Evaluating and optimizing the functional composition of community centres: a data-informed approach assisting 15-minute community life circle

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ABSTRACT

Developing the 15-minute community life circle is considered a crucial strategy in many global cities, with the goal of providing suitable facilities and services for communities. In recent years, the community centre has played a significant role in bridging the "last mile" gap in life circles. However, current development has shown limitations in terms of analyzing community residents' demands, considering public services and commercial facilities, and ensuring accuracy. To address these issues, this study integrates diverse urban data sources and advanced spatial analysis tools to establish a data-driven, systematic, scalable, and highly accurate analytical framework for evaluating and optimizing the functional composition of community centres. Specifically, this approach guides the functional composition from three dimensions: population composition, public service facilities, and commercial facilities. User portraits are created using LBS data to understand population composition, while points of interest (POIs) and morphological data are utilized to calculate the coverage of various facilities for public services. Urban network analysis (UNA) tools are employed to measure service effectiveness. In terms of commercial facilities, the effectiveness of shops is evaluated based on consumption average price, service rating, and operating hours, using Meituan data and UNA tools. A residential district that lacks various kinds of facilities in Shanghai, China has been selected as the case to illustrate the performance of this approach. Improvements in this direction contribute to improving the service quality of the 15-minute community life circle. It also reveals new potentials in fine-scale urban management integrating multi-sourced urban data and quantitative morphological tools.

Keywords: functional composition, multi-sourced urban data, data-informed, community centre

INTRODUCTION

Research background

In recent years, the construction of 15-minute life circles has become an important development strategy for global cities, as cities continue to develop and resource allocation at the grassroots level becomes more refined (Pozoukidou and Chatziyiannaki, 2021). In China, there have been domestic explorations and practices in creating 15-minute life circles. Community centres, as a development model that combines social and economic value, have played a significant role and have become a new typical type (Li *et al.*, 2021; Zhuo *et al.*, 2020). Specifically, community centres are comprehensive one-stop platforms that provide public and commercial services for residents in surrounding communities. This model originated in Singapore and has been widely applied and proven effective in various countries (Feng *et al.*, 2019).

In general, the facility allocation of community centres serves the specific residents of the community and fulfills both public service (Goldfarb and Grinberg, 2019) and business functions (McShane and Coffey, 2022). As the development of life circles becomes more refined, creating well-rounded community centres with precise services, comprehensive functions, and complete facilities has become a crucial step in implementing the "last mile" of the 15-minute life circle(Liu and Li, 2021). However, due to the developmental nature of community centres and their multi-dimensional functional value, conducting detailed research, evaluation, and rational allocation of their functional components often poses challenges in their design and development(Lee and Park, 2018). Previous practices have made beneficial explorations in the functional allocation of community centres(Chen, 2016), but they have also exposed some urgent problems(Zhang, 2022), summarized as "lack of design decision-making" and "overly broad indicator formulation" during the practical process. Currently, there is a shared demand among the government, developers, and community residents to study the reasonable functional composition of community centres. Therefore, there is a need to establish methods for the fine-grained evaluation and optimization of the functional composition of community centres.

Analyzing the functional allocation of life circles often requires precise data and methods. In recent years, Urban data has become more multidimensional, with higher coverage and resolution. Analysis techniques are also evolving to consider more complex factors, becoming more refined and scientific. This allows for the incorporation of diverse urban elements into spatial analysis. As a result, big data and spatial analysis techniques are no longer just macro-planning tools for cities and regions, but can also support analysis and research at the life circle and community scales(Lu and Wu, 2022; Ye *et al.*, 2019b). This opens up possibilities for quantitatively evaluating and optimizing the functional composition of community centres.

Literature review

The main issues related to the functional composition of the 15-minute community life circle

The composition and configuration of community centres have been extensively studied in relation to life cycles. This can be summarized into three crucial aspects: the composition of the community population, the accessibility and fairness of public services, and the impact of commercial facilities. Firstly, research on population composition indicates that residents of different incomes and ages have varying demands for the configuration of life cycle facilities. Additionally, the distribution of the population will influence the location and type of facility configuration, thus impacting the quality of the life cycle(Azmi and Karim, 2012). Therefore, it is necessary to analyze the population composition of life cycles. Furthermore, the level of basic public service facilities in the community is reflected in the comprehensiveness, fairness, and accessibility of various services. Current research on the configuration of 15-minute life cycle facilities mainly includes categories such as medical, public transportation, sports and leisure, education, and cultural facilities(Salkin and Lavine, 2010; Witten *et al.*, 2016). In relevant layout studies, the accessibility of space directly affects the fairness and benefits of resource allocation. Some scholars have quantitatively explored and attempted the location, accessibility, and impact of community public service facilities using location-allocation

models(McLafferty and Broe, 1990), two-step moving search methods(Langford *et al.*, 2008), and shortest travel distance evaluation methods(Wang and Zhou, 2022), which have some application value. However, due to limited integrated factors and insufficient breadth and depth of quantification, they are not sufficient to support the detailed analysis requirements of life cycle construction practices. Finally, commercial facilities in the community also play a vital role in creating life cycles. Commercial operations in the community are unique and necessary community services, and the development level of commercial facilities is linked to the living standards and quality of life of community residents (El Hedhli *et al.*, 2013). Many scholars believe that community commercial facilities should prioritize residents' needs, and improve adaptability and diversity, thereby increasing community satisfaction (Hu *et al.*, 2023). Currently, most research on community commerce is highly focused, lacks integration with various public services, and lacks sufficient quantitative analysis.

Research on the functional composition of the community life circle offers a broad theoretical foundation for the functional arrangement of community centres. However, current studies on facility configuration related to the 15-minute life circle primarily concentrate on a single aspect. They often involve limited quantitative assessments of basic public service facilities, without comprehensive analysis of population composition and commercial facilities. Additionally, there is a lack of in-depth and quantitative methods for a detailed analysis.

New trends from technology to practice: Exploring the data-supported paradigm for fine-grained analysis of community centres

In recent years, urban research has benefitted from the emergence and wide application of multiple sources of urban big data and new spatial analysis methods. For instance, LBS data allows for the construction of user profiles (França *et al.*, 2016). POI data is used to determine the coverage range of community facilities and assess their functional composition (Zhai *et al.*, 2019). Crowdsourced data, such as Meituan data, provides insights into the types and operational characteristics of commercial facilities, offering a quantitative basis for business entry (Shi *et al.*, 2021). In terms of spatial analysis techniques, scholars have enhanced traditional spatial syntax. For example, the UNA tool is employed to measure and analyze the service effectiveness of retail (Sevtsuk, 2014) and convenience facilities (Hidalgo *et al.*, 2020). These individual explorations of new data and techniques have laid a solid foundation for future fine-grained, systematic, and applied research.

Subsequently, scholars have proposed integrated frameworks that combine various types of data and technologies to support urban construction and renewal at small scales, such as life circles and streets. For example, Ye et al. integrated green view rate and accessibility analysis to aid in the selection of greenway locations during street renewal (Ye *et al.*, 2019a). Teng et al. integrated POI, building, and street network data to calculate the convenience of each building within the 15-minute life circle (Zhong *et al.*, 2020), providing guidance for planning. These studies demonstrate the potential of multiple sources of urban data and new analysis techniques in practical applications. However, there is currently no universally applicable and highly refined framework for the analysis, evaluation, and optimization of the functional composition of community centres.

This study aims to integrate emerging urban data from multiple sources to expand the dimensions of functional analysis. In addition, new spatial analysis techniques are employed to ensure the precision of the analysis. The study is divided into four parts. The first part provides an introduction to the research background. The second part explains the research framework and methods. The third part showcases the reliability of the analysis through a case study of Shanghai. The fourth part summarizes the innovations and value of this study, and proposes limitations and future directions.

METHODOLOGY

Research framework

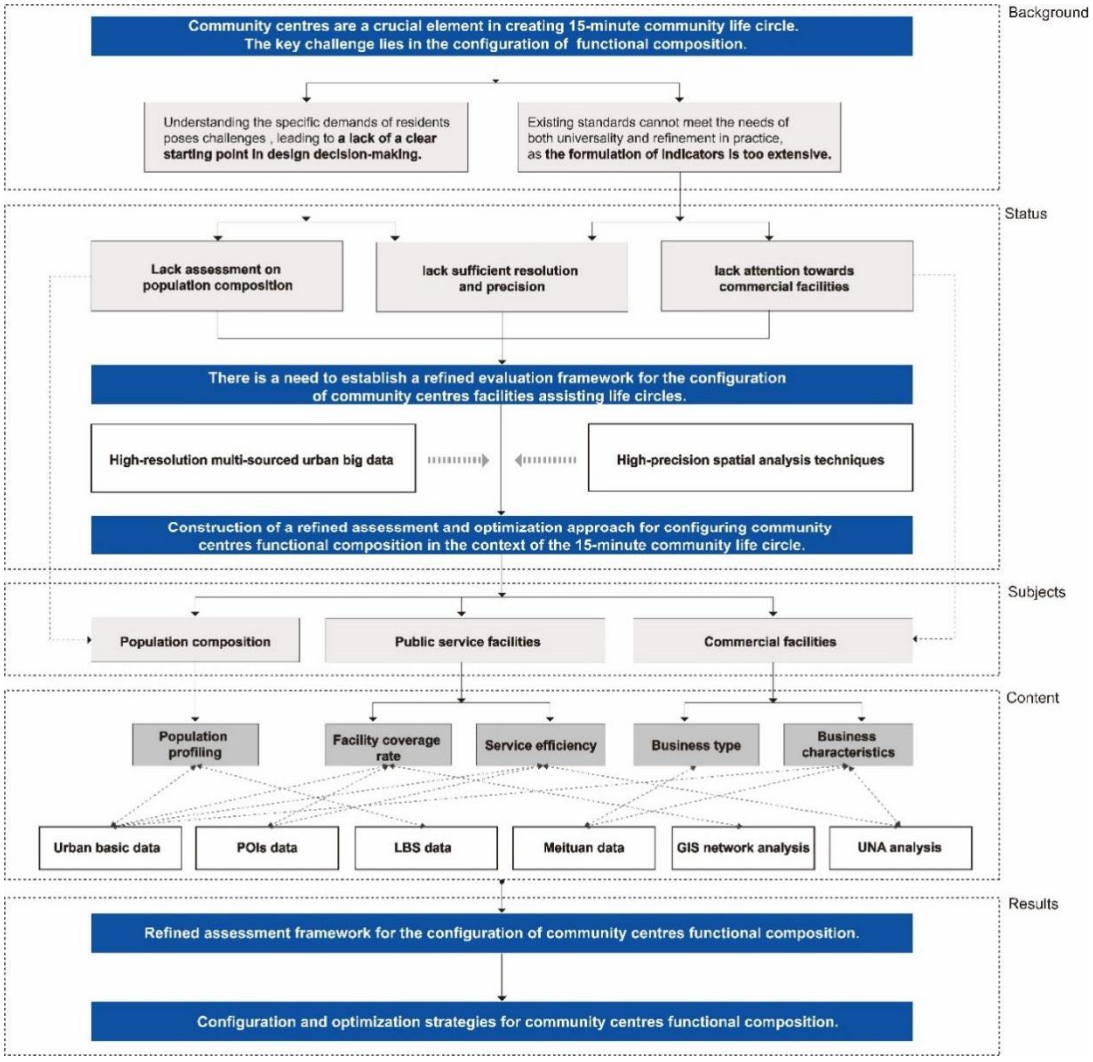

Figure 1. *Research framework.*

This study aims to develop a refined method for evaluating and optimizing the functional composition of community centres. Three indicators, namely population composition, public service facilities, and commercial facilities, are selected as the analytical dimensions. A set of data evaluation paradigms

centered on facility allocation is constructed, incorporating new spatial analysis technologies such as the UNA tool and multiple data sources including LBS, POIs, and Meituan. Using the Jingnan community centre as a case study, this research conducts a detailed measurement of the functional composition, which has been challenging to accurately evaluate in the past, and provides corresponding recommendations. The development of this method aims to empower design practice and promote the refinement and scientific basis of life circle facility allocation.

Method of defining the life circle and facility classification

The 15-minute community life circle refers to the area that can be reached within a 15-minute walk. In this study, the community centre is used as the base, and the network analysis tool in ArcGIS is employed to delineate the 15-minute life circle range, which accurately represents the accessibility area (Kaczynski *et al.*, 2014). Additionally, the 10-minute and 5-minute life circle ranges are included as references.

Regarding facility classification, this study primarily considers China's policies and the feasibility of cleaning POI data, combined with standards from various locations for specific classification. In general, public service facilities and commercial facilities serve as the fundamental classification framework. Public service (Table 1) facilities are further divided into six categories: community management, education, culture, physical education, healthcare, and elderly care. They are further subclassified based on different types and service radii. The classification of commercial facilities is based on the types provided by crowdsourced data sources, focusing mainly on store attributes such as customer price, business hours, and service ratings.

Table 1. *Classification of public service facilities.*

Public service facilities

Category	Subcategory	Service radius
Community management	Government agencies	800m
	Social organizations	300m
Education	Training institutions	800m
	Childcare institutions	500m
Culture	Cultural activity centre	800m
Physical Education	Fitness centre or gymnasium	500m
Healthcare	Medical clinic	800m
	Health and wellness care	300m
Elderly care	Senior activity room	300m

Technical approach

The evaluation of functional composition is divided into three parts. Firstly, LBS data is utilized to analyze the population composition and create demographic profiles. Secondly, the combination of POIs data, UNA, and GIS network analysis tool is employed to assess the coverage and service effectiveness of basic public service facilities. Lastly, Meituan data and the UNA tool are used to analyze the operational characteristics of commercial facilities, enabling a comprehensive evaluation of commercial services.

This study commences by analyzing the population composition of the life circle using LBS data. LBS data provides extensive information, including age, income, and place of residence. The LBS data used in this research was obtained from a third-party data service provider. The data, based on a 250m * 250m grid, consists of three sets of original data CSV files from "workdays + weekends" on April 17-20, 2019, May 28-30, 2020, and January 14-16, 2021, with grid ID and user number as retrieval criteria. After data cleaning, analysis is conducted on the age composition, consumption level, place of residence, and workplace distribution.

Next, the analysis focuses on basic public service facilities. Based on POIs data, both GIS network analysis and UNA tools are employed to calculate coverage and service effectiveness. The calculation of coverage is to determine the minimum requirement for facility allocation. The service area is delineated based on the facilities' service radius, and the ratio of this area to the life circle area is calculated as the coverage rate. Regarding service effectiveness, UNA, a refined spatial analysis tool, is utilized to evaluate the effectiveness of resource allocation. UNA allows for assigning additional weights to buildings based on specific characteristics, providing more accurate and reliable results for design. In this study, Gravity is used as an indicator. This indicator considers spatial distance decay and enables the assignment of weights to buildings to represent different network characteristics. It is one of the most commonly used measures in UNA analysis. The formula is as follows:

$$Gravity[i]^r = \sum_{j \in G-\{i\}, d[i,j] \leq r} \frac{W[j]}{e^{\beta - d[i,j]}}$$

$Gravity[i]^r$ is the gravity index of building i on graph G within a search radius r. $W[j]$ is the weight of destination j. $d[i,j]$ is the shortest path between i and j. β is the exponent adjusting the distance influence.

In the specific calculation process, the evaluation is based on street network data, and the weight of the total building area is used to measure the population served. The gravity values of various types of facilities are calculated in relation to their surroundings, and the increase in gravity compared to the average gravity of existing facilities is used to predict their service performance.

Finally, an evaluation of commercial facilities is conducted, primarily by combining data from Meituan. Meituan data is updated by businesses themselves, providing accurate and timely information. It covers a wide range of store attributes, including service level, operating hours, and average consumer spending. This data supports detailed research. Using the UNA tool, gravity is calculated for different dimensions and categories, similar to the assessment of service effectiveness in basic public services, to predict the commercial performance through comparison of the increase.

RESULTS AND DISCUSSIONS

This study takes the Jingnan life circle in Pudong New Area, Shanghai as an example. The area consists mostly of residential communities of different grades, with distinct characteristics in facility distribution. The analysis aims to enhance the service level and vitality of the area by examining the corresponding facility allocation.

Analysis of user portraits based on LBS data

Through data cleaning and statistics of LBS data, the study summarizes the overall analysis of population characteristics into four charts (Figure 2), which can infer the main target groups and their needs in the Jingnan life circle. The analysis of residents' consumption levels shows that the income structure of the population in this life circle is relatively complete, with a slightly higher proportion of middle to high consumption level individuals. In terms of age composition, middle-aged people make up the majority, and there is also a significant proportion of people over 60 years old, close to 10%. In terms of residency and occupation, around 70% of the population resides in this life circle, occupying a considerable proportion. Additionally, over 50% of the population works in this life circle. The above analysis obtained the user profile within the scope of this study, providing a basis for the customized strategy of functional composition.

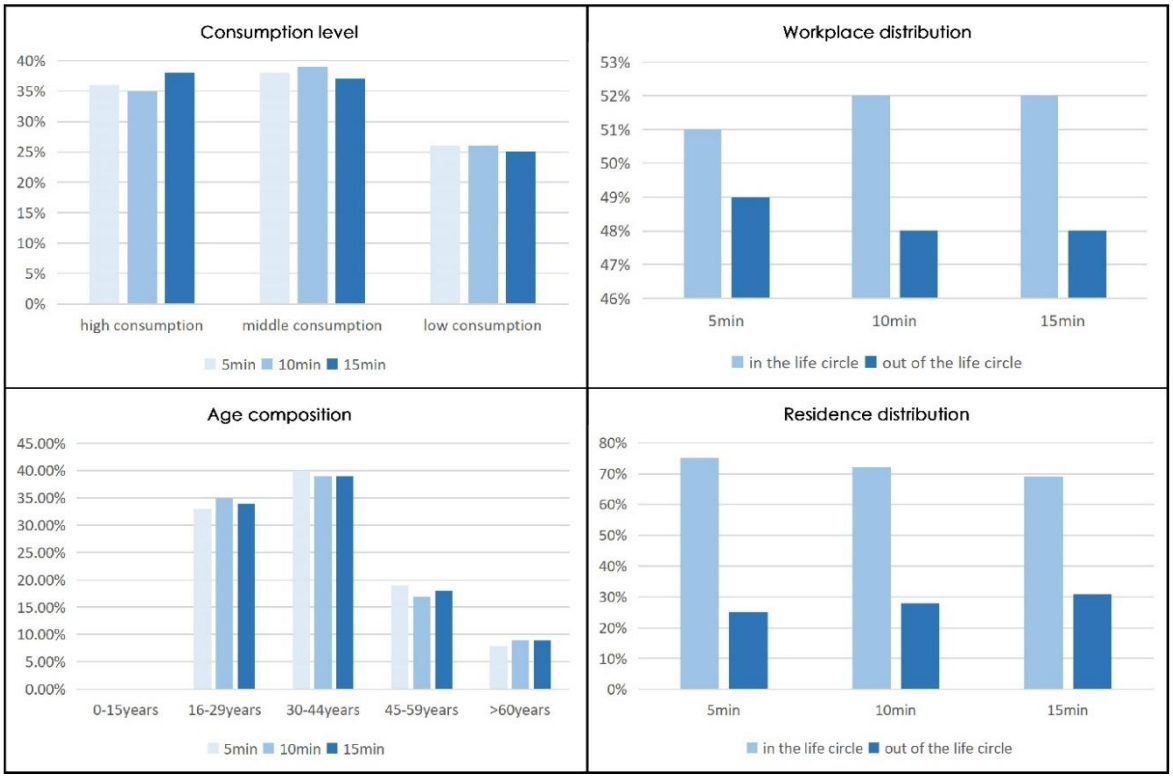

Figure 2. *User portraits analysis based on LBS data.*

Analysis of coverage and service effectiveness of public service facilities based on POIs data

The evaluation of public service facilities involves calculating coverage (Figure 3) and predicting service effectiveness (Figure 4). The coverage measurement reveals that government institutions, training institutions, fitness venues, and hospital clinics have high coverage rates and well-established configurations in the three research areas. Social group facilities and elderly activity rooms have low coverage rates in these areas. Although childcare facilities have high coverage rates, there are still some gaps within the 10-minute radius. The coverage rates of cultural activity facilities and healthcare facilities decrease as the radius extends from 5 minutes to 15 minutes.

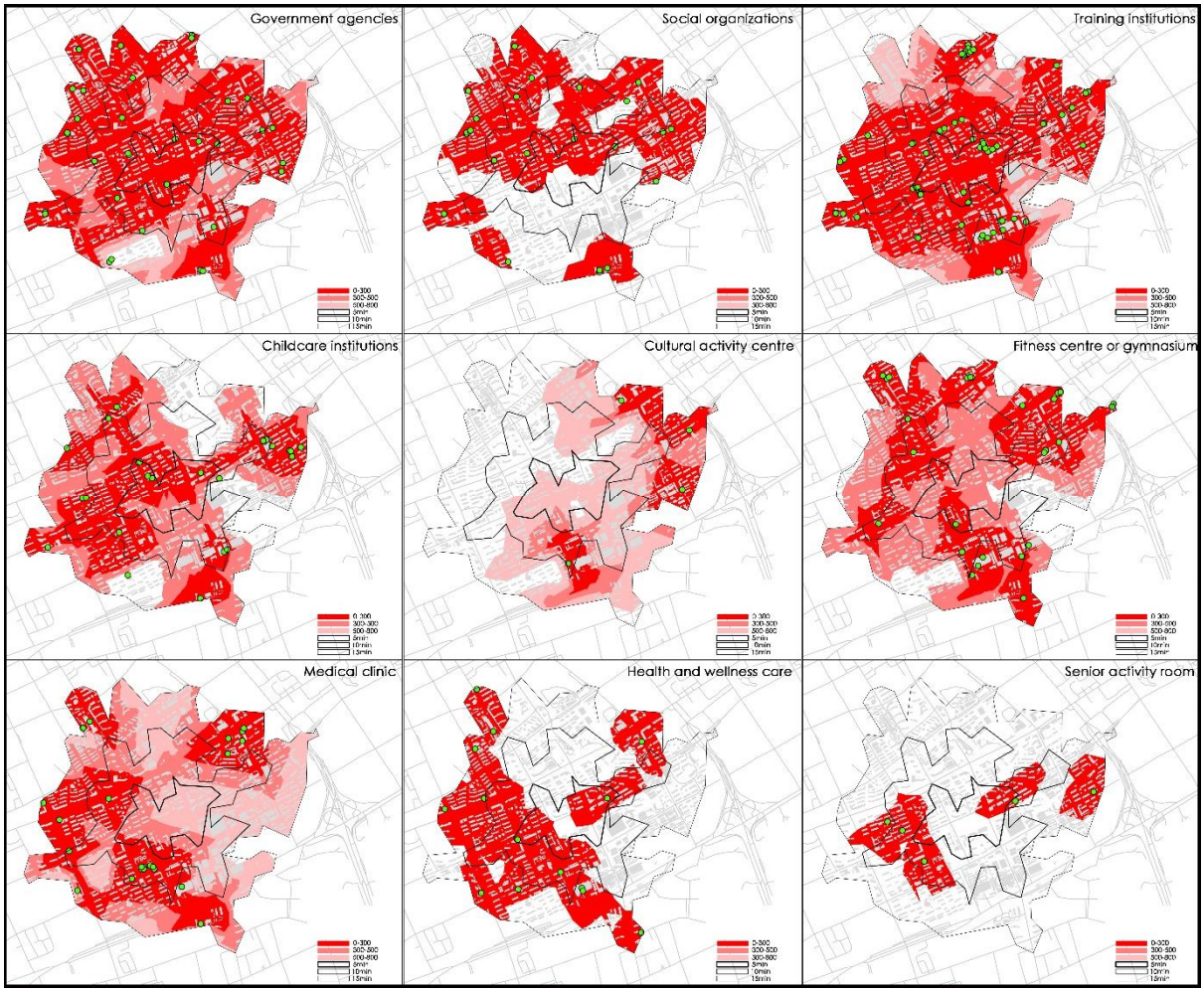

Figure 3. *Coverage analysis of public service facilities.*

The service effectiveness measurement was conducted using the UNA tool. This study found that facility types with relatively significant service benefits include government institutions, cultural activity centres, and social groups. Training institutions, healthcare facilities, and elderly activity rooms follow closely behind. Additionally, childcare facilities and fitness venues also demonstrate some improvement in service effectiveness compared to existing facilities.

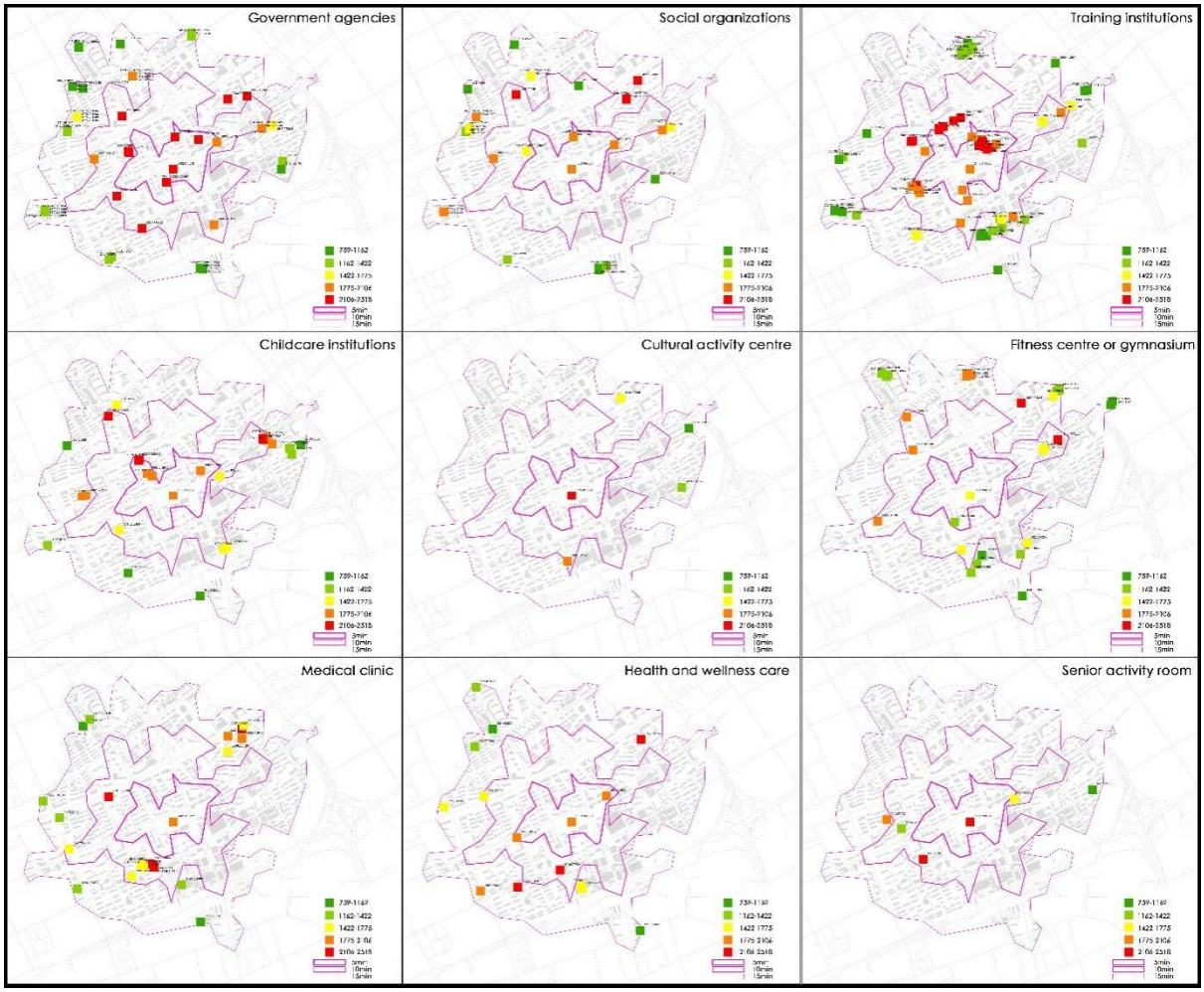

Figure 4. *Service effectiveness analysis of public service facilities.*

Analysis of business characteristics of commercial facilities based on Meituan data

The study conducted analysis and prediction of the operational status of commercial facilities within the life circle by cleaning the Meituan data and using the UNA tool for gravity measurement. The findings reveal that convenience services have the largest proportion of commercial facilities within the research area, followed by dining options, indicating a vibrant overall living atmosphere. Gravity analysis of customer prices, store ratings, and operating hours shows that commercial facilities within the price ranges of 1 to 100 yuan and 5000 to 10000 yuan demonstrate higher predicted effectiveness in service efficiency. However, existing high-rated stores with ratings between 4.5 and 5 show insufficient service efficiency. In terms of operating hours, the existing facilities provide good coverage throughout the day, with no significant improvement in service efficiency observed across different time periods.

Assessment and recommendation of functional composition

The analysis results can be used to make preliminary recommendations for the development of various facilities, contributing to the creation of a more tailored, diverse, and user-friendly guide for configuring community centres within the life circle. For example, the user portrait reveals that it is crucial to adequately establish facilities for elderly care. In terms of public service facilities, the comprehensive assessment of coverage and effectiveness suggests that the optimization of social groups and cultural activity centres should be prioritized. Following this, health care and facilities for elderly activities should be given the next level of priority. For commercial aspect, if there are already a large number of convenient commercial facilities, businesses should consider whether this type of facility has reached saturation before entering the market. The analysis of business characteristics suggests that commercial facilities with a price range of 1-100 yuan and 5000-10000 yuan and high service levels would have promising prospects. The research framework proposed in this study for the functional composition of community centres within a 15-minute life circle is applicable universally, providing accurate and efficient support for analysis.

CONCLUSIONS

This study explores a research paradigm and approach for assessing and optimizing the functional composition of community centres in a more effective and generalizable manner. To address the limitations of previous analysis methods, this study combines multiple sources of urban data to analyze and evaluate the facilities and service targets of life circles from various perspectives. With the support of new spatial analysis technologies, such as UNA, it becomes possible to evaluate and predict the effectiveness of facilities at a more detailed level. The innovative application of these new data and technologies allows for the measurement of previously "unmeasurable" aspects and provides technical support for assessing and optimizing the functional composition of community centres.

Within the context of creating a 15-minute life circle, the evaluation and optimization method proposed in this study enables the development of basic public services and commercial facilities in a more refined, diversified, and customized manner. By promoting this method, stakeholders can find the optimal solution for configuring the functions of community centres, and it can also assist the government in formulating normative indicators. Through collaboration in creating a 15-minute life circle, the integration of multiple sources of urban data and quantitative morphological tools demonstrates its enormous potential in fine-scale urban analysis.

However, this study has certain limitations. Further research is needed to refine the classification of facilities and determine appropriate service radii. Additionally, the data used in this study can be further optimized. For example, the third-party-provided LBS data lacks personal information for children without mobile devices. Lastly, this analysis focuses on evaluating facilities based on the established location of community centres and does not involve tasks such as site optimization. Therefore, the next research direction should be the establishment of a data-informed decision-making system for the entire process of community centres and life circles.

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