https://doi.org/10.15302/J-LAF-1-020093 Received Date | 2024-02-18 Accepted Date | 2024-04-24

Research on Time-Division Multiplexing Planning and Design Strategies for Parking Lots Under the Theory of Compact Cities

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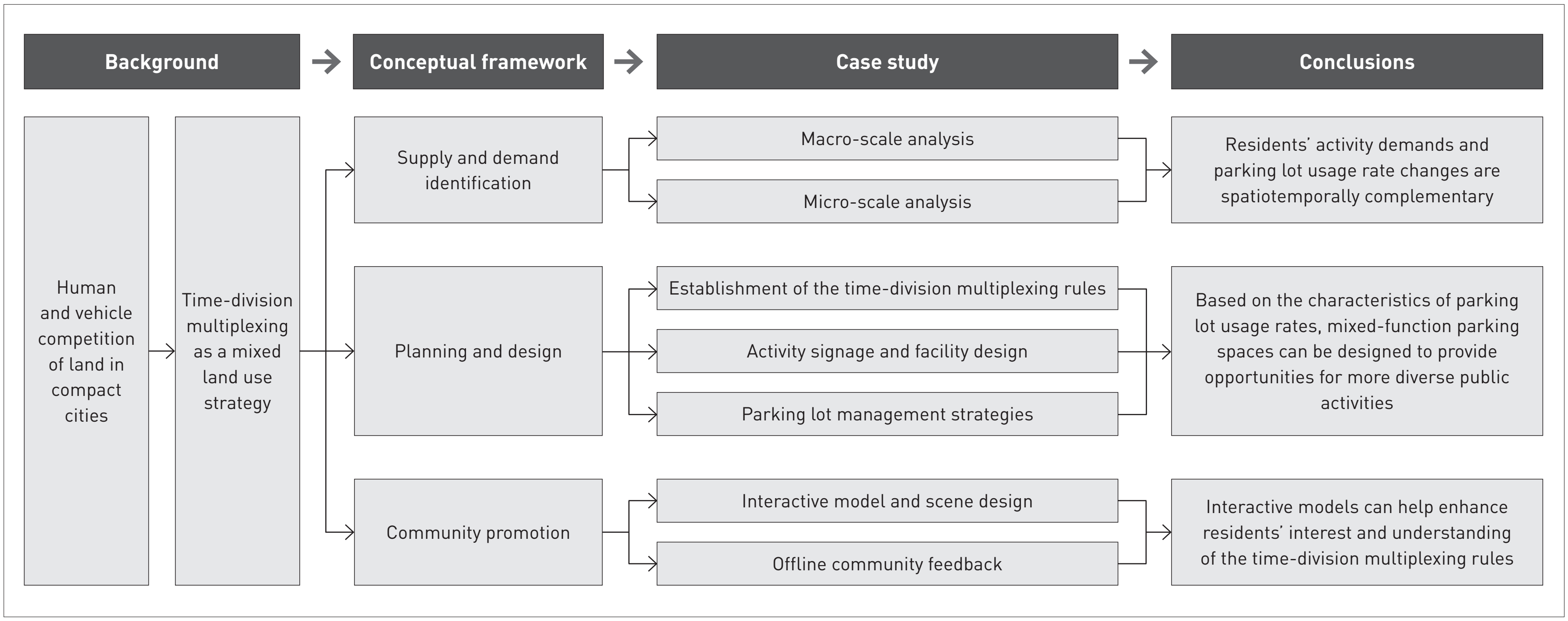
GRAPHICAL ABSTRACT



ABSTRACT

In compact cities, one of the main challenges is the competition for limited urban land resources between people and vehicles, where shared parking infrastructure may offer a potential solution. Building on existing literature, this study presents a technical framework for the time-division multiplexing strategy of transportation infrastructure, and explores its application in an old central urban area in China as a case study. This strategy includes three main steps: supply and demand identification, planning and design, and community promotion. Firstly, from macro to micro scales, identify characteristics of parking lots' usage rates and the public activity demands based on mobile signaling data and field survey results. Secondly, develop the time-division multiplexing rules for parking lots according to the above characteristics and detailed spatial planning and design schemes. Finally, design an interactive model

that can provide the public's real-time feedback to ensure effective implementation of the schemes by guiding public behavior. Grounded in compact city theories, this approach extends spatial land use limitations by introducing a temporal dimension. By blending big data coverage with field surveys and interviews, and integrating planning and design with public participation, this study offers an effective solution to urban conflicts between people and vehicles.

KEYWORDS

Time-Division Multiplexing; Parking Lots; Digital Empowerment; Mobile Signaling; Planning and Design; Public Participation

HIGHLIGHTS

- Focuses on time-division multiplexing strategies to address people and vehicle conflict by optimizing the use of limited space over time
- Develops a three-step time-division multiplexing strategy for parking lots, including supply and demand identification, planning and design, and community promotion
- Identifies the spatiotemporal characteristics of residents' activity demands and parking needs with mobile signaling data and field survey results
- Proposes a mixed-function design method based on the characteristics of parking lot usage rate
- Highlights the features and advantages of interactive models in promoting these rules to the public

EDITED BY Ying WANG, Tina TIAN

1 Introduction

1.1 Land Use Conflict Between People and Vehicles in Compact Cities

Compact city is an urban planning strategy aimed at promoting environmental, economic, and social sustainability through spatial configurations featured with relatively high density and mixed land use.[1][2] However, the dense spatial layout exacerbates the competition between people and vehicles for limited urban land resources, a contradiction that has not been alleviated by advocating for prioritizing the development of public transportation. In fact, the experience of developed countries suggest that the growth in car ownership and dependence on cars are difficult to mitigate through the development of public transportation[2], as car travel has the irreplaceable advantage of flexibility[3]. Meanwhile, the continuous growth in car ownership forces cities to construct more static transportation facilities such as parking lots[4], squeezing the activity spaces of residents and consequently giving rise to a series of efficiency and equity issues. For instance, a limited number of concentrated urban parks are insufficient to meet the widespread demand among citizens for open spaces[1][5]~[7], while the uneven distribution of service facilities also affects the realization of social equity[8]. Thus, the conflict between people and vehicles in compact cities is increasingly prominent and urgently needs to be addressed.

1.2 Time-division Multiplexing as a Mixed Land Use Strategy

Time-division multiplexing (TDM), originally a term from the field of information and communication engineering, refers to the technique of transmitting multiple signals over the same communication channel in different time slots[9]. Compared to allocating multiple channel spaces, the TDM strategy saves valuable channel resources by finely planning the same channel in the time dimension. This concept provides inspiration for spatial utilization in compact cities. Traditional mixed land-use strategies (including horizontal mix within streets or communities, and vertical mix within individual buildings) focus on the space itself[10]. However, spaces nowadays can accommodate a variety of daily activities due to their increasing fluidity[11]. Therefore, based on the TDM concept, planning and design that considers the varying time distribution of different activities might be conducive to the mixed use of urban spaces.

In fact, the utilization of land resources for parking infrastructure in a TDM way has been a widespread spontaneous phenomenon to some extent. For instance, Eran Ben-Joseph et al. found that parking lots in American cities often host spontaneous activities such as ball games, concerts, and camping[12]. The PARK(ing) Day event, initiated by the Rebar Art and Design Studio globally, temporarily converts street parking spaces into small parks to advocate for more public open spaces[12][13]. Scholars have also conducted planning strategy studies on idle parking lots, including the combined function design of parking spaces[14] and multifunctional planning of parking spaces under elevated highways[15]. With the development of sharing economy, the TDM-based land use has become a planning strategy that embodies social equity and maximizes resource utilization, enabling more stakeholders to benefit from limited land resources.[16][17]

1.3 Literature Review and Research Question Definition

Although scholars have explored the multifunctional and composite use of compact urban spaces in the temporal dimension, most existing studies are limited to qualitative descriptions of phenomena and specific spatial designs. They often overlook the preliminary supply and demand identification and subsequent implementation management, and thus have yet to develop a systematic technical pathway for TDM planning and design of spaces.

Firstly, existing literature on the TDM planning and design of parking lots generally does not explore how to effectively identify potential parking spaces that can accommodate public activities. In recent years, technological development such as mobile positioning has facilitated the precise detection of dynamic geographical characteristics of urban populations and vehicles, providing technical support for discovering such spaces[18]. On the one hand, geospatial big data can record and identify the spatiotemporal patterns of human activities based on the relationship between activities and the environment[19]~[22]. On the other hand, advancements in sensor systems enable fundamental improvement of methods in assessing and monitoring infrastructure status[23]. Thanks to the deployment of the Internet of Things and large-scale urban sensor networks, individuals with smartphones have become "sensors" of urban dynamics[11]. Urban planners and designers can identify the spatiotemporal distribution patterns of people and vehicles through mobile signaling data, thereby discovering urban spaces with TDM potential.

Secondly, some literature proposes specific design methods for multifunctional mixed-use parking lots. For instance, Ben-Joseph suggested meeting public activity needs by installing basketball hoops, setting up temporary stages, and adding movable chairs[12]; Yanhong Hu proposed to generate design plans of multifunctional parking lots considering the correlation between the parking function and other functions (such as car charging, car grooming, and commercial leisure)[14]. However, these solutions are limited to the spaces themselves and lack resonance with the broader urban spatial structure. To better achieve the TDM planning and design of parking lots at the urban scale, planners should consider both the usage situation of parking lots and the recreational demand of residents, ensuring a practical match between spatial supply and demand.

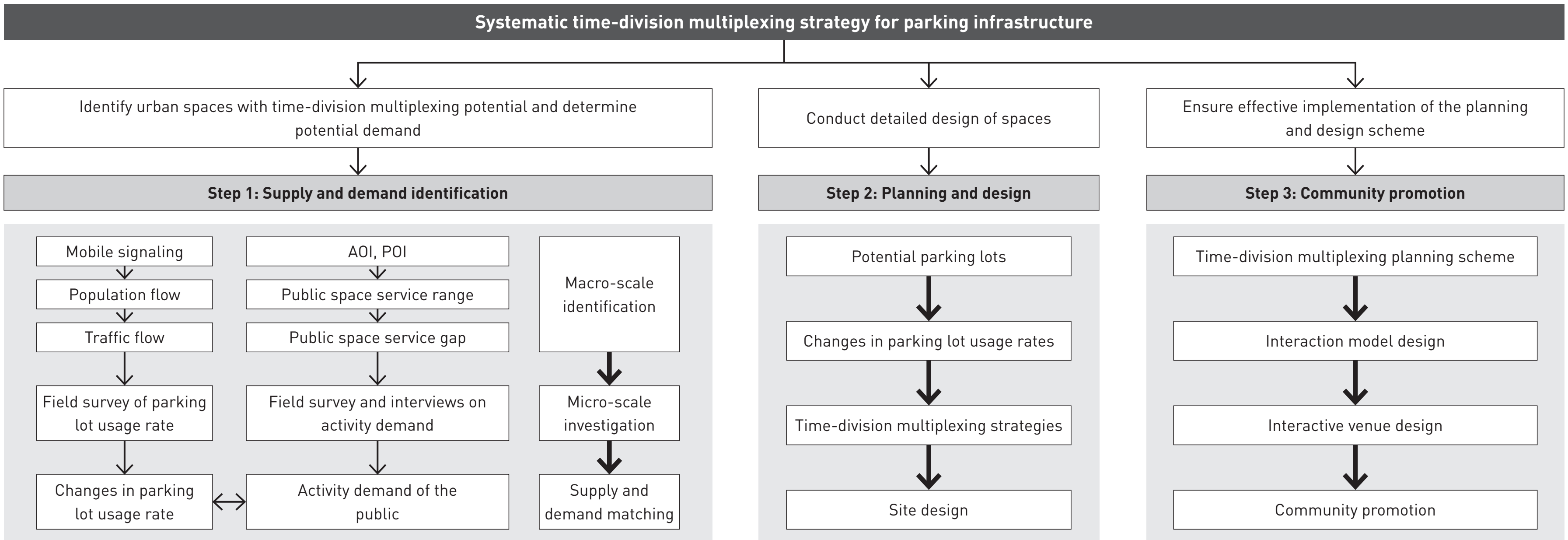
Thirdly, TDM planning and design essentially depends on the concept of sharing and spatiotemporal characteristics of user behavior[16]. Its successful implementation ultimately relies on the self-management of urban residents, for which it is necessary to introduce appropriate public participation to avoid purely top-down technical logic. Research indicates that interactive forms of public participation (with interactive models, workshops[24]) are more effective, where gamified approaches to participation are gradually becoming an important concept. Games are not just for entertainment, but with clear educational purposes that can encourage user engagement and promote the planning process[25]. Therefore, interactive and gamified forms of public participation can effectively support the implementation of TDM planning and design strategies.

Thus, to provide references for the TDM planning and design of parking lots in compact cities, this study aims to address the following questions: How to identify urban spaces with TDM potential and determine potential demand? How to achieve it through detailed design of spaces? And, how to ensure effective implementation of the planning and design scheme with gamified public participation?

2 Conceptual Framework for TDM Planning and Design of Urban Parking Space

The TDM planning and design strategies for urban spaces need to comprehensively consider the usage demands of different groups at different time frames, requiring both technical expertise and practical logic. The conceptual framework proposed in this study comprises three stages of supply and demand identification, planning and design, and community engagement. The key steps include identifying idle parking spaces and potential public activity needs, designing spaces tailored to specific activity needs, and increasing public acceptance through promotion (Fig. 1).

Firstly, in the stage of supply and demand identification, utilize spatiotemporal big data such as mobile signaling to characterize changes of the overall population flow in urban spaces. This can help identify areas with significant variations in the flow and assess the vacancy status of parking spaces. Simultaneously, analyze the coverage area of urban public space services with AOI (Area of Interest) and POI (Point of Interest) data that can represent urban functions. By combining the idle time and spatial distribution characteristics of parking spaces with the service range of existing public spaces, areas where the TDM planning and design of parking lots can meet public activity needs will be identified. Subsequently, micro-scale field surveys can be conducted to further confirm the



1. Technical roadmap.

specific vacancy status of potential parking lots and the activity needs of the corresponding population. Secondly, in the planning and design stage, specific planning and design are carried out for potential parking lots based on the above results. Through approaches such as spatial transformation, installation of activity facilities, and signage design, attractive multifunctional usage scenes will be created. In the last stage, TDM rules formed in the design proposal will be converted into interactive models, basing on site conditions. Corresponding interactive scenes are designed for proposal promotion and application within the community.

In summary, the conceptual framework utilizes digital technology to identify the objects of planning and design, while promoting the implementation of the plan through public participation and interaction. This forms a systematic planning strategy for the TDM design of parking lots.

3 Case Study

This study focuses on a high-density built environment in the central urban area of a city in China. The region, characterized by its long-established development, dense buildings, and high population, is part of the old central urban area, covering approximately 2.65 km^2 and containing 50 surface public parking lots. Due to insufficient underground space and a large number of daily visitors from the outskirts or other cities, the municipal government issued a special plan for parking facilities in 2018, significantly increasing the number of surface public parking lots. This has resulted in a shortage of activity space for residents in the area and strained the relationship between pedestrians and vehicles.

3.1 Integrating Digital Technology and Field Survey Research for Supply and Demand Identification

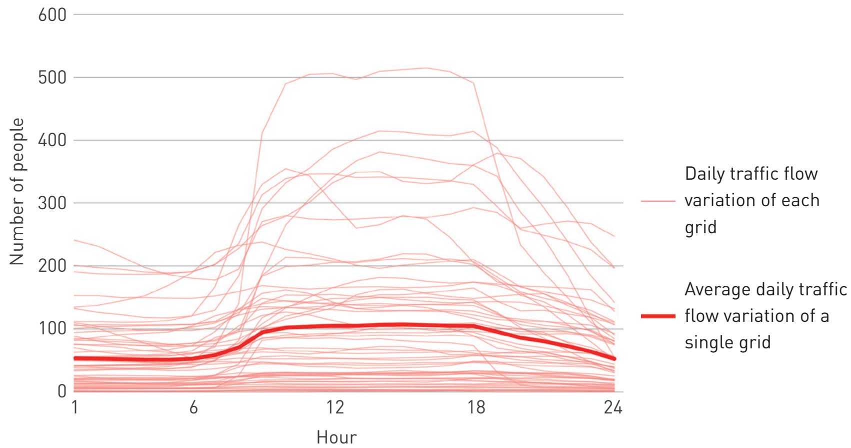
3.1.1 Potential Spaces for TDM Planning and Design and Gaps in Public Space Demand at the Macro Scale

At the urban scale, this study first utilized mobile signaling data extracted from China Unicom (August 2019) with a precision of 250 meters to detect areas with significant daily flow variations. Based on the characteristic scale of such data, we further divided the research area into 59 grids with a side length of 250 meters, obtaining the 24-hour mobile positioning data for each grid. Overall, each grid exhibited a high flow during the day and low flow at night (Fig. 2). With the standard deviation and mean of these positioning data, the coefficient of variation, representing the degree of flow variation in each grid, can be defined:

$$CV = \frac{S}{\bar{x}} \times 100\%,$$

where CV represents the coefficient of variation, S represents the standard deviation, and $\bar{x}$ represents the mean.

CV is a value greater than zero, where a larger value indicates greater dispersion among the data[26]. Its application mainly



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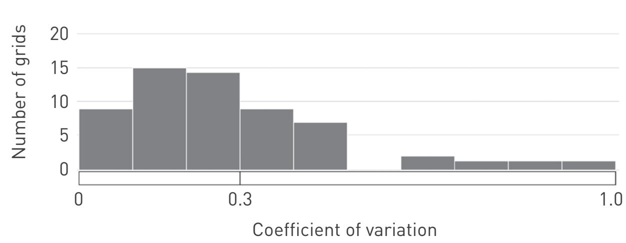

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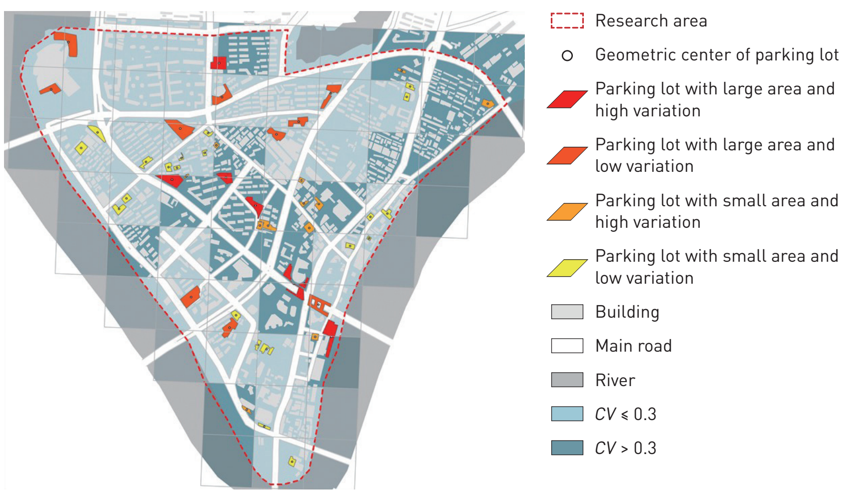
2. Changes of population flow by mobile signaling in the study area.
3. Histogram of the coefficient of variation for grids in the study area.
4. Identification of the TDM potential of parking lots.
5. Identification of insufficiency of public spaces.

involves comparing the differences in flow changes between different areas[27]. Based on the coefficient of variation data of the grids within the research area, it was regarded as high if exceeds 0.3, and low otherwise (Fig. 3). A high value implies significant higher fluctuations in population flow within the grid, while a low value for minor fluctuations. Furthermore, considering the overall characteristic of daytime flow exceeding nighttime flow within the research area, a high coefficient of variation might show higher daytime flow and lower nighttime flow within the grid, indicating a large influx of people during the day and a significant outflow at night. As traffic flow is generated based on population movement, many studies utilize traffic data, like card swipe data and bicycle data, to reflect the flow of people in cities[28][29]. Thus, this study inferred that the vehicle flow in the research area exhibited similar variation characteristics to the population flow. Therefore, the coefficient of variation of the grid where the geometric centroid of a parking lot was located was taken as the coefficient of variation of the parking lot, representing the fluctuation in its usage rate.

In addition, the TDM potential of parking lots is also related to their own area size. Using the average area size of parking lots within the research area (2,058 m^2) to distinguish between large and small areas, combined with the coefficient of variation, this research categorized four types of parking lots' TDM potential, i.e., large area with high variation, large area with low variation, small area with high variation, and small area with low variation (Fig. 4).

Within the research area, most public spaces are located in the peripheral waterfront areas, while those in the central area are relatively scarce (Fig. 5). Based on the 500-meter service radius requirement for urban community parks[30], this study divided residential areas into two categories: those located outside the 500-meter service range (lacking highly accessible public spaces) and those within the service range (having highly accessible public spaces). Results revealed that the spatial overlap between the public space gap and the TDM potential spaces is mainly concentrated in the central part of the research area. This further



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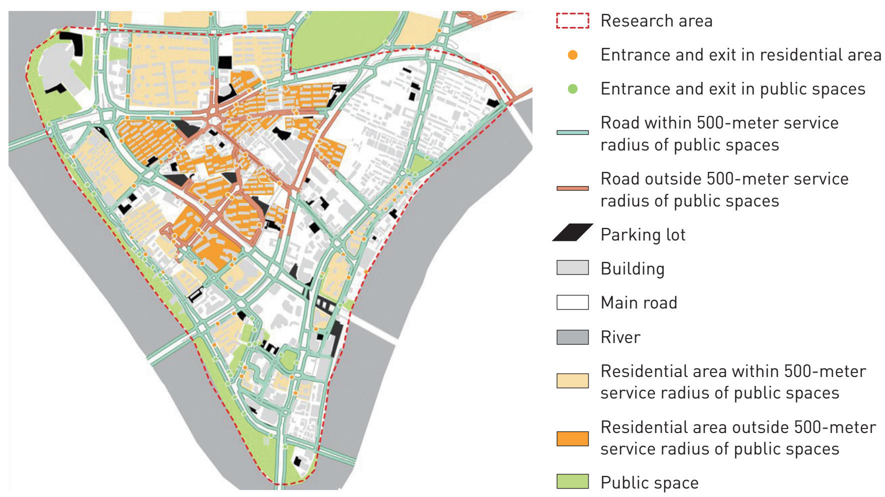

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highlights the rationale for using TDM parking lots to supplement the insufficiency of public spaces.

3.1.2 Analysis of Parking Lots' TDM Potential and Residents' Activity Demands at the Micro Scale

Based on the supply and demand characteristics identified at the macro scale, this study selected three large area–high variation public parking lots (Parking Lots A, B, and C, Table 1) in the center of the research area, which are located outside the 500-meter service range of public spaces, for micro-scale site surveys. This includes a more detailed analysis of moment-by-moment changes in parking lot usage rates and characteristics of human activities at different times. The survey was conducted on October 16 ~ 19, 2019, including both weekdays and the weekend.

The results showed that only Parking Lot B maintained high usage rates on both weekdays and weekends, whereas Parking Lots A and C had high usage rates only during daytime hours (08:00 ~ 16:00) on weekdays, exhibiting a clear tidal pattern (Fig. 6). For instance, in Parking Lot A, the usage rate reached 100% at 09:00 on weekdays, began to decline around 19:00, and dropped below 15% after 22:00. While its usage rates on the weekend were generally lower than those on weekdays, dropping to less than 25% around 19:00 and approaching 12% after 22:00.

The survey also found recreational activities spontaneously organized by residents in these parking lots. For example, before 07:00 and after 18:00 on weekdays, nearby residents would use Parking Lot A for walking and exercising; Parking Lot C, adjacent to old communities, also sees residents participating in public activities throughout the day, not just in the early morning and evening. Moreover, the research team conducted random interviews with residents using the parking lots to understand their daily usage pattern and their demands for public activities. On October 17, 2019, the team held a community forum, inviting 20 long-term residents or workers with observations and insights into urban space use to discuss the TDM potential of parking lots. Feedback indicated that due to the scarcity of parks and squares in this area, residents using parking lots for morning exercising and walking had become routine. Their use of the parking lots mainly occurred in the early morning and evening, when they had more free time and there were fewer vehicles. This implied that in terms of the temporal dimension, the change in residents' activity demands and the usage rate of parking lots were complementary, suggesting that TDM parking spaces can supplement the gap in public spaces.

6. Changes in parking lot usage rates.

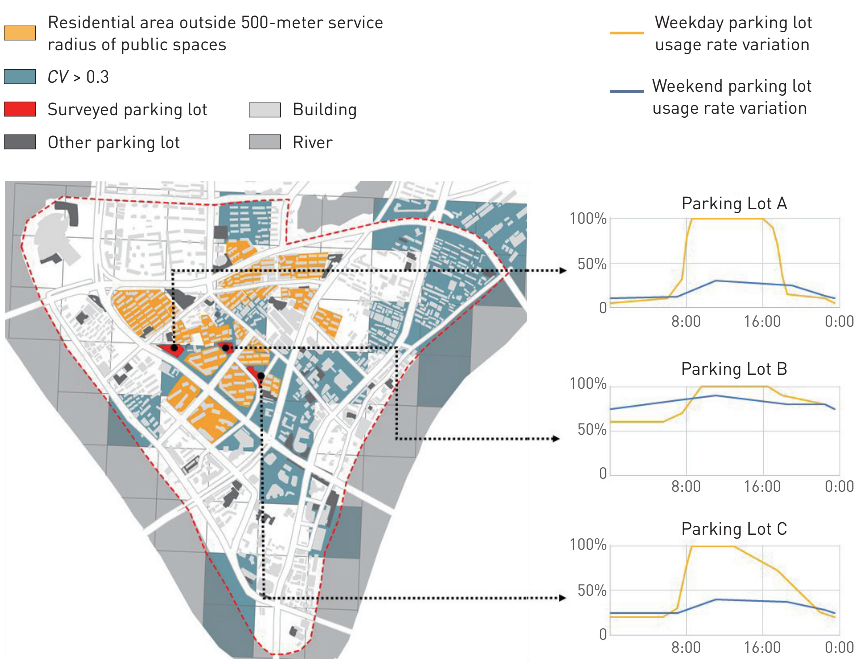

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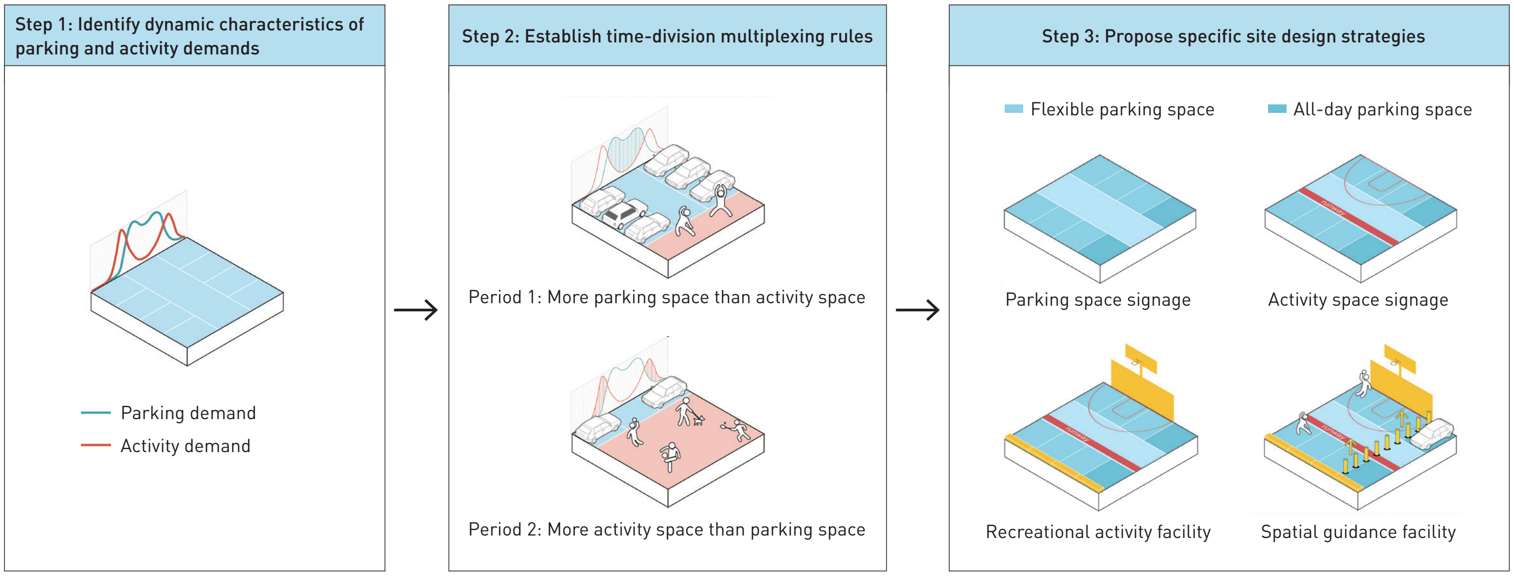
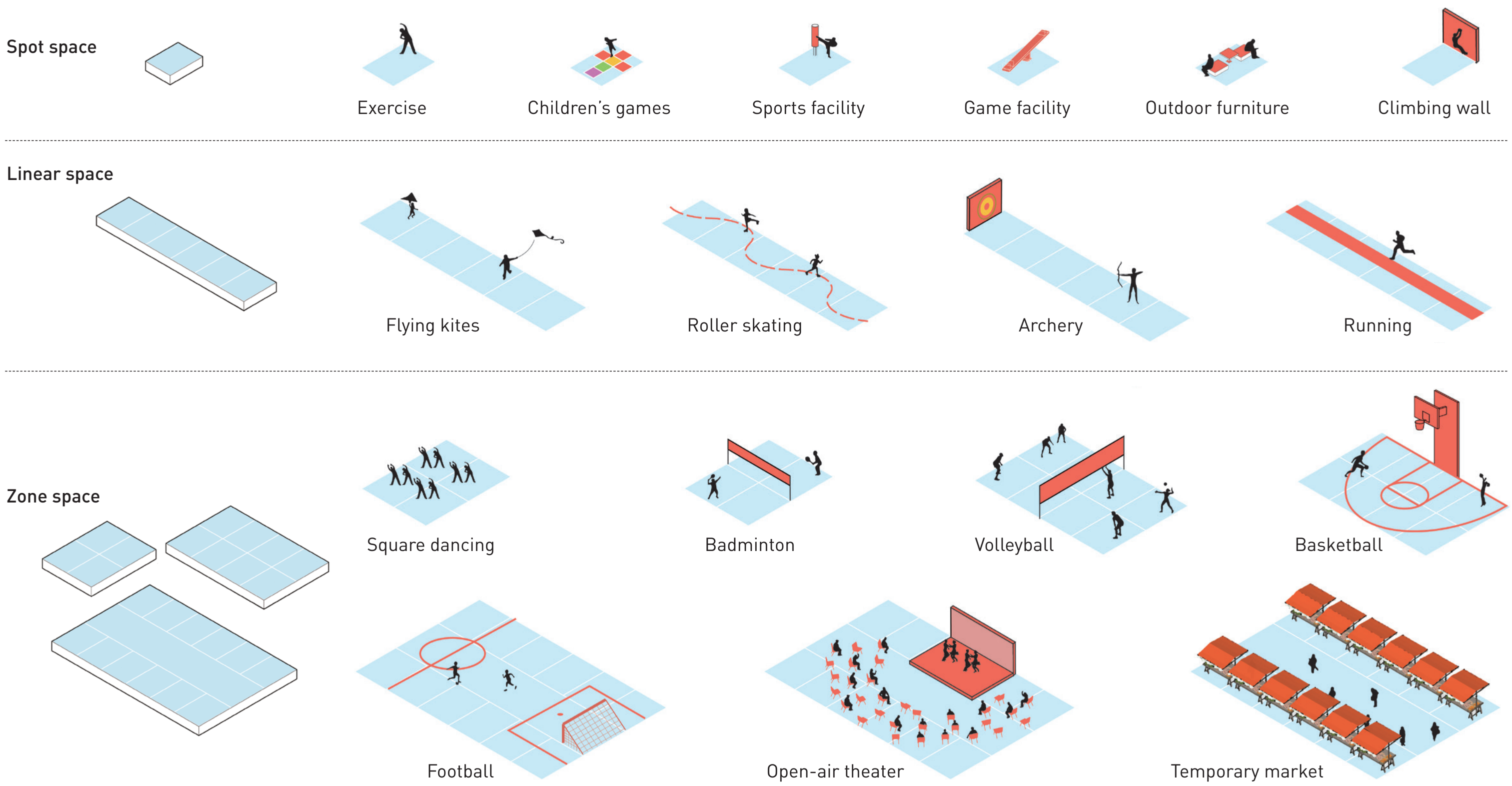
Table 1: Specific information of parking lots

Name	Area (m^2)	Green space ratio	Open Form	Parking spot number	Manager
Parking Lot A	4,810	43%	Ground, public	119	District government
Parking Lot B	2,930	2%	Ground, public	100	District government
Parking Lot C	3,350	12%	Ground, public	115	Property management company

3.2 Planning and Design Strategies for TDM Parking Lots

This study further took Parking Lot A as an example to propose a set of TDM rules based on the dynamic characteristics of parking lot usage rate and residents' activity demand. Through planning methods, the parking lot can function as both a parking space and an activity space in appropriate times. For safety reasons, when parking demand is low and residents' activity demand is high, the parking space can be allocated to serve residents' activities. Conversely, when the parking demand is high, the activity space can be reduced or even eliminated. Finally, it is vital to ensure



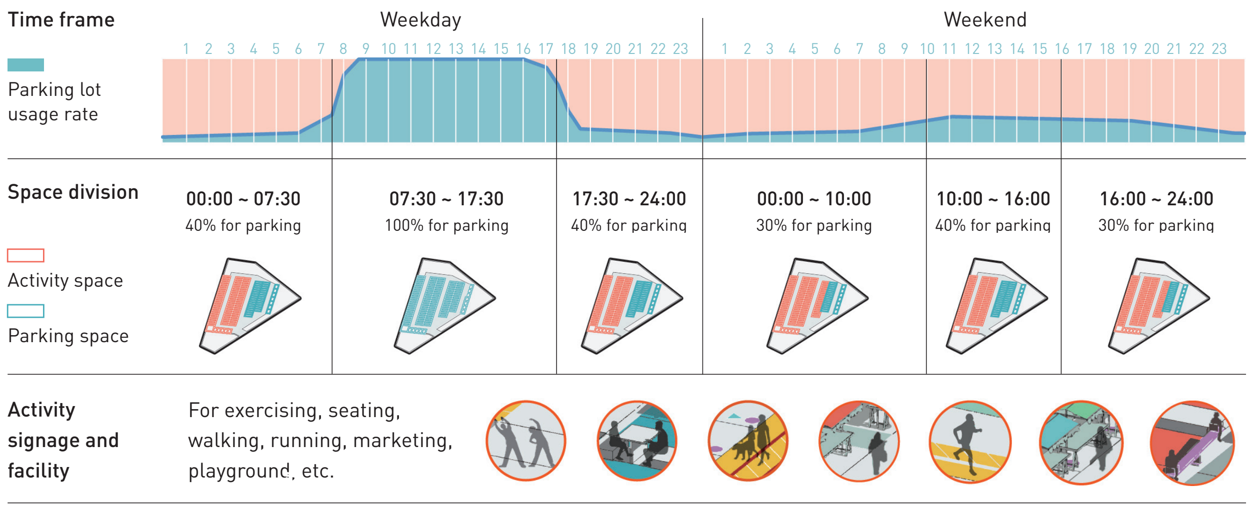


7. An example of the planning and design strategies.
8. Design modules for activity signage and facilities.

the implementation of the TDM strategies based on the spatial characteristics of the parking lot and with the assistance of corresponding guidance facilities (Fig. 7).

Design of the parking signage needs to both delineate neatly arranged parking spaces in accordance with relevant regulations and classify spaces into two types (all-day parking lots and flexible parking lots) based on the extent of conversion between parking and activity spaces. Notably, the all-day parking lots are exclusively for vehicle parking at all times, while the flexible parking lots serve both parking and activity functions, with the mixed-use ratio varying according to the usage rate characteristics of different parking lots.

Activity signage and facilities can guide and emphasize potential activities within the parking lots. Based on the size of the parking spaces, this study proposed a series of activity design modules in varied spot, linear, and zone spaces (Fig. 8). Different colors, lines,



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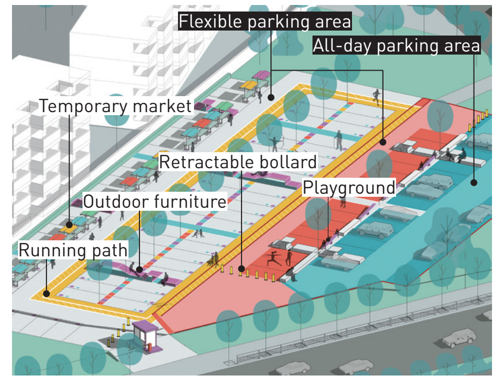

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9. TDM rules for Parking Lot A.
10. Design plan for Parking Lot A.

and geometric shapes in the activity signage can guide site locations and differentiate activities, such as marking tracks or children's play patterns. The selection and placement of activity facilities should not interfere with parking, such as placing basketball stands, sandbags, and fitness equipment outside the parking path. Additionally, collective public activities like morning, night, and flea markets can be introduced. To ensure safety during these activities, retractable bollards can help clearly separate activity spaces from parking spaces. Meanwhile, related managers need to guide and regulate activities, or introduce a reservation system to reasonably schedule usage times and the number of participants.

Based on the aforementioned design strategies, the study divided TDM periods for Parking Lot A according to the weekday and weekend usage rates: first determining the parking space to be reserved in each period and the corresponding spatial allocation mode, then designing activity signage and arranging activity facilities based on the current demand and surrounding land characteristics (Fig. 9). Three types of mixed functions were designed for Parking Lot A: 1) the entire space used for parking on weekdays (07:30 ~ 17:30); 2) 40% of the parking area retained during the weekday mornings and nights (17:30 ~ 07:30 of the next day), and during the daytime on weekends (10:00 ~ 16:00); 3) 30% of the area reserved for parking on weekend mornings and nights (16:00 ~ 10:00 of the next day). In the next step, the team divided the parking area into three parallel spaces based on the spatial characteristics, one for all-day parking lots and two for flexible parking lots to carry different functions. According to the survey results, nearby residents have needs for jogging, exercising, etc., so track elements can be introduced into the parking space, with space left for placing benches and exercise facilities (Fig. 10). On weekends, when most of the parking space is idle in Parking Lot A, the management can consider collaboration with commercial operators to use the freed-up space for larger-scale market activities.

3.3 Gamified Community Promotion Based on Public Participation

After the planning and design of TDM parking lots, it is also necessary to guide public behavior to ensure its implementation. For this purpose, the research team designed an interactive model equipped with circuitry. The materials used in this model include wooden boards, LEDs, breadboards, and DuPont wires.

In Parking Lot A, for example, the interactive model included six small models with the same appearance, representing the six time periods of weekdays and weekends. These models were equipped with different sensing circuits according to the TDM rules, as well as small accessories with sensing circuits representing different user groups such as drivers, residents, and stall keepers. People can place these accessories according to the TDM rules. If they meet the space usage requirements for that time period, the top of the accessory will light up green; otherwise, it will light up red.

The gamified community promotion primarily serves two functions. First, unlike traditional display boards, the form of a physical interactive model can attract higher public attention. Second, through real-time game interaction, the public can quickly grasp the TDM rules for the parking lot. The research team found that during the interaction, even without explanation, the public could quickly understand the rules through the real-time feedback of red and green lights, thereby comprehending the effect and significance of these TDM parking lots (Fig. 11).

4 Discussion and Conclusions

This study takes parking lots as an example to propose a TDM strategy for compact urban spaces, mainly through steps of supply and demand identification, planning and design, and community engagement. In the first phase, it reveals the spatiotemporal complementary characteristics between residents' activity needs and parking lot usage rates. In the second phase, a mixed-function design method can be introduced based on the variation of parking lot usage rates. In the final phase, it emphasizes the role of interactive models in implementing the TDM rules. By integrating the temporal dimension, the TDM strategy overcomes the limitations of spatially mixed-use land resources, maximizing the efficient use of land. Overall, this strategy expands the functions of urban spaces like parking lots, alleviating the common issue of public space scarcity in compact cities[5][7] and providing a new approach to enhancing the urban operation fairness and efficiency[8].

The TDM strategy integrates theories related to digital empowerment and public participation, extending the planning and design issues of urban parking infrastructure from the design itself to the identification of supply and demand at the front end and its promotion and implementation at the back end, thus constructing a framework that balances scientific, technical, and social aspects. On the one hand, the data and technological empowerment of the information age can help planning and design professionals comprehensively and efficiently understand the spatiotemporal characteristics of urban parking spaces. On the other hand, due to the complexity of the built environment and the limitations of current big data's spatiotemporal resolution, planners and designers also need to adhere to field surveys, entering urban spaces to deeply analyze problems. Therefore, this study utilized the broad coverage advantage of big data to quickly identify a large number of underutilized urban spaces, while leveraging strengths of field research and interviews to clarify the specific idle situations of parking infrastructure and the activity demands of surrounding residents. Both of them provided substantial basis for subsequent planning and design. Notably, when implementing the TDM strategy, planners also need to consider guiding public behavior. The interactive model proposed in this study can enhance public understanding and acceptance of the planning and design schemes, encouraging them to provide appropriate feedback and adjustment suggestions, which helps increase the feasibility of the planning strategies.

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11. Public participation with the interactive model.

However, this study also has some limitations. Firstly, due to differences in urban parking lot management entities and parking data, the determination of parking lot usage rates mainly relied on population flow data and manual field surveys, rather than the electronic technology at parking entrances directly, resulting in a relatively complex technical process. This issue is expected to improve with the further standardization and systematization of smart city digital infrastructures. In terms of public participation, the interactive model can be developed into an online game combined with virtual reality technology to gather more feedback[31]. Due to limited conditions, this study failed to quantitatively evaluate the effectiveness of gamified community promotion and could only infer indirectly through the educational effect of public participation activities. Future research can optimize evaluation methods to further validate the effectiveness of the framework. Additionally, this study has certain application limitations as population movements exhibit strong randomness, inevitably leading to conflicts between public activity demands and parking needs. With the development of intelligent vehicles, drivers may be able to remotely move their vehicles to non-activity areas. Furthermore, the safety issues associated with coexisting activities and parking also require further in-depth research in spatial design, management, and operation.

Competing interests | The authors declare that they have no competing interests.

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https://doi.org/10.15302/J-LAF-1-020093 收稿日期 | 2024-02-18 录用日期 | 2024-04-24 中图分类号 | TU984.11+3, TN929.53 文献标识码 | A

紧凑城市理论下的停车场分时复用规划设计策略研究

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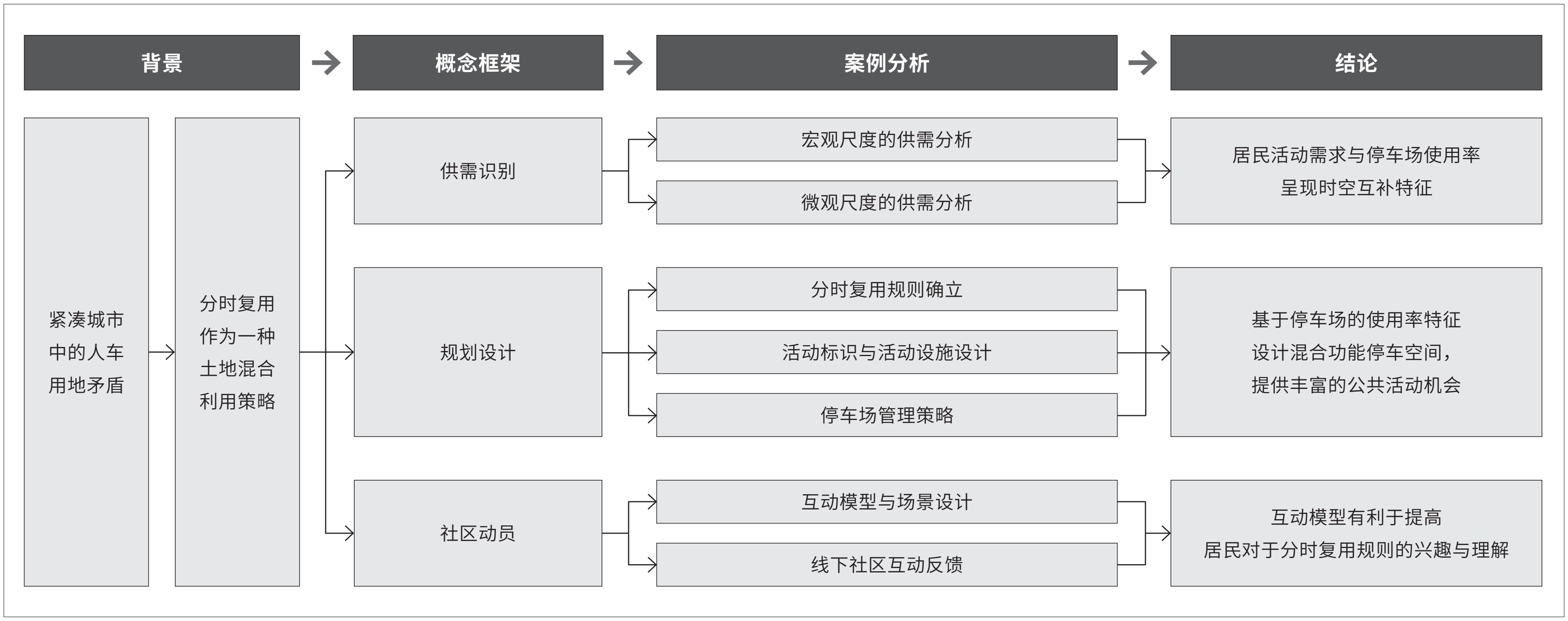
图文摘要



摘要

紧凑城市面临的一大主要问题是人与机动车对有限城市土地资源的争夺，而停车基础设施空间的共享使用有望调和这一矛盾。本研究在既有文献的基础上，提出了交通基础设施分时复用的技术框架，并以某地一处老旧城区为例展开应用探索。该系统性规划技术策略主要包括“供需识别－规划设计－社区动员”三大步骤：1）从宏观尺度到微观尺度，结合手机信令数据与实地调研数据，对停车场使用率和居民活动需求特征进行识别；2）基于上述特征制定分时复用规则，进行具体的空间规划设计；3）基于分时复用策略，设计具有实时反馈功能的互动模型，通过引导公众行为保证规划结果的有效实施。综上，本研究回应了土地在空间维度混合利用的局限性，从时间维度出发，结合大数据、实地调研与访谈等途径，融合规划设计和公共参与方法，为减缓城市中的人车矛盾提供了有效的解决思路。

关键词

分时复用；停车场；数字赋能；手机信令；规划设计；公共参与

文章亮点

- 聚焦分时复用策略，通过对有限空间在时间维度上的混合利用，回应人车矛盾问题
- 提出的停车场分时复用策略包括“供需识别－规划设计－社区动员”三个步骤
- 结合手机信令和实地调研，揭示了居民活动与停车需求的时空互补特征
- 提出了基于停车场使用率变化特征的混合功能设计方案
- 揭示了互动模型在停车场分时复用规则的公共传播中的特征与优势

编辑 王颖，田乐

1 引言

1.1 紧凑城市中的人车用地矛盾

紧凑城市是一种通过相对高密度及土地混合利用的空间配置来促进环境、经济和社会可持续发展的城市规划策略。[1][2]然而，紧凑的空间布局加剧了人与机动车对城市有限土地资源的竞争，这类矛盾并未因倡导优先发展公共交通而消除。事实上，发达国家的经验表明，汽车保有量的增长与汽车依赖问题难以通过公共交通的发展来缓解[2]，因为汽车出行具有难以取代的灵活性优势[3]。汽车保有量的不断增长迫使城市建设更多的停车场[4]等静态交通设施，挤压城市居民的活动空间，进而引发一系列效率和公平问题——例如，少数集中分布的城市公园难以满足市民对开放空间的广泛需求[1][5]~[7]，服务设施的不均衡分布也影响了社会公平的实现[8]。总的来说，紧凑城市中的人车矛盾日益凸显，亟待解决。

1.2 分时复用作为一种土地混合利用策略

“分时复用”原本是信息与通信工程学科的术语，指采用同一通信频道在不同的时间段传输多个信号的技术[9]。相比于开辟多个信道空间，分时复用策略对同一信道在时间维度上的精细规划节约了宝贵的信道资源，这种“以时间换空间”的理念为紧凑城市理念下的空间利用提供了启发。传统的土地混合利用策略（包括街道或社区内的横向混合、单个建筑物内的纵向混合）均着眼于空间维度本身[10]。然而，随着当代城市空间流动性的加快，同一空间承载了多种多样的生活内容[11]。因此，受启发于分时复用理念，倘若依据不同类型的活动所分布时间段的差异进行妥善规划，有望实现城市空间的多功能复用。

事实上，对停车基础设施用地资源的分时复用在一定程度上已成为当下一种广泛的自发现象。例如，伊兰·本—约瑟夫团队发现，美国城市中的停车场中常常出现球类运动、音乐会、露营等自发性活动[12]。Rebar艺术和设计工作室在全球范围内发起PARK（ing）Day活动——将街边停车位临时转化为小型公园——以呼吁开辟更多的公共开放空间[12][13]。亦有学者对闲置停车场进行了规划策略研究，包括停车空间的复合化设计研究[14]、高架桥下停车空间的多功能规划[15]等。在共享经济的背景下，土地的分时复用已经成为一种体现社会公平、实现资源最大化的规划策略，能让更多的利益相关者从有限的土地资源中受益。[16][17]

1.3 研究进展综述与研究问题界定

尽管已有学者探索了紧凑城市空间在时间维度上的多功能、复合化使用，但目前大多数研究仅限于定性的现象描述和具体的空间设计，而忽略了前期的供需识别及后期的实施管理等问题，尚未形成系统性的分时复用规划技术路径。

首先，现有关于停车场分时复用的文献普遍未探讨如何在城市范围内有效识别具有分时复用潜力的空间，即适宜开展公共活动的闲置空间。近年来移动定位等技术的发展推动了城市人口及机动车动态地理特征的精确检测，为上述潜力空间的发现提供了技术支持[18]。一方面，地理大数据能够基于活动和环境的关系记录并识别人群活动的时空规律[19]~[22]。另一方面，传感器系统的进步为从根本上改变基础设施的状态评估和监测方法提供了可能[23]。得益于物联网和城市大规模传感器的部署，拥有智能手机的个体成为了城市态势的“传感器”[11]，规划设计人员可通过手机信令等移动定位数据识别人群和车辆的时空分布规律，进而发现具有分时复用潜力的城市空间。

其次，虽然相关文献提出了一些具体的停车场多功能混合利用设计方法——如本—约瑟夫认为可通过在停车场安装篮球框、设立临时舞台、增加可移动椅子等方法满足公共活动的需要[12]，胡艳红强调基于停车功能与其他功能（如汽车充电、汽车美容、商业休闲）之间关联性的强弱程度，形成多种类型混合功能的设计[14]——但这些方案都局限于场地内部，缺少与更广泛的城市空间结构关系的呼应。为了更好地实现城市尺度下停车场的分时复用，规划设计师还应结合城市停车场的闲置情况与人群活动需求，实现空间供需的切实匹配。

再者，分时复用本质上是一种基于共享理念和使用者行为时空特征

的规划策略[16]，其成功推行最终有赖于城市居民的自我管理，因而需适当引入公众参与，避免单一自上而下式的技术逻辑。有研究指出，双向交流的公众参与方式（如互动模型、工作坊等[24]）效果更加显著，而游戏化的参与途径也逐渐成为其中一个重要概念。游戏活动不只具有娱乐功能，也可以结合明确的教育目的发挥鼓励用户参与、推动规划进程等作用[25]。因此，双向的、游戏化的公共参与方式可有效支持分时复用策略的落地。

综上，为给紧凑城市中停车场的分时复用规划设计提供参考，本研究旨在回应以下问题：如何识别具有分时复用潜力的城市空间及确定潜在需求？如何通过空间设计使之有效发挥分时复用效果？以及，如何通过游戏化的公共参与模式推广分时复用规则，确保规划设计方案的落实？

2 城市停车空间分时复用概念框架

城市空间的分时复用是综合考虑不同人群在不同时段的使用需求、技术要求与实践逻辑的一种规划策略。本研究提出的概念框架包括“供需识别—规划设计—社区动员”三个阶段，其关键环节分别为识别闲置的停车空间与潜在的公共活动需求、针对特定活动需求进行空间设计，以及通过动员推广增加公众接纳度（图1）。

首先，在供需识别阶段，利用能体现人群移动态势的手机信令等时空大数据对整体城市空间的人流量变化进行刻画，以获取城市中流量变化差异较大的区域，进而判断停车空间的空置情况；与此同时，基于表征城市功能的AOI、POI等数据，分析城市公共空间服务的辐射范围。结合停车空间的闲置时间与空间分布特征，以及现有公共空间的服务范围，筛选出可以通过对停车场的分时复用设计补给公共活动需求的区域。而后可结合微观尺度的实地调查结果进一步确认潜力停车场的具体闲置情况与相应区域人群的活动需求。其次，在规划设计阶段，根据上述结果对具有潜力的停车场进行具体规划设计。通过空间改造、活动装置和标识设计等途径，营造具有吸引力的多功能使用场景。最后，将设计方案中的分时复用规则与场地转化成互动模型，设计相应的互动场景，在社区中进行推广与应用。

综上，“供需识别—规划设计—社区动员”的技术路径运用了数字技术来对规划设计的对象进行识别，又通过公共参与互动来推动规划设计的实施，形成了对停车场分时复用的系统性规划策略。

3 案例分析

本研究以某城市中心城区一处高密度建成环境作为分析对象。该区域建设年代较久，建筑及人口密集，属于老旧中心城区，面积约 $2.65km^2$，包含50个地面公共停车场。由于地下空间不足，每日又有大量从城市外围或其他城市到访的人群，市政府于2018年出台停车设施专项规划，大量增设地面公共停车场，导致区域内居民活动空间紧缺，人车关系紧张。

3.1 供需识别：结合数字技术与实地调研

3.1.1 宏观尺度下停车场分时复用潜力空间和公共空间缺口

在城市尺度上，本研究首先采用中国联通250m精度的手机信令数据（2019年8月）进行城市人群流动的特征刻画，以探测出日流量变化较大的区位。基于手机信令数据的特征尺度，将研究区域划分成59个边长为250m的网格，并获取每个网格中24小时的移动定位数据。整体而言，每个网格的全天流量变化具有日间高、夜间低的特征（图2）。基于这些定位数据的标准差与平均数，可定义各网格中的人流量变化程度，即变异系数：

$$CV = \frac{S}{\bar{x}} \times 100\%,$$

其中，CV为变异系数，S为标准差，$\bar{x}$为平均数。

变异系数是一个大于零的值，数值越大表示数据之间的离散程度越大[26]，主要被用于对比不同区域之间的流量变化差异[27]。基于研究范围内网格的变异系数数据，划定变异系数大于0.3为高值，低于0.3为低值（图3）——高值意味着网格中的人流量变化较大，低值则较小。同时，结合研究区域内日间流量高于夜间流量的整体特征可知，变异系数高意味着该网格的日间流量较高而夜间流量较低，即在日间有大量人员进入，夜间有大量人员离开。交通流量产生于人群的流动，许多研究利用刷卡数据、单车骑行量数据等来反映城市中的人流量情况[28][29]，因此本研究推断研究区域中的机动车流量具有与人流量相似的变化特征。进而以停车场几何质心所在的网格为参照，取几何质心所在网格的变异系数作为该停车场的变异系数，以表征停车场使用率的波动情况。

除了变异系数，停车场的分时复用潜力也与自身的面积大小相关。以研究区域内的停车场面积的平均值（2 058m^2）作为区分大小面积的指标，结合变异系数，最终总结出停车场分时复用潜力的四种类型，即大面积高变化、大面积低变化、小面积高变化与小面积低变化（图4）。

研究区域内的公共空间大多位于外围的滨水区域，中心区域的公共空间相对匮乏（图5）。基于城市社区公园的500m服务半径要求[30]，本研究将居住区划分为两类：位于500m服务范围外的居住区（缺少可达性高的公共空间），和位于500m服务范围内的居住区（拥有可达性高的公共空间）。分析发现，公共空间的缺口在空间上与分时复用潜力空间基本重叠，均集中在研究区域的中心部分，进一步揭示了利用分时复用停车场补足公共空间缺口的合理性。

表1：停车场具体信息

名称	面积（m^2）	绿地率	开放形式	停车位个数	管理方
A停车场	4 810	43%	地面、公共	119	区政府
B停车场	2 930	2%	地面、公共	100	区政府
C停车场	3 350	12%	地面、公共	115	物业公司

3.1.2 微观尺度下停车场分时复用潜力和居民活动需求分析

根据宏观尺度下的供需特征识别结果，选取研究区域中部位于公共空间500m服务范围之外的3个大面积高变化类公共停车场（A停车场、B停车场、C停车场，表1）进行微观尺度的场地调研，包括更精细的停车场使用率的时刻变化及不同时段的人群活动特点。调研工作于2019年10月16~19日（包含工作日和周末）进行。

结果显示，只有停车场B的使用率一直维持在较高水平，而停车场A和C仅在工作日的日间（08:00~16:00）有较大的使用率，呈现出明显的潮汐特征（图6）。以A停车场为例，工作日的车位使用率在09:00左右达到100%，在19:00左右开始下降，在22:00后则低于15%；周末的车位使用率整体低于工作日，在19:00点左右不足25%，在22:00后则接近12%。

同时，调查发现，这些停车场中均出现了居民自发组织的休闲活动。例如，在工作日的07:00前与18:00后，附近居民会在A停车场中散步或进行身体锻炼；C停车场毗邻老旧社区，除了早晚时段，日间也会不间断有居民到停车场内公共活动。同时，研究团队随机采访了在停车场内活动的居民，以了解停车场的日常使用情况及居民的公共活动诉求。此外，团队于2019年10月17日举办居民座谈会，邀请20名长期在此地居住或工作、对城市空间使用有一定观察和见解的市民参与，就停车场分时复用的潜力展开讨论。据反馈，由于研究区域内的公园、广场较少，居民使用停车场晨练、散步已经成为日常现象，而他们对于停车场的使用主要集中在清晨与傍晚后自身较为空闲的时间，且该时间段停车场中车辆较少。由此可见，在时间维度上，居民活动需求量变化与停车场使用率变化呈现出互补特征，分时复用停车空间将起到对公共空间缺口的补足作用。

3.2 规划设计：分时复用停车场规划设计策略

基于停车场使用率和居民活动需求的动态特征，本研究进一步以A停车场为例，提出了一套停车场分时复用规则，即通过规划手段，使停车场能够在适当的时段内分别发挥相应的停车空间与活动空间功能。出于安全考虑，当停车需求较少且居民活动需求较多时，释放停车空间服务于居民活动；当停车需求较大时，减少乃至取消居民活动空间，以保障停车需求。最后，依据停车场的空间特征及借助相应的引导设施，保障分时复用策略的实施（图7）。

停车标识不仅需要按照相关规范划分整齐的停车位，还要依据停车空间与活动空间互相转化的程度，划分全天候停车位与灵活停车位两种类型。其中，全天候停车位不承担居民活动，任何时候均用于车辆停放；灵活停车位兼具停车与活动空间的功能，其功能混合比例依据不同停车场的使用率变化特征而有所差异。

活动标识与活动器材可以引导并强调停车场中潜在的活动内容。本文基于停车位尺寸，根据空间点状、线状、面状等不同形式提出了一系列基于不同活动的设计模块（图8）。活动标识中不同的颜色、线条和几何图形可用于引导场地位置、区分活动内容，如在场地内标注跑道、儿童游戏图案等。而活动器材的选择与放置不应影响停车行为，须放置在停车路径外的空间中，如在停车场地外放置篮球架、沙袋、健身器材等。同时，还可引入集体性公共活动，如早市、夜市、跳蚤市场等。为了保证活动的安全，一方面，可以引入可升降隔离柱以明确区分活动空间与停车位，另一方面还需加强管理人员对活动的指引与规范，或引入预约系统，合理安排使用时间与人数。

根据上述设计策略，基于A停车场工作日与周末的停车位使用率情况划分分时复用的时段，并明确每个时段应该预留的停车空间及相应的空间划分模式，进而根据停车场内当前的自发活动情况及周边用地特征设计活动标识、安装活动设施（图9）。可在A停车场中设计三类混合功能情景：1）在工作日的日间（07:30~17:30）全部作为停车空间；2）在工作日的晨间与夜间（17:30~次日7:30）及周末的日间（10:00~16:00）保留40%的停车区域；3）在周末的晨间与夜间（16:00~次日10:00）保留30%的停车区域。根据停车场的空间特征，平行划分三段空间，其中一段为全天候停车空间，另外两段为可承载不同功能的灵活停车空间。根据调研结果，周边居民具有晨跑、晨练等休闲游憩需求，因而可在停车场中引入跑道元素，同时留出可放置座椅和运动设施的空间（图10）。在周末，A停车场中大量停车空间闲置，管理方可考虑与商业运营公司合作，将释放出来的活动空间用于举办大规模的市集活动。

3.3 社区动员：基于公共参与的游戏化途径

在规划设计的基础上，还需通过公众行为引导确保停车场分时复用策略的落实。为此，研究团队设计了一套带有电路的互动模型。该模型运用的材料包括木板、发光二极管、面包板、杜邦线等。

以A停车场为例，该互动模型共包括6个具有相同外观的小模型，分别代表了工作日和周末的6个时段，并依据分时复用规则配置了不同的感应电路，另设置了同样带有感应电路的小配件，代表车主、居民、摊贩

等不同用户群体。人们可根据分时复用规则来放置配件，如果符合该时段的空间使用要求，则配件上端就会亮起绿灯，否则就会亮起红灯。

游戏化的社区动员主要可发挥两种作用：一方面，有别于传统的规章制度展板，实体互动模型的形式能够吸引更高的公众关注度。另一方面，通过实时的游戏交互，公众能够快速掌握停车场分时复用的规则。研究团队发现，在游戏互动过程中，即使未经讲解，公众也能够通过红灯与绿灯的实时反馈，快速掌握游戏规则，从而理解停车空间分时复用的作用和意义（图11）。

4 讨论与结论

本文以停车场为例，提出了包括“供需识别—规划设计—社区动员”三个步骤的紧凑城市空间分时复用策略：在供需识别中揭示了居民活动需求与停车场使用率之间存在时空互补特征，在规划设计中提出了基于停车场使用率变化特征的混合功能设计方法，在社区动员中强调了互动模型在分时复用规则落实过程中的作用。通过引入时间维度，分时复用策略突破了土地资源在空间上混合利用的限制，可最大程度实现土地资源集约利用。总体上，这一策略开拓了停车场等城市空间的功能，释放了更多公共活动空间，从而缓解紧凑城市普遍面临的公共空间匮乏问题[5][7]，为城市运营公平与效率的提升提供了新思路[8]。

分时复用策略融合了数字赋能与公共参与理论，将城市停车基础设施的规划设计问题从设计本身向前端的供需识别及后端的推广实施拓展延伸，构建了一个兼具科学性、技术性与社会性的规划设计框架。一方面，信息时代的数据和技术赋能可更加全面、更加高效地帮助规划设计人员理解城市停车空间的时空特征；另一方面，由于现实建成环境的复杂性，以及当前大数据时空分辨率较低的局限，也需要规划设计人员坚持实地调研，真实地进入城市空间中，深入分析问题。鉴于此，本文首先综合了传统数据与新数据方法，在利用大数据的广覆盖优势快速识别大量低效利用的城市空间的同时，还借助实地调研与访谈，明确城市空间中停车基础设施的具体闲置情况及周边居民的活动需求，为后续的规划设计提供了充实的依据。值得注意的是，规划者在实施分时复用策略时，不仅需要对客观物理环境进行设计，还要考虑对公众行为的引导。本研究提出的互动游戏模型能够提高公众对规划设计方案的理解与认可，鼓励他们给予适当的反馈和调整建议，有助于提升规划策略落地的可能性。

本研究亦存在不足之处。首先，受制于城市停车场运营管理主体及停车数据的差异，本研究未能直接通过停车场闸口电子技术来获取使用率数据，而是通过人流量与实地调研结果进行推演与确认，技术路径较为复杂。这一问题有望随着智慧城市数字基座的进一步标准化和系统化得到改善。在公共参与方面，互动模型可结合虚拟现实技术开发为线上游戏，以获得更多的受众和反馈[31]；本研究因条件局限，未能对游戏化社区动员的实践效果进行定量评估，而仅通过公众参与活动现场的教育效果进行间接推定，后续研究将优化评估方法，进一步验证方法框架的有效性。同时，本研究存在一定的应用局限，由于人群流动具有较强的随机性，不可避免会存在公共活动需求与停车需求相冲突的情况。随着汽车的智能化发展，车主或可通过远程操控将汽车转移到非活动区域，从而解决这一问题。而活动与停车共存的安全性问题也需要在空间设计、管理运营上做进一步的深化研究。

图 1. 技术路线图
图 2. 研究区域内手机信令检测的人流量变化
图 3. 研究区域内各网格变异系数直方图
图 4. 停车场分时复用潜力识别
图 5. 公共空间缺口的识别
图 6. 停车场使用率变化
图 7. 规划设计策略示例
图 8. 活动标识与活动器材设计模块
图 9. A 停车场分时复用规则
图 10. A 停车场设计效果图
图 11. 公共参与互动现场