chongqing's Yuzhong District. It sought to analyze the factors influencing social activities and propose optimization strategies to expand the radiative range of CBDs. By integrating extensive data analysis with field survey data, this study attempts to identify the primary spatial environmental factors that affect the coordination and balance between CBDs and inner-city residential areas. The innovation of this study lies in employing a multidimensional evaluation approach to comprehensively analyze the relationship between spatial environmental factors and social activities, thereby offering a more holistic perspective for urban environment quality assessment. Additionally, conceptualizing street space as transitional edges presents the potential for integrating urban functional areas and provides new insights for existing urban renewal strategies. Chongqing's Yuzhong District was chosen as the study area due to its typical mountainous city characteristics and its role as a core region where the transitional edges between the CBD and inner-city residential areas exhibit unique socio-spatial dynamics. These streets facilitate the transition between commercial and residential functions and significantly influence the CBD's ability to drive the surrounding environment.

This study aimed to answer two questions:

What spatial environmental factors significantly influence social activities within the inner-city transitional edges of Chongqing's Yuzhong District?

How can spatial environmental factors enhance the radiative effect of a CBD and promote spatial coordination and development of inner-city residential areas?

2. Literature Review

The concept of inner-city transitional edges can be understood from two dimensions: the inner-city transitional zone and the transitional edge. The inner-city transitional zone typically lies between different urban functional areas, serving as a buffer to modulate the differences between various land-use types. This function is particularly crucial between a CBD and residential areas [2,4,7]. The theory of transitional edges further refines this concept by emphasizing the role of street edges as socio-spatial interfaces, focusing on the integration of physical, spatial, and social dimensions [8]. Streets, as the core components of inner-city transitional edges, not only connect different urban functional areas at the physical level but also support and promote diverse social activities at the social level [9–11].

Research indicates that the boundary effects of transitional edges serve as a link in transforming the physical environment and enhancing the mobility of adjacent spaces, thereby extending their functional influence to a broader area [12]. Optimizing the environmental quality and accessibility of transitional edges can facilitate interactions between a CBD and its surrounding areas, enhancing the overall sustainability of urban development [4,13,14]. Further studies show that improving street environments, increasing walkability, and ensuring safety can significantly enhance residents' daily activity experiences and social interaction frequency [15–17]. However, current research primarily focuses on a single perspective of transitional edges, such as vitality [18], restorative urbanism [19], and functionality [6]. There remains a gap in comprehensively utilizing these transitional areas to support CBD expansion and promote social integration.

Although previous studies have proposed various evaluation methods and frameworks for streets and public spaces, there has yet to be a systematic integration of these methods to evaluate transitional edges with a multidimensional framework. For instance, Appleyard et al. [20] assessed the environmental quality of three streets in San Francisco, examining four aspects—livability, safety, traffic conditions, and social interaction levels—through interviews and observations, finding a direct correlation between social interaction levels and street environment. Stadnikov et al. [21] demonstrated that street layout, service functionality, and commercial demand for site services are critical indicators of public space quality. Brownson et al. [22], through interviews, surveys, field observations, and archival data, evaluated population density, land-use mix, recreational facility use, and street layout, suggesting further research on the relationship between the environment and human behavior based on existing evaluation models. Apparicio et al. [23] evaluated public space environments from three dimensions: social environment, physical environment, and service accessibility, highlighting the challenges in disadvantaged areas characterized by degraded physical environments, high levels of social deprivation, and lack of facilities. In a recent study, Santos [24] proposed a more comprehensive evaluation method, assessing street pedestrian environment quality from five aspects: connectivity, convenience, comfort, cleanliness, and community vitality.

By integrating these multidimensional evaluation frameworks, this study proposes a framework for evaluating the quality of transitional edges, encompassing four key dimensions: connectivity, social function, comfort, and conviviality. Connectivity assesses the continuity of transitional edges and their connection with surrounding streets and public transport nodes, quantified by the number of intersections and bus stop distributions [25,26]. This connectivity helps facilitate the expansion of CBD functions and enhances social interaction. Social function focuses on the diversity of economic activities in transitional edges, measured by commercial density and functional mix [27,28], to support diverse social activities and enhance the CBD's radiative effect. Comfort focuses on the safety and convenience of walking, evaluated by sidewalk width, tree coverage, and lighting facilities [29,30], providing more attractive activity spaces for residents. Conviviality evaluates the capacity of transitional edges to provide social and public activities and the enjoyment of the built environment, primarily assessed through the setup of street buffers and street furniture (such as benches and tables) [25,31]. These highly sociable spaces help enhance the area's social vitality and cultural diversity.

3. Materials and Methods

3.1. Method Overview

This study aims to develop a multidimensional framework for evaluating the quality of the socio-spatial environment of transitional edges, encompassing four key dimensions: connectivity, social function, comfort, and conviviality. Each dimension includes specific indicators that reflect different aspects of the socio-spatial environment. The data for these indicators were collected using a combination of open-source spatial data, Baidu heat maps, Points of Interest (PoI) data, and field surveys. These data were processed and analyzed using Geographic Information System (GIS) 10.2 software and statistical analysis tools. GIS-based spatial analysis methods, such as kernel density analysis and spatial join tools, were employed to quantify the density and distribution of each indicator, linking spatial attributes with street segments. Finally, a multiple linear regression model was applied to understand the impact of these indicators on social activities within transitional edges. The regression analysis aimed to identify significant predictors among the indicators, determining how each factor influences population density, which serves as a proxy for the intensity of social activities.

Figure 1 presents the methodological flowchart. This framework focuses on the socio-spatial environment quality of transitional edge spaces and the social activities of residents within these spaces. By analyzing these elements, the study explores the main influencing factors of social activities in transitional edges, providing a data foundation for proposing optimization strategies to expand CBD functions and mitigate socio-spatial isolation.

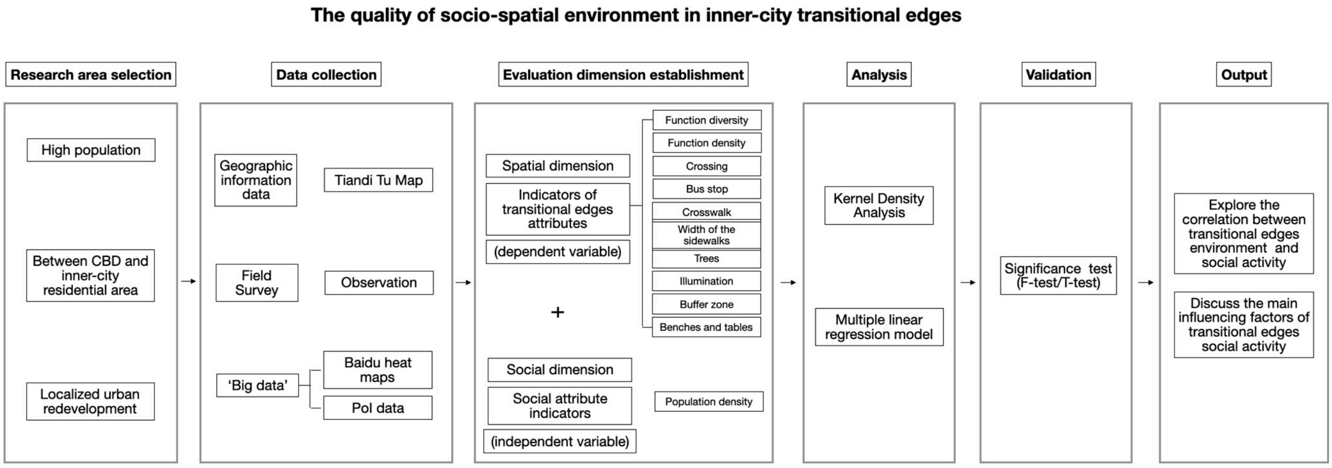


Figure 1. The flowchart of the quality of transitional edges environment evaluation.

3.2. Research Area

The study selected the area between the Jiefangbei CBD and inner-city residential areas in Chongqing's Yuzhong District as the target area, as shown in Figure 2. In selecting the research area, researchers considered criteria such as the adjacency of the CBD to inner-city residential areas, population density, and the background of local urban redevelopment. After field surveys, Jiefangbei CBD was found to meet the study requirements. Jiefangbei CBD is located in Chongqing's Yuzhong District, comprising the "core" area of Jiefangbei and the "periphery core" area of Chaotianmen, fulfilling both commercial and trade functions. The "core" area extends east from Xiaoshizi; west to Jintang Street; north to Cangbai Road, Linjiang Road, and Minsheng Road; and south to Heping Road and Xinhua Road, covering 0.92 square kilometers. The "periphery core" area of Chaotianmen covers 0.69 square kilometers. The total area of Jiefangbei CBD is 1.61 square kilometers, primarily covering the Jiefangbei Street area in Yuzhong District. In 2013, based on Chongqing's economic development needs, the planned area of Jiefangbei CBD was expanded to 3.5 square kilometers. By 2020, the permanent population was 57,485. This area is the earliest developed CBD in Chongqing, with a complete road network and relatively high density.

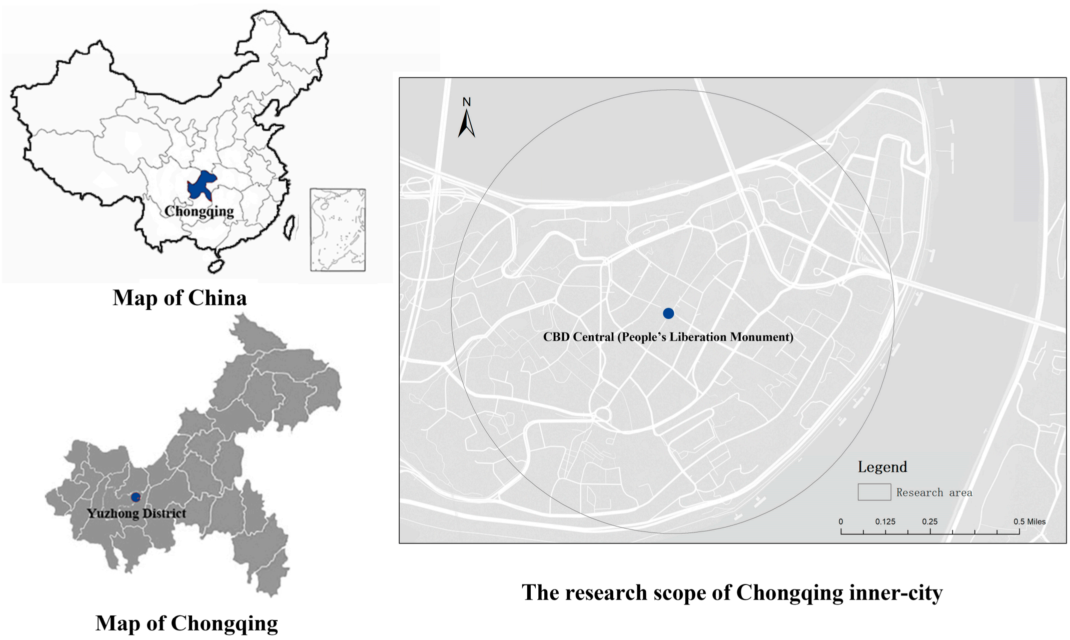


Figure 2. The research scope of Chongqing inner city. Source: (Author, 2024).

In addition, this area is particularly notable for its unique geographical location and functional zoning, making it an ideal site for studying urban transitional edges. The Jiefangbei CBD is not only a major commercial and trade center but also surrounded by inner-city residential areas that offer rich material for examining the diversity of socio-spatial environments. Specifically, the area implements diverse social activities (see Figure 3a,b). In contrast, the complex mountainous terrain (see Figure 4a,b) further provides opportunities to explore the socio-spatial dynamics of transitional edges in hillside cities.

(**a**) (**b**)

Figure 3. (**a**,**b**) Social activity in transitional edges. Source: (Author, 2024).

(**a**) (**b**)

Figure 4. (**a**,**b**) Transitional edges in hillside city. Source: (Author, 2024).

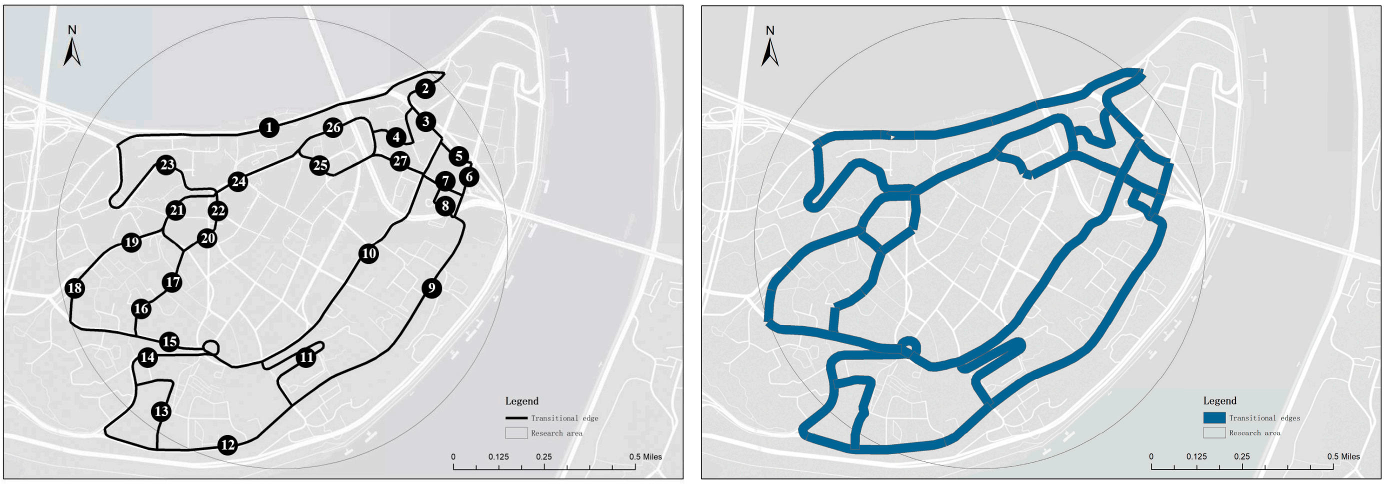
In this study, 27 streets were selected and divided into 41 sections using ArcMap 10.2 software, with each street numbered.

3.3. Research Data

Evaluating transitional edge environments primarily utilizes road network data, Baidu heat map data, PoI, and field survey data. The road network data are the foundational framework for the quantitative analysis of transitional edges. Baidu heat map data are used to calculate the relative density of the population distribution within transitional edges, reflecting the social activity in these areas. PoI data, composed of various features, display the diversity and mix of social functions within the transitional edges. Field survey data include greenery density, street service facility density, and street dimensions, reflecting the comfort and conviviality of the transitional edges.

3.3.1. Road Network Data

The road network data were extracted from Tianditu's open-source data and processed using ArcMap® 10.2. Due to the high level of detail in the original road network and existing topological errors, cartographic generalization and topological processing were conducted for subsequent applications, as shown in Figure 5a. After processing the original road network data, a 20 m buffer was established around each road segment, as illustrated in Figure 5b.



(**a**) (**b**)

Figure 5. (**a**) Inner-city transitional edges road and (**b**) Segment with 20 m buffer. Source: (Author, 2024).

3.3.2. Baidu Heat Map Data

Baidu heat map data were acquired through the Baidu Huiyan API, covering the pedestrian heat data of Chongqing on weekdays and weekends. The data were collected at hourly intervals at 10 am, 5 pm, and 8 pm, serving as an important data source for evaluating the intensity and distribution of pedestrian social activities, as depicted in Figure 6.

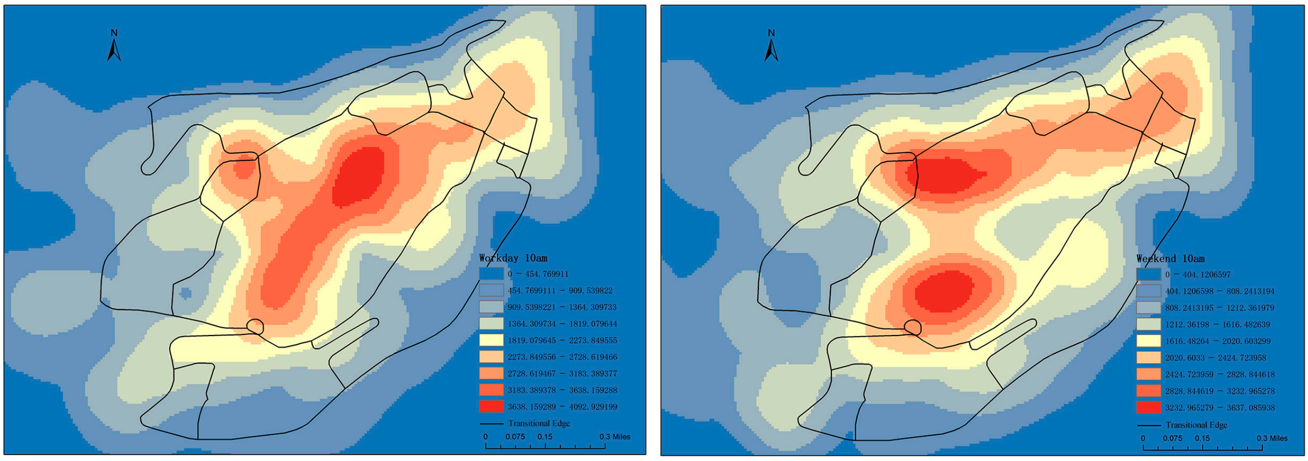


Figure 6. *Cont*.

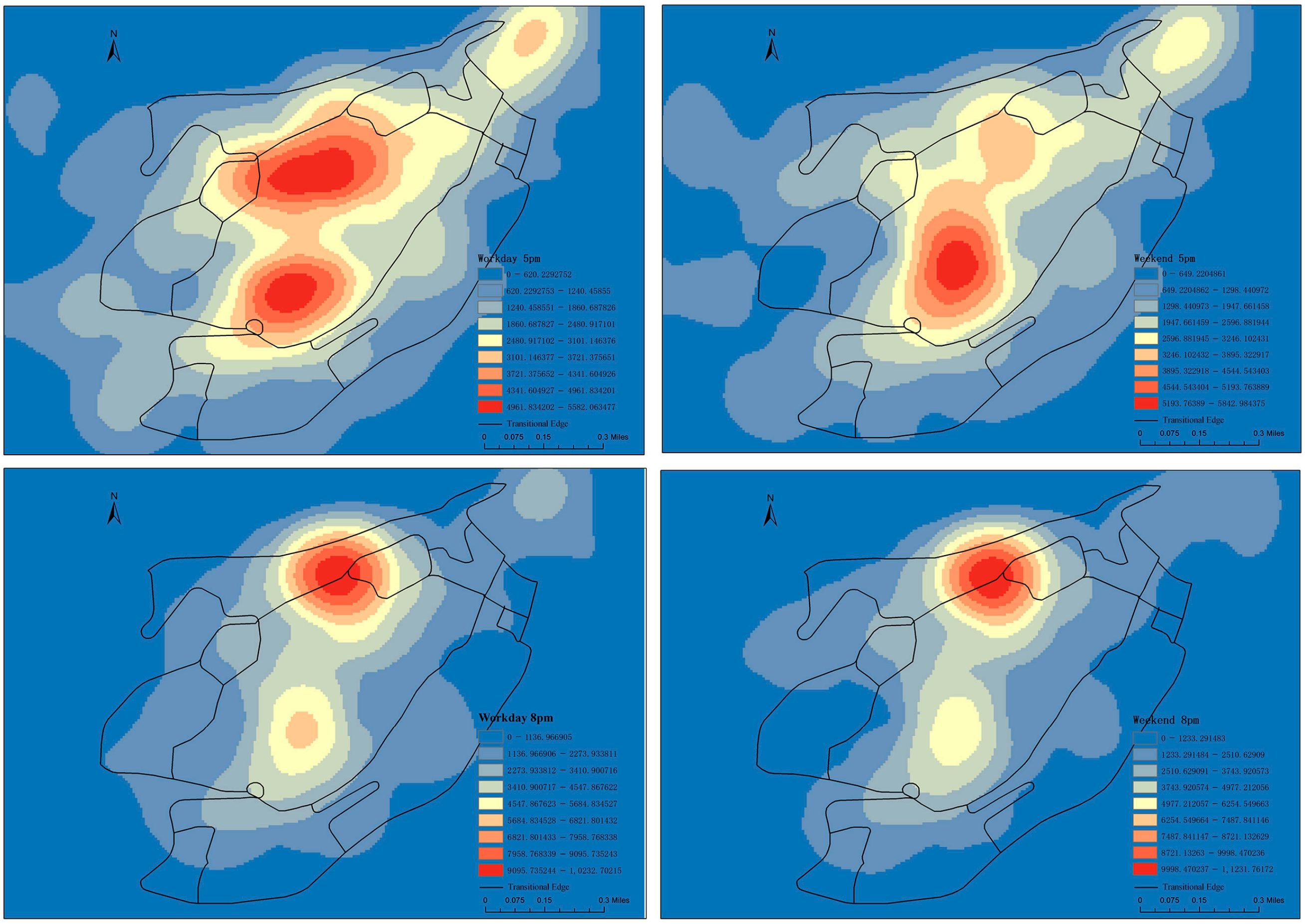


Figure 6. Average heat map (weekdays and weekends at 10 am, 5 pm, 8 pm). Source: [32].

3.3.3. Point of Interest (PoI) Data

PoI data, analyzed through big data technology, illustrate people's clustering and activity patterns in urban spaces, demonstrating the impact of urban functional areas on social activities. PoI data include detailed information such as name, address, and spatial coordinates, characterized by high timeliness, comprehensive coverage, and accurate positioning, clearly showing the spatial distribution and intensity of activities within transitional edges. The PoI data used in this study were sourced from the Baidu Encyclopedia up to September 2023. This dataset includes each point's name, address, and classification information. Data preprocessing was conducted to ensure the quality of the PoI data, involving data cleaning and organization. Data cleaning included removing duplicate entries, low-quality or missing information points, and points with unclear functional directions. Initially, the PoIs were divided into 8 main categories and 35 subcategories through filtering and categorization, as presented in Table 1.

Table 1. PoI categories.

Main Categories	Subcategories
Food and beverage	Tea house, Cake shop, Café, Restaurant, Others
Company enterprise	Insurance, Factory, Company, Others
Shopping consumption	Shopping mall, Convenience store, Supermarket, Bird and flower market, Electrical appliance store, Building supplies, Others
Traffic facilities	Charging station, Underground, Bus stop, Ferry, Others
Hotel accommodation	Economical chain hotels, Hotels, Others
Science and education culture	Exhibition, Driving school, R&D institution, Training unit, Others
Tourist attraction	Memorial hall, Tourist attractions, Others
Life service	ATM, KTV, Lottery sales, Telephone business hall, Cinema, Pet medicine, Toilet, GYM, Club, Barber, Others

Following this, PoI points were selected within the research area based on the extracted road network buffer zones, as illustrated in Figure 7.

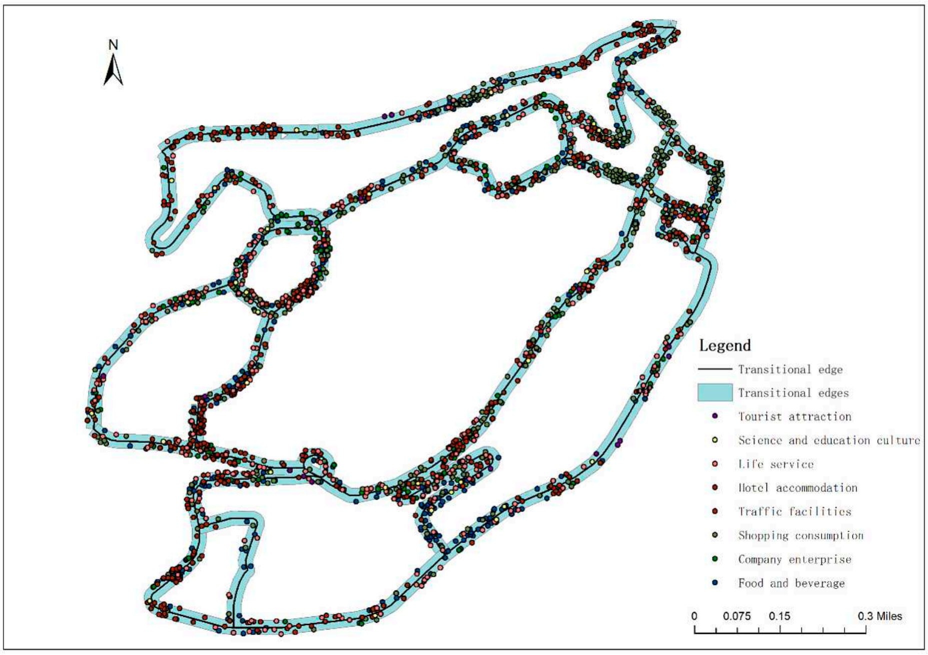
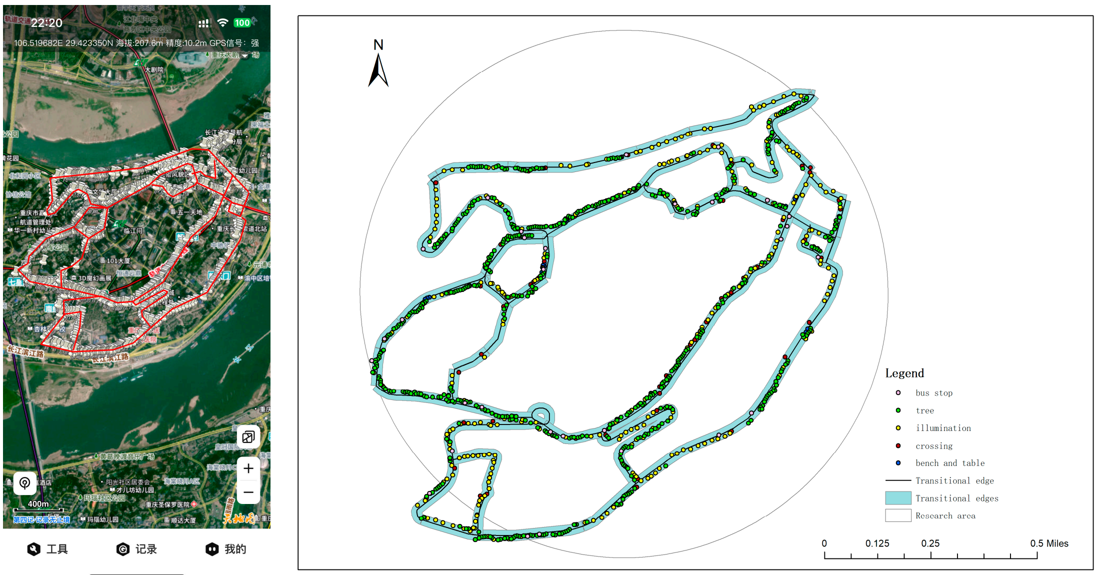


Figure 7. Distribution of PoI in transitional edge. Source: (Author, 2024).

3.3.4. Field Survey

The research team obtained field survey data through direct observation and recording. This included the number and location of pedestrian crossings, street widths, street buffers, trees' density, lighting, and furniture. During the survey, streets were numbered, photographed, and recorded, and the collected data were summarized into Excel spreadsheets and imported into ArcGIS 10.2 software to be converted into vector point features. This ensured that the natural spatial environment of the transitional edges was accurately captured and provided a reliable reference basis. The record is depicted in Figure 8a,b.



(**a**) (**b**)

Figure 8. (**a**) Disiji APP and (**b**) Site survey records. Source: (Author, 2024).

By utilizing these diverse data sources, this study aimed to comprehensively evaluate the spatial environment of inner-city transitional edges, offering valuable insights for urban planners and designers.

3.4. Construction of the Transitional Edge Environment Evaluation System

3.4.1. Indicator System Construction

The primary users of transitional edges are pedestrians and residents. While enhancing urban redevelopment efficiency and improving inner-city environments, these areas should provide social activity spaces and social function services. The social dimension of transitional edges primarily depends on users' social activities within these spaces. This determines the extent to which the built environment of transitional edges can attract people to walk, provide accessibility, and meet citizens' needs for communication, walking, recreation, and essential services. Therefore, this study evaluates transitional edges from both social and spatial dimensions.

On the one hand, the social dimension is evaluated through social surveys. The social dimension of transitional edges is assessed based on the relative density of the population within these areas. Baidu heat maps are utilized to analyze the population aggregation within transitional edge spaces, with the population density from Baidu heat maps representing the social dimension of transitional edges.

On the other hand, the spatial dimension of transitional edges is evaluated based on environmental factors. Environmental analysis involves studying the interaction between spatial layout and its components by analyzing urban spaces' morphological and data characteristics [33]. This study extracted the density of bus stops, pedestrian crosswalks, social functions, social function diversity, road greenery, and service facilities as environmental influencing factors of the spatial dimension of transitional edges.

3.4.2. Quantification of the Indicator System

In this study, connectivity refers to the degree of connection between the pedestrian network and other streets and public transportation nodes, evaluated by the number of intersections and bus stops [25,26]. Convenience indicates the presence of various economic activities and is measured by the density and diversity of social functions [27,28]. Comfort represents safety and ease of walking, assessed by street width, the presence of trees, and adequate lighting [29,30]. Conviviality measures the pleasantness of the built environment and the potential for social interaction, evaluated by the presence of street buffers and street furniture (such as benches and tables) [25,31], as illustrated in Table 2.

Table 2. The data source of the urban quality attributes.

Dimension	Attributes	Data Source
Social activities	Population density	Baidu heat map
Connectivity	Crossings	Baidu map street view complemented with field survey
	Bus stop	PoI data
Function	Function diversity	PoI data
	Function density	PoI data
Comfort	Width of the sidewalks	Field survey
	Trees	Field survey
	Illumination	Field survey
Conviviality	Buffer zone	Field survey
	Benches and tables	Field survey

1. Social activity: Baidu Population Density

To minimize the impact of necessary daily activities (such as commuting or attending school) on the spatial distribution of Baidu population density, we selected data from three types of days: weekdays, weekends, and public holidays. The data were collected at three time periods: 10:00–11:00 a.m., 5:00–6:00 p.m., and 8:00–9:00 p.m.

The average heat value at each time point was calculated using Equation (1) as the Baidu population density. The higher the heat value, the higher the transitional edge's relative population density and social activity heat. Due to the inability of heat maps to fully reflect accurate population data, we further visualized the Baidu population density by dividing it into 7 levels and 3 categories: levels 6–7 represent areas of high social activity, levels 4–5 represent areas of medium social activity, and levels 1–3 represent areas of low social activity.

$$\overline{H} = \sum H_i / m^2 \quad (1)$$

where $\overline{H}$ is the average heat value, H_i is the heat value of the transitional edge at a certain time point, and H_i represents the number of time slots.

2. Functionality: Function Density

Social function density is the ratio of the number of various facilities' PoIs within different analytical units of transitional edges to the area of the analytical unit, as shown in Equation (2). The number of different types of PoIs is normalized to ensure that the number of PoIs is not affected by the scale of the analytical unit. The higher the function density, the more service points provide daily facilities within the transitional edge, which is more conducive to attracting residents' social activities.

$$S_1 Density = POI\_num / area\_size \quad (2)$$

where $S_1 Density$ is the function density of the analytical unit within the transitional edge, POI_num is the total number of PoIs within the analytical unit, and $area\_size$ represents the area of the analytical unit.

3. Functionality: Function Mixing Degree

The degree of social function mixing is calculated using information entropy to measure the POI mix within different analytical units of transitional edges, as shown in Equation (3). The higher the mix degree, the more service facilities are provided within the transitional edge, meeting the needs of people with different travel purposes.

$$S_2 Density = -\sum_{i=1}^{n} \left(p_i \times ln_{p_i}\right), (i = 1, \ldots, n) \quad (3)$$

where $S_2 Density$ is the function mix of the analytical unit within the transitional edge, n is the number of PoI categories within the transitional edge, and p_i represents the proportion of a specific type of PoI in the total number of PoIs within the transitional edge. The number of various types of PoIs is then normalized.

4. Connectivity: Transportation Node Density

Transportation node density is the ratio of the number of various transportation facility nodes within different analytical units of transitional edges to the area of the analytical unit, as shown in Equations (4) and (5). The types of transportation nodes include external transportation nodes, such as bus stops, and internal transportation function nodes, such as intersection counts. To ensure that the number of transportation nodes is not affected by the scale of the analytical unit, the number of different types of transportation nodes is normalized. The higher the transportation node density, the stronger the internal and external accessibility of the transitional edge, which is more conducive to internal transit for residents and the connectivity between the CBD and inner-city residential areas.

$$A_1 Density = INT\_num / area\_size \quad (4)$$

$$A_2 Density = BUS\_num / area\_size \quad (5)$$

where $A_x Density$ is the transportation function density of the analytical unit within the transitional edge, X_num is the total number of transportation nodes within the analytical unit, and $area\_size$ represents the area of the analytical unit.

5. Comfort: Greenery Density, Lighting Facility Density, Street Width.

Greenery density within transitional edges differs from the general concept of greening rate. Due to the particularity of transitional edge spaces, large green areas are not feasible. Therefore, this study considers the number of street trees in the street landscape, as their density influences citizens' perception of the environmental comfort of transitional edges. A similar situation occurs with lighting facility density. The study recorded greenery and lighting facility density through field surveys. The collected greenery and lighting facility density data were then imported into ArcGIS software and converted into vector point features. The greenery and lighting density features were linked to each street using spatial join tools to obtain environmental data with density attributes.

Street width is used as a comfort indicator, as it may affect the environmental rating of transitional edges. During field surveys, the width of each street was recorded and classified into five levels. The collected street width level data were imported into ArcGIS software and converted into vector point features. The street width level features were linked to each street using spatial join tools to obtain environmental data with street width level attributes.

6. Conviviality: Buffer Zone Density and Benches and Tables Density

Buffer zone density and bench and table density are the ratios of the number of nodes providing leisure places within transitional edges to the area of the analytical unit. To ensure that the number of buffer zones and benches and tables is not affected by the scale of the analytical unit, the number of different types of buffer zones and benches and tables is normalized. The study recorded the density of buffer zones and benches and tables through field surveys. The collected buffer zone and benches and tables density data were imported into ArcGIS software and converted into vector point features. The buffer zone and benches and table density features were linked to each street using spatial join tools to obtain environmental data with density attributes.

3.5. Analysis of Influencing Factors on Transitioanl Edge Environment

The multiple linear regression model is primarily used to understand the impact of various environmental factors on social activities within transitional edges, utilizing SPSS 25 software. The dependent variable is the Baidu population density (pop_i) of the transitional edge (i), and the independent variables include bus stop density, intersection density, function density, function mixing degree density, greenery density, lighting density, street width, buffer zone density, and benches and tables density.

The sample size for the multiple linear regression analysis was determined using a complete data analysis approach, encompassing all available data within the study area. The analysis was conducted at the street level, with 41 streets included in the study.

The values corresponding to the sample size were extracted from various data sources in the value extraction part. For each street section, specific values for each indicator were derived from spatial data layers and field survey results. For example, tree density and street lighting data were collected through field surveys and subsequently converted into vector point features in GIS for spatial analysis. Similarly, PoI data were used to calculate function density and function mixing degree within each street section. In contrast, bus stop and intersection densities were derived from GIS-based spatial data layers. This comprehensive data collection and processing approach ensured that the regression model accurately represented all relevant environmental factors.

The steps of the multiple linear regression analysis are described as a correlation analysis: we conducted a correlation analysis of the environmental components of the transitional edge to exclude factors that did not pass the statistical significance test ($p > 0.05$). The second step was model construction: we built and analyzed the multiple linear regression model. The final step was model validation: we used F and T tests to validate the multiple regression model.

4. Results

4.1. Data Visualization

Given the relatively small scale of the study area, we utilized ArcGIS software to spatially visualize the quantitative results of each indicator by associating them with the road network within the study area. These visualizations illustrate the socio-spatial characteristics of the transitional edges in Chongqing's Yuzhong District, aiding in a detailed assessment of current conditions and identifying opportunities for optimizing transitional edges. This approach aims to enhance the radiative effect of the CBD and promote spatial coordination and development of adjacent areas.

1. Baidu Population Density

The Baidu population density map provides a detailed visualization of pedestrian distribution within the transitional edges of Chongqing's Yuzhong District (see Figure 9). The data indicate that higher population densities are concentrated near major commercial areas and transportation hubs, characterized by a mix of commercial activities and services that naturally attract higher foot traffic. While these findings align with general urban planning principles, this study finds that high-density areas are influenced not only by proximity but also significantly by local socio-spatial factors, such as street layout and transitional characteristics, which facilitate pedestrian flow and social interaction.

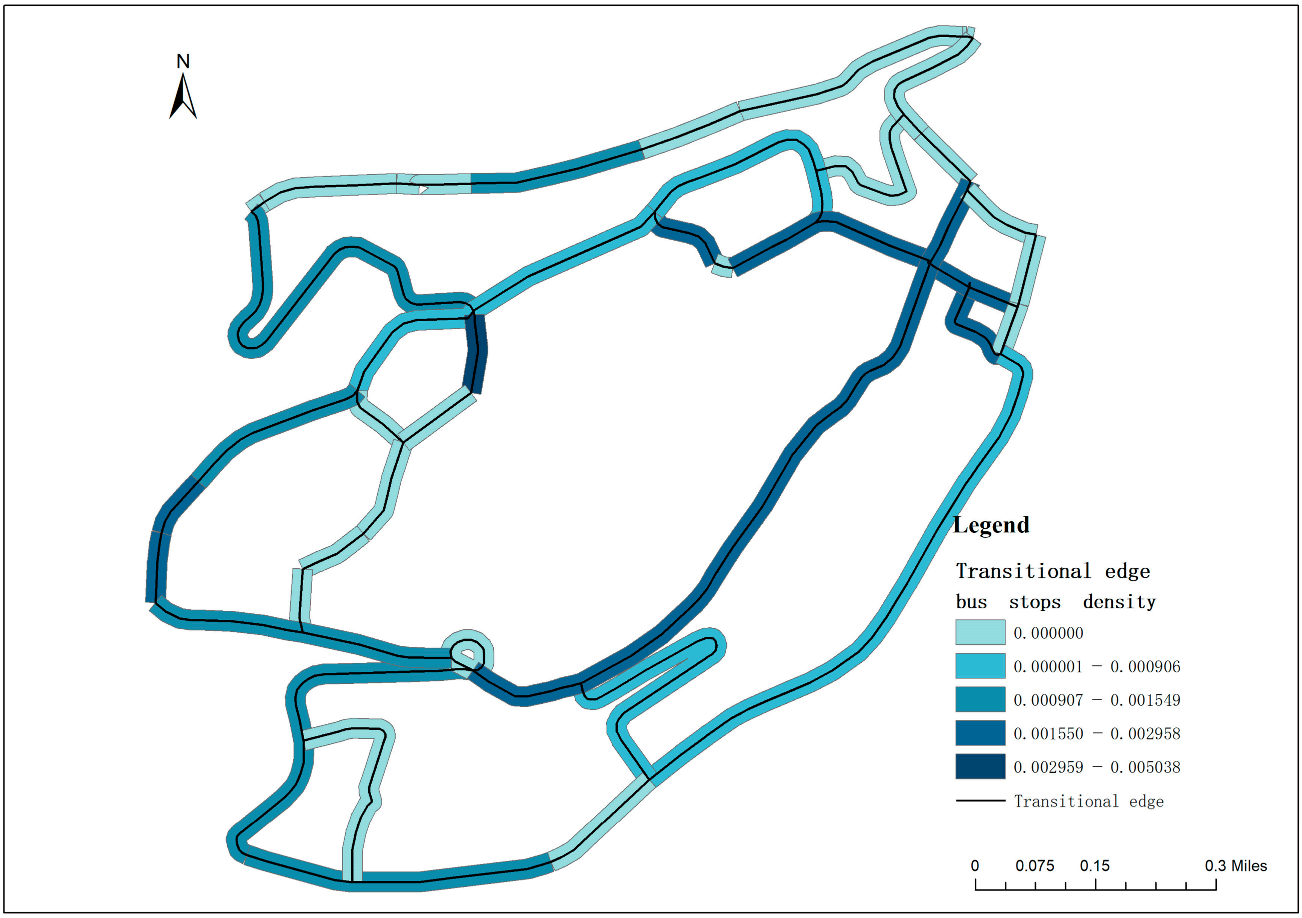
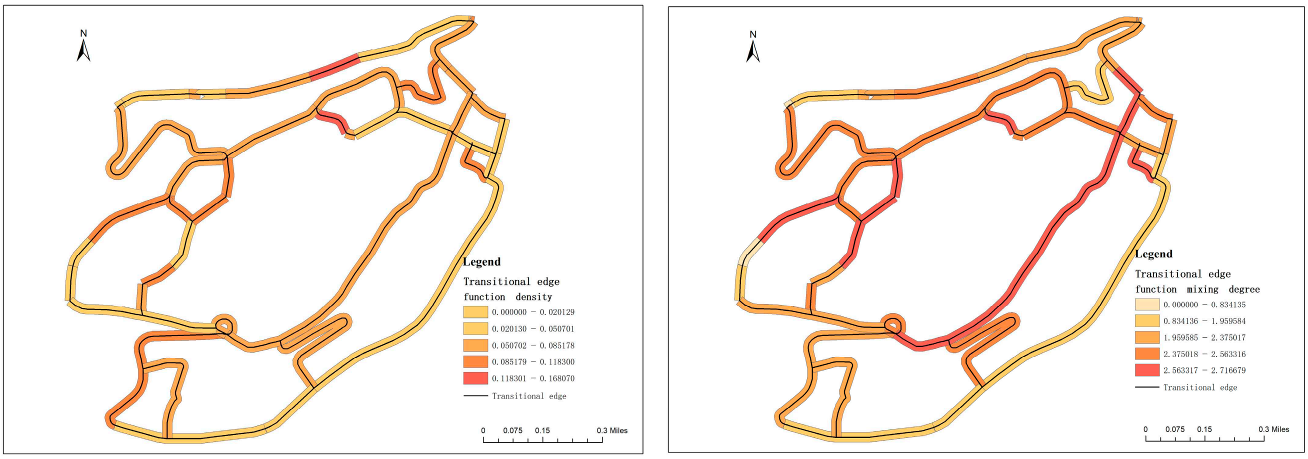


Figure 9. The population density in the transitional edge. Source: (Author, 2024).

2. Social Function Density and Function Mixing Degree

This study utilized PoI data to quantitatively assess the social function density of urban transitional edge areas. Social function density is defined as the ratio of the number of PoI points to the total length of streets in the area, reflecting the richness of service facilities available to meet the daily needs of residents. Additionally, the study evaluated the function mixing degree by measuring the diversity of different categories of PoIs within the transitional edge buffer zones, using information entropy theory for quantification. Areas with a higher function mixing degree offer a more diverse range of facilities, better accommodating residents' varied social activity needs. Unlike the typical effects of proximity to the CBD, this more profound understanding of functional diversity provides data-driven insights into how mixed-use development can foster a more resilient and socially vibrant environment in transitional edges. The spatial distribution pattern (see Figure 10) reveals that inner-circle streets within the transitional edges, such as Zhonghua Road and Datong Road, exhibit higher social function density. This is not solely due to their proximity to the CBD but also their balanced distribution of facilities. This characteristic is less common in purely residential or commercial zones.

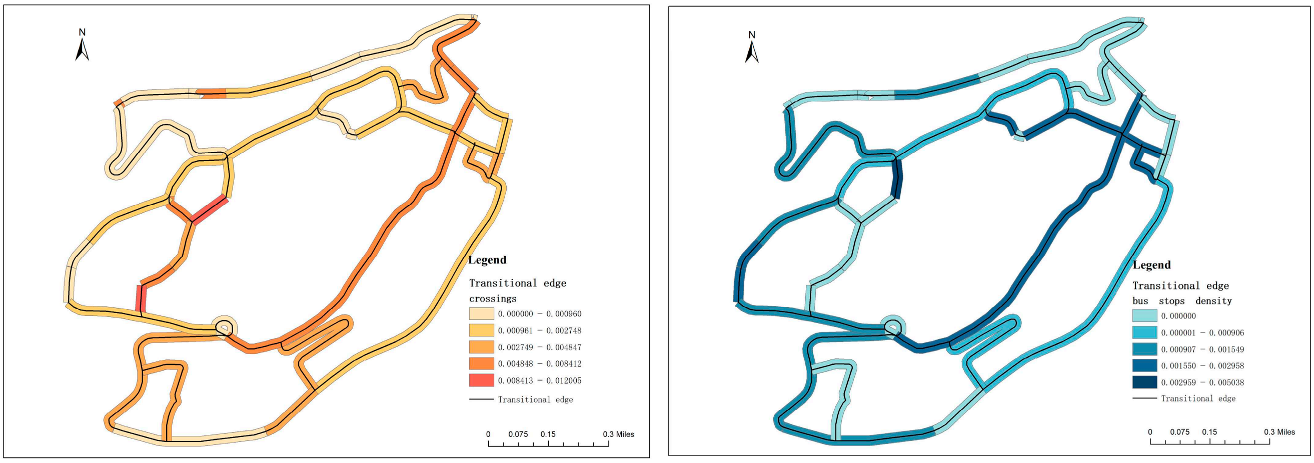


(**a**) (**b**)

Figure 10. (**a**) Social function density and (**b**) Social function mixing degree. Source: (Author, 2024).

3. Crossing and Bus Stop Density

Based on Baidu panoramic maps and field survey data, the crossing and bus stop density within the transitional edges was categorized into five natural breaks (see Figure 11a,b). GIS visual analysis shows that areas like Xinhua Road have high crossing and bus stop densities, indicating greater accessibility. High-density areas, such as Panjia Lane and Datong Road, are typically located near well-established, older residential neighborhoods with a high population density and vibrant commercial activities. This density facilitates pedestrian movement, reduces reliance on private vehicles, enhances social interaction, and integrates different urban functions. The study also highlights that, unlike typical urban streets, the transitional edges in Chongqing feature specific routes characteristic of a hillside city. For instance, Beiqu Road is positioned alongside a hill. At the same time, Jialing River Riverside Road runs along the river, limiting pedestrian activity to one side of the street with minimal need for crossing. These unique pathways significantly influence pedestrian movement and accessibility, which are crucial for enhancing the radiative effect of the CBD.



(**a**) (**b**)

Figure 11. (**a**) Crossing density and (**b**) Bus stop density. Source: (Author, 2024).

4. Street Width, Tree, and Lighting Density

Based on field survey data analysis, street width, tree density, and lighting density were classified into five natural break categories (see Figure 12). The variations in street width are significant, with differences of up to 20 m between the most comprehensive and narrowest sections on the same street. This variability is closely related to the local road conditions and the positioning of buildings on both sides. Wider streets, such as Baixiang Street and Heping Road, provide more space for pedestrian activities and street-side interactions, promoting social activities and enhancing the radiative effect of the CBD. This finding is particularly relevant to transitional edge areas, where wider streets facilitate smoother transitions between urban zones. In contrast, narrower streets like Mianhua Street and Beiqu Road are constrained by the structure of older communities, limiting pedestrian flow and reducing opportunities for social interaction.

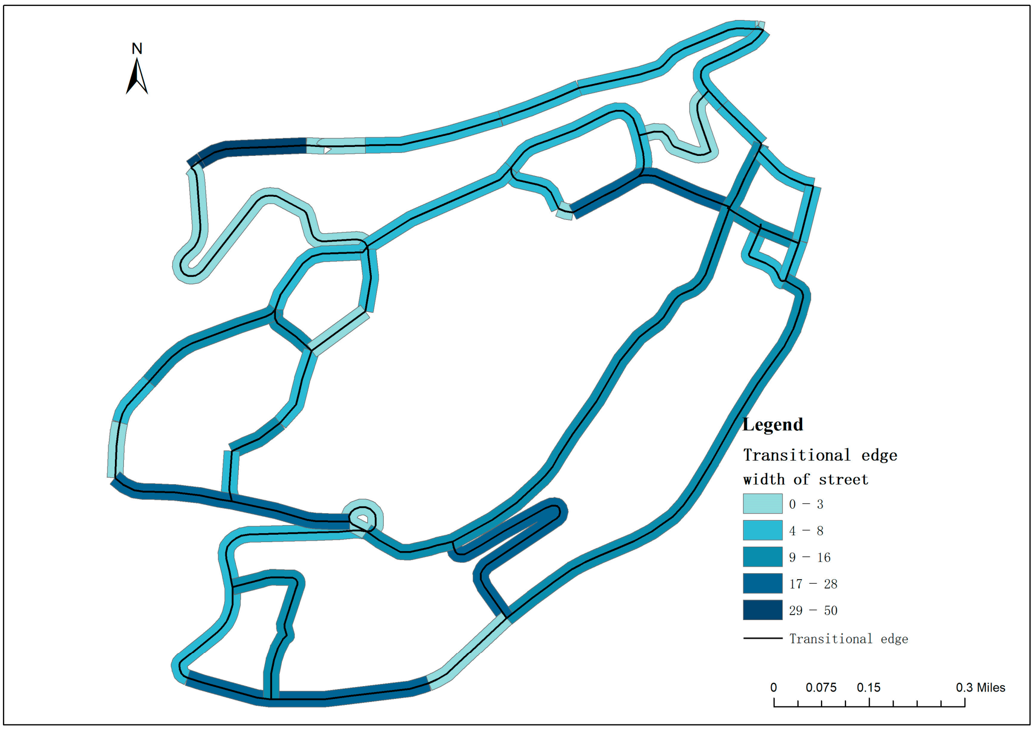
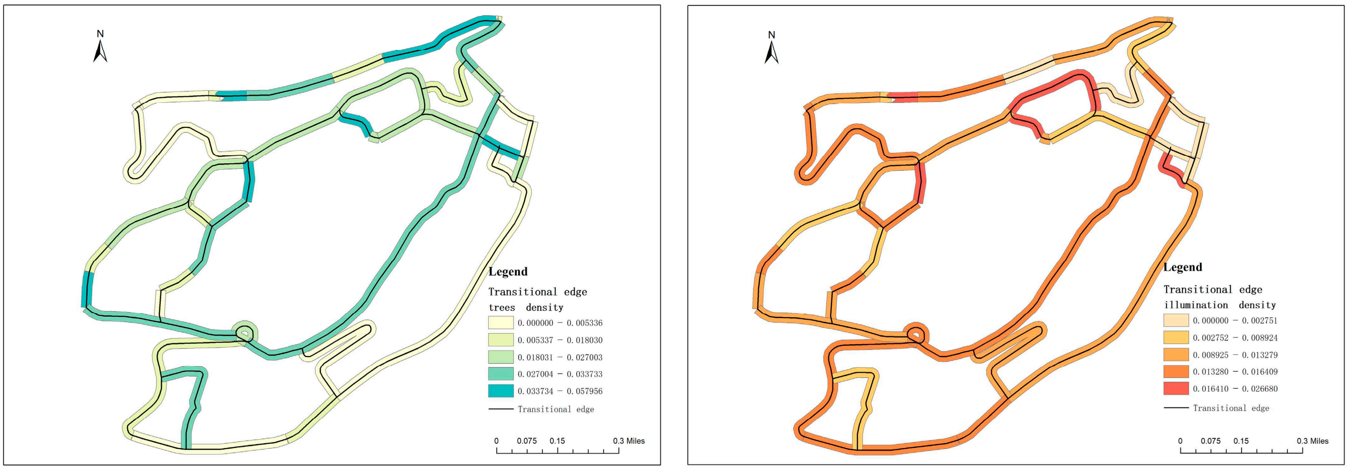


Figure 12. Width of transitional edge street. Source: (Author, 2024).

Areas with a high tree density, concentrated in the northwestern and southwestern parts of the district, offer more shade and natural beautification, enhancing the pedestrian experience and creating a more pleasant social environment (see Figure 13a). In Chongqing's subtropical climate, greenery effectively reduces temperatures, increasing the comfort of outdoor activities. This aspect is especially crucial in transitional edges, where the quality of the street-level environment directly impacts social engagement. Conversely, areas with a lower tree density, such as Cangbai Road and Minzu Road, have prioritized traffic flow over greenery in recent urban redevelopment projects, reducing social activities.



(**a**) (**b**)

Figure 13. (**a**) Tree density and (**b**) Illumination density. Source: (Author, 2024).

Lighting density is relatively even across most streets, ensuring good illumination (see Figure 13b). Major roads like Xinhua Road and Linjiang Road have the highest lighting density, providing nighttime safety for pedestrians and vehicles. This multi-layered lighting, including streetlights, neon lights, and shop signage, creates a safer and more attractive nighttime environment, fostering social and economic activities in transitional edges with residential and commercial functions.

5. Street Buffer Zones, Benches and Tables Density

The density of street buffers, benches, and tables reflects social amenities in the transitional edges. These facilities provide essential spaces for rest and social interaction, making streets more attractive and functional for various users. Higher densities of street furniture and buffer zones enhance the quality of public spaces by offering areas where people can gather, rest, and engage in social activities. Consequently, these amenities are crucial in promoting social interaction and inclusivity, particularly in the inner-city transitional edge areas.

The spatial distribution of street buffers (Figure 14a) indicates that streets with these features are primarily located in the peripheral areas of the transitional edges, close to inner-city residential zones, reflecting local pedestrian flow patterns. Notably, streets such as Xinhua Road and Linjiang Road, which lack buffer zones, often serve as major traffic corridors with high flow rates, highlighting a trade-off between traffic efficiency and the provision of social spaces.

Further analysis of the density of benches and tables (Figure 14b) reveals that the overall density of these amenities is relatively low in the study area. Streets with high densities of these facilities, such as Zhonghua Road and Minzu Road, indicate a greater demand for social and recreational spaces. In contrast, streets like Jialingjiang Riverside Road have scarce amenities, suggesting they are primarily used for transit. This spatial configuration reflects the diverse roles of streets in transitional edges, necessitating a balance between integrating social functions and other urban priorities.

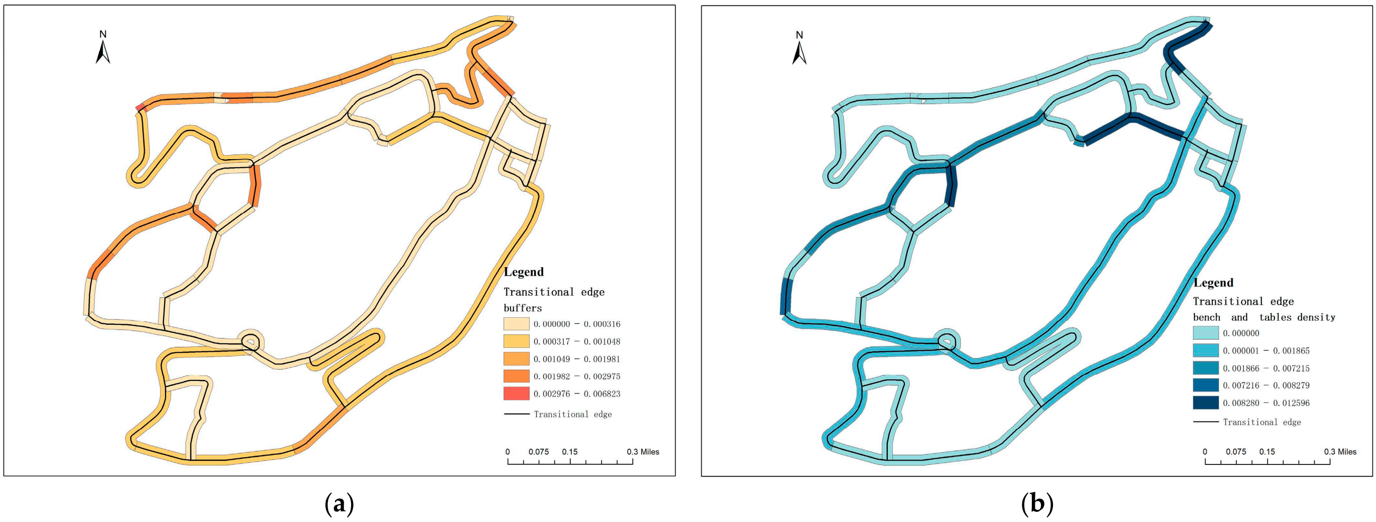


Figure 14. (**a**) Buffer zone density and (**b**) Benches and tables density. Source: (Author, 2024).

6. Major finding

Based on the results, the spatial data visualization achieved through ArcGIS software enabled a multidimensional quantitative assessment of the socio-spatial environmental quality in the transitional edges of Chongqing's Yuzhong District. The findings reveal significant variations in social activities and environmental quality within these areas. Precisely, regions closer to the CBD exhibit a higher population density, social function density, function mixing degree, and density of sidewalks and bus stops. These indicators suggest that these areas have a superior socio-spatial environment that supports frequent social interactions and diverse urban functions. Particularly in the complex terrain of transitional edge areas, increased tree and lighting densities significantly enhance the pedestrian experience and nighttime safety, thereby improving overall environmental quality and strengthening the radiative effect of the CBD. Conversely, areas closer to residential zones lack functional and environmental attractiveness and show relatively sparse social activities. These findings indicate that the socio-spatial environmental quality of Yuzhong District's transitional edges is influenced by proximity to the CBD and specific spatial environmental characteristics and functional layouts.

4.2. Environmental Influencing Factors on Social Activities in Transitional Edges

According to the correlation analysis results of social activities in transitional edges (Table 3), benches and tables density, buffers, width of sidewalks, and crossings did not pass the significance test. Therefore, these four variables were eliminated. The other five factors were found to be related to social activities in transitional edges, with tree density, function density, and function mixing degree showing high positive correlations, and illumination density and bus stops showing weak positive correlations.

The regression equation is:

$$\begin{aligned}\text{Baidu Population Density} &= \beta 0 + \beta 1 \times \text{Bus Stop Density} + \beta 2 \times \text{Crossing Density} + \beta 3 \\ &\times \text{Function Density} + \beta 4 \times \text{Function Mixing Degree} + \beta 5 \times \text{Tree Density} + \beta 6 \\ &\times \text{Illumination Density} + \beta 7 \times \text{Street Width} + \beta 8 \times \text{Buffer Density} + \beta 9 \times \text{Bench and Table} \\ &\text{Density} + \varepsilon\end{aligned} \tag{6}$$

where β0~β9 represent the regression equation coefficients, and ε is the error term. This equation implies that when the values of bus stop density, crossing density, function density, function mixing degree, tree density, illumination density, street width, buffer density, and benches and tables density are determined, the Baidu population density can be estimated using this equation.

Applying the model in Equation (6), SPSS software was used to perform linear stepwise regression analysis by importing the data. The final results are shown in Table 4.

Table 3. Pearson correlation analysis.

Pearson Correlation	Trees density	Illumination density	Function density	Benches and tables density	Crossings	Buffers	Bus stops density	Width of the sidewalks	Population density	Function mixing degree
Trees density	1									
Illumination density	0.15	1								
Function density	0.107	0.252	1							
Benches and tables density	0.308 *	0.018	0.04	1						
Crossings	0.038	0.163	0.062	−0.11	1					
Buffers	−0.056	0.188	−0.16	0.054	0.219	1				
Bus stops density	0.269	0.385 *	0.146	0.455 **	−0.266	0.031	1			
Width of the sidewalks	−0.241	0.037	−0.299	−0.077	0.199	0.727 **	−0.108	1		
Population density	0.463 **	0.425 **	0.588 **	0.29	0.045	−0.183	0.319 *	−0.265	1	
Function mixing degree	0.294	0.086	0.559 **	0.116	0.108	−0.588 **	−0.027	−0.698 **	0.582 **	1

* $p < 0.05$ ** $p < 0.01$.

Table 4. Parameter estimates (n = 41).

	Unstandardized Coefficients		Standardized Coefficients	t	*p*	Collinearity Statistics	
	B	Std. Error	Beta			VIF	Tolerance
Constant	−0.096	0.127	-	−0.754	0.456	-	-
Trees density	5.089	1.842	0.303	2.762	0.009 **	1.128	0.887
Illumination density	11.124	4.422	0.273	2.516	0.016 *	1.099	0.91
Function density	2.336	0.925	0.327	2.525	0.016 *	1.567	0.638
Function mixing degree	0.141	0.065	0.286	2.189	0.035 *	1.602	0.624
R Square				0.615			
Adjusted R Square				0.572			
F				F (4.36) = 14.382, p = 0.000			

Dependent Variable: population density. * $p < 0.05$ ** $p < 0.01$.

The linear stepwise regression model was tested for significance using the F-test. The F-test aims to determine whether the overall independent variables significantly impact the dependent variable. As shown in Table 4, using tree density, illumination density, function density, benches and tables density, crossings, buffers, bus stop density, width of the sidewalks, and function mixing degree as independent variables, and population density as the dependent variable, the stepwise regression analysis results showed that only four items—illumination density, trees density, function density, and function mixing degree—were included in the model. The R-squared value was 0.615, meaning that tree density, illumination density, function density, and function mixing degree could explain 62.4% of the variation in population density. Furthermore, the model passed the F-test (F = 14.382, p = 0.000 < 0.05), indicating that the model is adequate.

Significance testing (*t*-test) was used to check the regression coefficients in the linear stepwise regression model. The *t*-test was used to verify whether each independent variable significantly impacted the dependent variable. When the absolute value of t is significant, and the significance level is less than 0.05, the regression coefficient passes the significance test. Table 4 shows that the absolute values of t for the four components of social activities in transitional edges (tree density, illumination density, function density, and function mixing degree) were 2.762, 2.516, 2.525, and 2.189, respectively, with significance levels of 0.009, 0.016, 0.016, and 0.035. The regression coefficients of these four variables were significant (passing the *t*-test). In contrast, the regression coefficients of the other five components (benches and tables density, buffers, bus stop density, width of the sidewalks, and crossings) were not significant (failing the *t*-test). They were automatically excluded from the linear stepwise regression analysis.

In summary, in studying the influencing factors of social activities in transitional edges, we identified four primary dimensions to analyze their potential impact in detail. Tree density and illumination density belong to the comfort dimension, while function density and function mixing degree belong to the function dimension. This indicates that the environmental factors of function and comfort dimensions directly impact liveliness, represented by population density. According to the standardized coefficient data in Table 4, the influencing factors are ranked in descending order: tree density, illumination density, function density, and function mixing degree. These findings validate some common urban planning principles and provide new insights, particularly concerning the unique urban space of inner-city transitional edges.

First, in this study, tree density, as a representative measure of street greenery, significantly impacted the density of social activities in transitional edges. The stepwise linear regression analysis demonstrated a positive correlation between tree density and population activity density, making it the most influential factor. This result underscores that in Chongqing's climatic conditions, street greenery is not just a visual comfort but also an effective means of climate regulation, helping to provide a more relaxed walking environment for pedestrians during hot seasons. Thus, enhancing street greenery within transitional edges can increase foot traffic by improving environmental quality, a unique finding under Chongqing's distinct climate and topographical conditions.

Second, lighting facilities play an indispensable role in pedestrian activity choices. The study results show a positive correlation between street lighting density and pedestrian activity frequency and perceived safety. Unlike ordinary urban areas, the transitional edges are characterized by a need to cater to daytime pedestrian requirements and extend nighttime activities through adequate lighting, thereby boosting the area's nighttime economic vitality. This finding particularly highlights that improving lighting facilities in transitional edges can significantly enhance social activities, especially increasing nighttime social interactions and the sense of safety.

Third, transitional edges rich in facilities and service points exhibit higher diversity and multifunctionality, significantly meeting residents' daily needs and encouraging street activities. Areas with a high functional density provide convenient services and facilitate social interactions and pedestrian flow. Compared to streets near residential areas with spatial constraints, the study found that those with abundant functional facilities are more effective at attracting and retaining people. This suggests there is potential for optimization in the functional design of transitional edges to stimulate social activities.

Lastly, compared to streets with single functions, those with a diverse mix of functions are more favored by users. Multifunctional streets often promote more social interaction and community building while reducing the time and spatial distance for residents or visitors to reach different destinations, thereby decreasing reliance on private vehicles. Moreover, streets with a higher degree of functional mixing tend to exhibit greater economic diversity, providing more employment opportunities and services, thereby enhancing the economic resilience of the area and the efficiency of street resource utilization. This multifunctionality is particularly important in transitional edges, as these streets act as extensions of the CBD and serve as bridges for social and economic activities in adjacent spaces.

5. Discussion

This study explores the factors influencing social activities in the inner-city transitional edges of Chongqing's Yuzhong District by integrating extensive data analysis with field surveys to construct a multidimensional evaluation framework for quantifying the socio-spatial environmental quality of these transitional edges. The findings reveal that the socio-spatial environmental quality of transitional edge areas in Yuzhong District varies significantly due to different spatial factors. Specifically, the side closer to the CBD exhibits higher socio-spatial environmental quality, characterized by a higher tree density, function density, and lighting density, all indicating better environmental quality and a higher frequency of social activities in these areas. In contrast, closer to residential areas, the outer side shows relatively lower socio-spatial environmental quality, with a lower tree density and function mixing degree, leading to relatively sparse social activities. While these results align with general urban planning principles, they further indicate that different spatial environmental factors play a crucial role in the distribution of social activities within urban transitional edge areas. The socio-spatial environmental quality in such transitional edges is influenced by proximity to the CBD and specific spatial environmental characteristics and functional layouts.

Through linear regression analysis, we identified that functionality and comfort are the most essential dimensions influencing social activities in these areas. Expressly, tree density and lighting density represent the comfort dimension, while function density and function mixing degree represent the functionality dimension. These factors show a significant positive correlation with population density, indicating vibrancy. This suggests that within transitional edges, the quality of street greenery and lighting significantly enhances the frequency and participation in social activities, surpassing the influence of mere geographical proximity. This means that the proximity to the CBD affects the intensity of social activities, and the specific environmental quality within these areas also plays a central role. For example, a higher tree density provides shades and visual comfort for pedestrians in transitional edge areas. It creates a unique microclimate, especially in a hillside city like Chongqing, which has a hot and humid climate. Adequate lighting density has also been proven crucial in increasing the frequency of nighttime activities (see Figure 15a), particularly on streets within transitional edges, which often need to support extended periods of commercial and social activities—features that have not been fully explored in previous studies on transitional edges. Notably, even with benches and buffers on some streets, these facilities did not significantly impact social activities in transitional edges. Urban street management policies could explain this. Regulations such as those in the "Urban Appearance and Environmental Sanitation Ordinance" prohibit street vendors and prevent storefronts from placing furniture outside, potentially limiting the occurrence and expansion of social activities (see Figure 15b).

(**a**) (**b**)

Figure 15. (**a**) Crowds in the Hongya Cave area and (**b**) Streets needing benches and tables. Source: (Author, 2024).

Based on the existing results, the comfort of transitional edge areas near residential zones is particularly crucial. Despite the study area being positioned in a highly socially active urban core, municipal authorities have provided relatively complete street environments, such as lighting and greenery. However, the comfort of certain streets still needs to be improved, revealing significant issues in resource allocation (see Figure 16a). Additionally, the limitations in developing transitional edge streets may stem from Chongqing's unique mountainous spatial characteristics and the diverse social needs of users. Especially under complex terrain conditions and dynamic changes in various social demands, transitional edges' spatial layout and functional arrangement face significant challenges (see Figure 16b). These factors present conflicts and challenges for design practices and policy-making, leading to notable deficiencies in the functionality of some streets.

(**a**) (**b**)

Figure 16. (**a**) Transitional edge near residential area and (**b**) Street edge in mountainous terrain. Source: (Author, 2024).

Moreover, the level of vibrancy in transitional edges is directly determined by the density and diversity of functions. The study shows that streets with multifunctional uses are more effective in attracting and retaining foot traffic, not only because they offer various services and facilities but also because they reduce dependence on vehicular transportation, promoting more frequent and spontaneous social interactions. Therefore, this study adds to the existing literature on CBDs and their surrounding areas by emphasizing the unique role and potential of the design and configuration of transitional edge areas in extending CBD functions and coordinating surrounding spaces.

Although this study used the Yuzhong District in Chongqing as a case study, the findings have a certain level of generalizability for broader transitional edge assessments. Specifically, the evaluation framework of this study, which combines connectivity, conviviality, functionality, and comfort dimensions, reveals how these factors influence social activities in different types of urban transitional edge environments. Functionality and comfort were found to be the main factors influencing social activities, and this finding is not only applicable to hillside cities like Chongqing but also has reference value for transitional edge environments in other cities. Particularly for areas with a high urban density and complex terrain, the methods and conclusions of this study can serve as a foundation for other studies, with parameters adjusted to suit the specific conditions of different cities.

6. Conclusions

This study quantitatively evaluated the social-spatial environment of inner-city transitional edges in Chongqing's Yuzhong District, constructing a comprehensive evaluation framework and verifying its reliability and effectiveness in practical application. Subsequently, we established a multiple stepwise linear regression model, and the results indicated that the density of street trees, lighting facilities, function density, and function mixing degree significantly influence the occurrence and distribution of social activities in transitional edges. From a practical perspective, the findings of this study could guide the construction of more harmonious and inclusive urban spaces. By increasing the density of street greenery and lighting facilities, pedestrians can have a more comfortable walking experience, attracting more people to engage in street activities and enhancing the overall vibrancy of urban streets. Increasing the density of social functions and function mixing degrees can provide residents with more daily services and social venues, meet diverse needs, and further stimulate social interaction and community cohesion. Optimizing the social functions and comfort of streets is more realistic and feasible than altering the physical structure of streets. Additionally, strategically planning bus stops and sidewalk density and planting more street trees can enhance the convenience of public transportation and pedestrian experience.

Furthermore, this study highlights the impact of topography on socio-spatial dimensions at urban transitional edges. In particular, the hillside terrain of Yuzhong District imposes constraints on the accessibility of extensions to the CBD functions, and the available space for street utilization is more limited. Therefore, the characteristics of hillside cities should be fully considered in the planning and design processes of transitional edges. These measures enable urban planners and designers to more effectively optimize the spatial layout of inner-city transitional edges, improve urban environmental quality, expand the functionality of CBD areas, and mitigate social isolation.

Despite the valuable findings of this study, there are several limitations. As a single-case study, the generalizability of the results is limited. Future research should expand the scope of cases to include diverse terrains, socio-economic backgrounds, and city scales to validate the findings' broader applicability and consistency. Additionally, data collection and analysis methods could be more diverse, such as employing spatial syntax analysis and street view image semantic segmentation to explore the relationship between spatial layout and social activities more deeply. Future research should also conduct long-term dynamic observations to capture the temporal and spatial variations of social activities.

The methodology of this study provides new perspectives for evaluating transitional edges but still requires further exploration. Future research should delve deeper into the specific roles of facilities under different socio-economic contexts and use refined research designs to understand the complex impacts of accessibility and conviviality factors on social activities. The current study should have thoroughly explored the specific functions of various facilities within transitional edge environments and their impacts on different social activities. Future studies should investigate these mechanisms more deeply, especially regarding their adaptability to different socio-economic contexts. Moreover, to better understand why accessibility and conviviality factors did not significantly affect social activities, future research could employ more detailed research designs to grasp these factors' complex roles.

Author Contributions: Conceptualization, X.H.; methodology, X.H.; software, X.H.; validation, X.H.; formal analysis, X.H.; investigation, X.H.; resources, X.H.; data curation, X.H.; writing—original draft preparation, X.H.; writing—review and editing, X.H., M.K., and N.B.U.; visualization, X.H.; supervision, X.H. and Y.M.; project administration, X.H. and Y.M.; funding acquisition, X.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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