Research Paper

Optimization of Open Spaces in High-Density Urban Areas Based on the Supply–Use Interaction Mechanism

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Abstract

The construction of high-intensity areas presents the characteristics of high-strength construction of high density, three-dimensional complex functions, high-frequency interaction of crowds, and complex interweaving of traffic, which has given rise to diversified needs for the use of open space, such as walking, gathering, rest, exhibition, etc. . In the limited open space, the diversified demand forms a composite superposition state of use. At the same time, with the continuous renewal and development of the city, the use demand shows the characteristics of dynamic change and scale growth, it further aggravates the contradictions and conflicts in the use of open space, showing the complexity, confusion and conflict in the use of open space.

Based on the in-depth analysis of the supply mode and use characteristics of open space in high-intensity areas, this paper reveals the interaction mechanism of ''Supply-use'' of open space in high-intensity areas, furthermore, this paper puts forward targeted spatial optimization measures and strategies to provide theoretical and methodological support for the sustainable optimization of open space in high-intensity areas under diversified and dynamic demand. At the same time, the logical framework of the ''Supply-use'' interaction mechanism is not limited to the existing paradigm. In future research and practice, the mechanism has the potential to further incorporate more types of users and goal orientations-such as non-human needs dimensions such as ecological protection and carbon sink management, thus, it can support the construction of open space optimization path under the guidance of multi-objective, and promote the design of open space to a more generalized systematic collaborative optimization.

Keywords: high-intensity area, open space, supply, use

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1. Introduction

High-intensity districts are typically located in urban core areas, exhibiting characteristics such as high density and intensity, three-dimensional functional complexity, high-frequency population interaction, and complex traffic interweaving, generating diverse demands for space usage, particularly for open spaces, including passage, gatherings, rest, exhibitions, etc(Chen & Ni, 2022). Within limited open spaces, diverse demands are superimposed onto the same physical space, forming a composite and overlapping usage pattern. Simultaneously, with continuous urban renewal and development, usage demands show characteristics of dynamic changes and scale growth, further exacerbating conflicts and conflict in open space usage, manifesting as complexity, chaos, and conflict phenomena in open space utilization, and even causing safety accidents such as crowd crushes. This is the contradiction between the dynamically growing usage demands in high-intensity areas and the static limitation of open spaces(Celani, 2019).

The mismatch between spatial supply and demand is the essence of this contradiction(Chen et al., 2017). The spatial supply model of open spaces in high-intensity areas—including morphological characteristics and enclosure relationships — affects the usage demands, usage patterns, and functional layout relationships of open spaces(Lu & Wang, 2021). The usage of open spaces includes diverse demands such as passageways, roaming routes, temporary markets, activity venues, entrance/exit gathering points, rest facilities, and green landscapes. The projection and release of usage demands in open spaces form complex interactive relationships(Liu et al., 2023). This interactive relationship requires further systematic organization and systematic response(Høj et al., 2021;Gong, Zhou & Tan, 2020;Jansson & Sunding, 2024;Li, Wu & Lü, 2020)

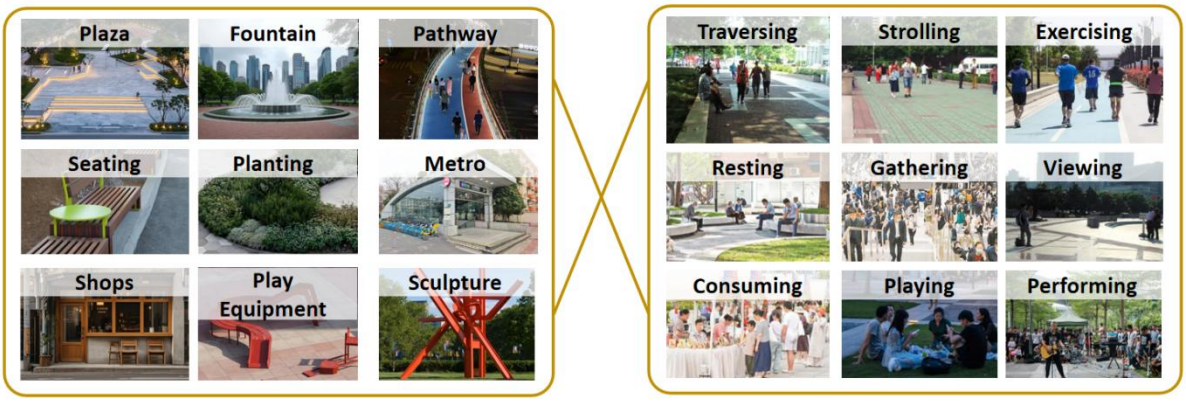

Figure 1 There is a complex interaction between the spatial supply and usage of open spaces in high-density areas.Source: drawn by the author

This study focuses on the operational characteristics and optimization pathways of open spaces in high-intensity areas, aiming to reveal their spatial mechanisms and design logic from the perspective of 'supply-usage' interactions. The study begins with a systematic analysis of open space in dense downtown areas in terms of satellite imagery, field observation, and behavior based on density, spatial morphologies, functional/functional types, and patterns of behaviors, fusing them to describe several representative spatial types. Following this analysis, the study continues to abstract three 'active' universal spatial usage patterns for open space in high-density urban neighborhoods, and then develops a three 'supply-use' typical interaction mechanisms — conflict mechanism, overload mechanism and mismatch mechanism—on the guarantee of the requires underlying differences and similarities of the supply structure and behavioral demands— explain contributor to systemic imbalance and operating difficulties (Peng, Fu & Zeng, 2024; Sajjad, Chan & Chopra, 2021).

After identifying the mechanisms, the study then moves on to develop systematic optimization strategies across range of open space sampling horizon, drawing on different disequilibrium types and their potential origins. Broadly the strategy rolls out across a range of dimensions, including end-user streamline organization, spatial rigidity, supply mechanism, case exemptions and temporary dilution, to add more carrying capacity, sustainability, adaptability, or use efficiency towards supply and behavior (end-user). Through the above approaches the explorative study aims to provide an explanatory and operational analytical framework for the cognition, design, and governance of open space in high-intensity urban areas.

2. Methodology——Usage Mechanism of Open Space Based on 'Supply-Use' Interaction

2.1 Model of Supply and Usage Mechanism for Open Space

The mechanism of open space use fundamentally involves the interaction between the space and its use (Peng, Fu & Zeng, 2024). The physical space provides the location for use which also ascribes attributes and boundaries to the physical space. Space supply and space use interact in an orderly manner with the help of a form of spatial design while guidance is not cashed or necessary. Spatial supply, through scale, form and facilities, guides, constrains and shapes types of use activities and patterns of behavior; use behaviour, through temporary configurations and spatial changes or change in social cognition, reestablishes the supply structure and physical form of the space. Therefore, interface supply and use operate as dynamic, in the moment, as the same space is being used at the same time the physical space is being modified (Sajjad, Chan & Chopra, 2021).

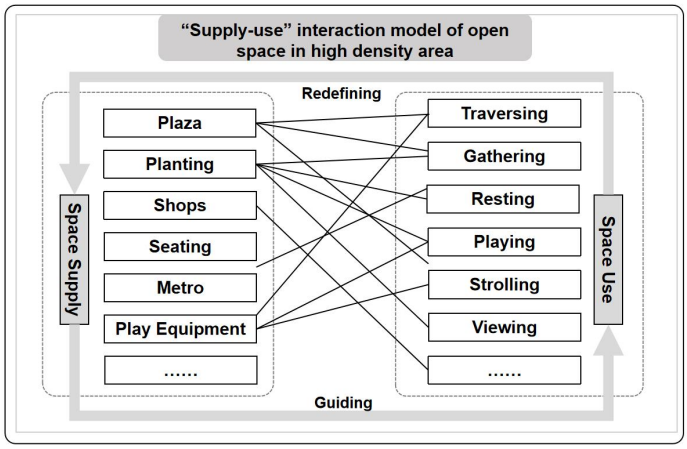

Figure 2 Supply-Use' Interaction Model of Open Space in High-Density Areas.Source: drawn by the author

The speed and intensity of this change vary across open spaces. The supply-use interaction is influenced by the attributes and characteristics of space use itself (Yang & Zheng, 2022). In high-intensity areas, limited distance with more rapidly changing use, the speed and intensity of changes in this interaction mechanism is brought to the forefront (Yung, Conejos & Chan, 2016). In addition, because of high heterogeneity in the spatial and use characteristics of open spaces in high-intensity area's, these changes may be played out in a series of typical pattern combinations (Sun & Zhao, 2018; Wang, Jiao & Dong, 2020).

Therefore, in the complicated scenario of open space structure in high density area's, some key questions arise, when use demand suddenly surpasses the physical space and the space unit seems to be have more activity intensity, how can relatively static physical spaces be utilized to absorb activity? Once new use types emerge, how can the original supply system adjust or rematch and reconfigure? The answers to this question have to be engaged through in-depth analysis and dynamic modeling of space supply-use interaction mechanism.

2.2 Research Design

This paper offers a systematic reanalysis of the usage patterns of open spaces in high-intensity areas using the perspective of the "space supply-space usage" interaction relationship. First, through observation and induction of different types of open spaces in high-intensity areas, we found basic operational patterns of supply-usage relationship configurations in stable states, and then built a corresponding analytical model to characterize the normalized operational characteristics of the supply-usage mechanism related to different spatial forms.

Second, the paper goes further to look at abnormal or unbalanced states when the open spaces actually operate, focused on the relationship changes as well as the mechanism switching (transformation) within the system with regard to the supply-usage perspective when space usage undergoes sudden changes. In this stage of looking at these changes, through comparative analysis of typical cases, the study shows the difference in imbalance mechanism types across different space types. For example, in "crossing commercial-recreational" types of spaces, an overload phenomenon has a disturbing impact on the spatial order. This is because their original supply-usage pattern has no buffer structure that absorbs peak demand eve if operating at the threshold, it is less likely the space can self-repair or reconfigure. In other spatial forms such as "central assembly-distribution" and "peripheral commercial-recreational" spaces, overload or conflict manifests differently: the former often shows localized efficiency declines, and the latter often exhibits a demand overflow before instantaneous change.

Therefore, while identifying stable conditions, and in summary, this paper analyzes and categorizes the interaction relationship configurations as mechanisms under abnormal conditions; conflict, overload and mismatch, and constructs a graphical representation path that fits four spatial types and mapped three mechanisms to show the dynamic logic interaction relationships of each mechanism in group systems.

3. Analysis of Open Space Usage Patterns in High-Intensity Districts

This paper, grounded in a summary of research on typical high-density district open spaces and empirical observations, identifies three typical open space use patterns in high-density districts: central assembly-distribution, peripheral commercial-distribution, and crossing commercial-recreational.

3.1 Central Assembly-Distribution Type

With regard to spatial supply, the overall pattern consists of core plazas, entrances/exits of subway stations, underground commercial connecting spaces, and ground-level pedestrian space. These spaces, which are multi-layered and highly interconnected, create an overall central open space system. The main characteristics of the space are high accessibility and a strong sense of visual openness, allowing for large-scale crowd gathering and dispersal.

The spatial use is primarily composed of crowd distribution, public activities, social stays, and the flow of pedestrians. There are apparent demo-measured time differences of this usage. The daily usage is primarily to deal with passage, while during holidays or other special occasions, the usage is related to mass assembly or stay. In general, this interactive characteristic of supply and use is manifested in traffic organization based on the core space: first, crowds gather and then diffuse outward. Where spatial usage takes the cyclical process of 'gather-diffuse-regather'.

Nanjing Fashion Lady Square serves a typical example. When usage is based on day-to day option, the space primarily serves functions of crowd organizing and transfer. But, during holidays or promotional events, the sunken space of the central square may be transformed into a gathering space. The overall shift of spatial function is from 'flow-type' during a regular day's supply-of-use operation to 'stay-type' during supplemental mass crowd assembly space showing strong temporal flexibility. Figure 3 Spatial use patterns Nanjing Fashion Lady Square demonstrating actions-or-assembly and stay.Figure 3 Spatial usage patterns of Nanjing Fashion Lady Square during regular days and gatherings



Figure 3 Spatial usage patterns of Nanjing Fashion Lady Square during regular days and gatherings.Source: drawn by the author

3.2 Edge Commerce-Distribution Type

In this model, the spatial supply primarily comprises external plazas of commercial podiums, open green belts along waterfronts or streets, and pocket-style rest spaces, often located at the boundaries of districts and closely connected to commercial façades, urban streets, and landscape systems. The spatial boundaries are highly flexible, establishing a freely-permeable recreation edge accomplished by the weaving of green, paving, and commercial interfaces, providing a good environmental base for slow-paced activities. From the point of view of spatial use, activities consist mainly of strolling for exercise, light consumption (café or shop), lingering with friends or family, and living behaviors taken in a daily pattern. Unlike distribution-type spaces, these spaces have a relatively low density of people, but longer periods of stay, with slow-paced and highly continuous patterns.

The composition of users is heterogeneous, including occupants from nearby residences, tourists, and office workers. User composition also suggests important daily and lifestyle dimensions in occupancy. The interactive characteristics of supply and use, manifest as edge-permeated diffusion. People typically enter from the commercial core area or urban sidewalk, and pause and disperse at the rest nodes and green edge, with people using activities occurring naturally along the landscape belt and commercial edge.

The space is typified by a more obvious function of gradation across time periods; with the daytime period dominated by rest and light consumption, and the nighttime period displaying greater intensity and time staying, due to the added lighting effects and commercial ambiance of the earlier day. The overall space has an activity distribution structure of 'core-edge-extension,' and operates as both an important buffer zone and 'urban living room', a connector between the commercial interiors and the public urban realm.

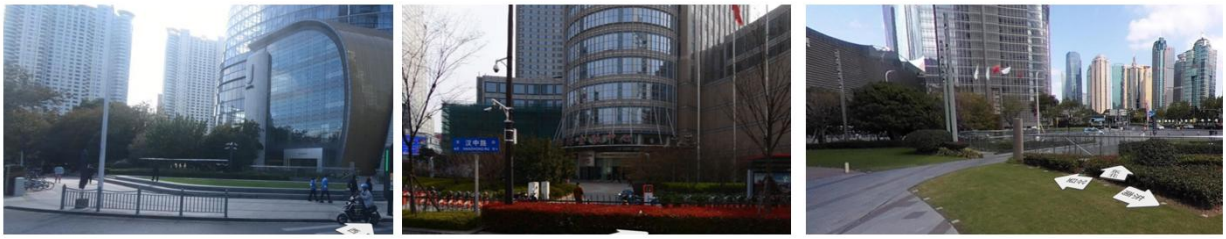

Figure 4 Edge commercial-distribution open space of Shanghai Central Plaza and a shopping center in Nanjing.Source: Baidu Maps

3.3 Transit Commercial-Recreation Type

This framework is largely built upon pedestrian circulation routes, interstitial landscaped corridors, open nodal zones, and commercial street-front al fresco extension areas that create a linear open system that possesses depth and directional orientation.

The spatial provision integrates the functions of circulation, viewing, experience, and resting, and has very open commercial facades with outdoor seating, al fresco dining, and landscape amenities that coalesce into highly engaging street life scenarios. In terms of spatial use, the bulk of use involves experiences associated with strolling, browsing, pausing for social interaction, light consumption, and spending time in stores. The nature of use is strongly associated with recreation and the rhythm of activities is both continuous and variable: the user typically pauses when navigating, and then continues navigation after pausing, resulting in a repeating rhythm sequence of 'navigate-pause-move again.' The al fresco seating also enhances social / consumption attributes and provide both public and semi-public characteristics to the street space. The interplay between provision and use displays a typical 'stasis within flow' mechanism. The resultant effect of the landscape elements, commercial facades, and al fresco seating provide for both movement and recreation within the same spatial system. In terms of conflict: linear spaces support continuous passage while outdoor seating and nodal pockets of landscape integrate high-quality stopping points that maintain spatial vitality while safeguarding circulation efficiency.

For example, in Shanghai Xintiandi during the weekdays, this space serves primarily as passageway and destination consumption; spatial circulation patterns develop into distribution patterns along the pedestrian circulation route with stops occurring mainly in the outdoor cafés and nodal pocket spaces. During holiday times or evenings, recreational attributes rise dramatically, al fresco seating begins to be utilized substantially, and the pedestrian space converts to a slow-paced experience dominated by the social domain, leisure-based activities, and experiential activities. The overall spatial attributes transition from linear flow associated with passage to multi-nodal stays associated with adaptive experiences, allowing Xintiandi to demonstrate highly adaptable patterns of use and pluralistic scenarios of urban life.



Figure 5 Experience-oriented facility layout in Shanghai Xintiandi's commercial-recreational open space.Source: Baidu Maps

4. The 'supply-use' interaction mechanism in high-intensity district open spaces

In this paper, 'supply' is defined as the service capacity and site carrying conditions offered to people by urban open spaces, which is the sum of spatial structure, physical facilities, functional configuration, environmental attributes. In various types of open space patterns, the relationship between spatial supply and spatial usage demand can suggest structurally similar yet dynamic patterns of interaction. From this basis, the paper sums up three typical 'supply-use' patterns of interaction: conflict mechanism, overload mechanism, and mismatch mechanism.

Based on an empirical analysis of typical high intensity urban districts, the paper further develops a 'supply-use' interaction model as a means to understand how supply and demand can be engaged in open space. Through three interconnected areas - the identification of use demand, refinement of what it means to engage a mechanism and strategic instantiation of supply for use - the analytical framework provides an understanding of operational logics within open space and optimization strategies. Such a framework generates both implementable 'real-world' design strategies as well as an important logics for spatial governance in developing design tool innovations and providing a developed understanding for governance mechanism coordination.

4.1 Conflict Mechanism

The conflict mechanism can be defined as the context characterized by relatively independent spatial usage activities that, during their evolution, are forced to share the same spatial supply, to the extent that their operational logic, behavioral rhythms, or usage requirements conflict with one another. Conflicts with the original arrangements in this context tend not to be established beforehand in planning or design, but rather developed over the actual operational phase. This is based on a fundamental difference between the growth rates of different types of usage: as the usage activities that grow rapidly begin to grow outwardly the extent of their occupation of spatial supply, they put pressure on usage types with slower, or even stable growth rates.

When a spatial usage type is pushed outward into adjacent supply, and the unit supply it is now occupying has original requirements that are incompatible with it (whether due to behavioral characteristics, parked functional attributes, or circulation logic) explicit conflict is created in the physical space. For example, the intrusion of transit flow into assembly or distribution spaces directly causes behavioral disruption, chaos in order, and safety for the assembly or distribution usages. Thus, the conflict mechanism ultimately reflects the dynamics of unbalanced competition among usage types under limited supply conditions which produces imbalance of spatial coupling.

4.2 Overload Mechanism

The overload mechanism refers to the phenomenon where a single space usage type undergoes rapid expansion in a short period, exceeding the capacity threshold of the original space supply, thereby forcing an interruption or restructuring of the supply–usage pairing relationship. Unlike the conflict mechanism, the overload mechanism emphasizes 'sudden quantitative surge' rather than 'interference between types'.

The idea behind "overload mechanism" reflects the rapid expansion of a single space usage type over a short timeframe, beyond the threshold of the functioning capacity of the supply, which interrupts or realigns the original supply-usage pairing. The noticeable difference from conflict mechanism is focused towards "sudden quantitative shift" instead of "interference within types.". When a usage demand begins to experience sudden growth (e.g., festival groupings, short term tourism peaks, event clustering, etc.) there is often strong exclusivity of usage trait that contend for physical space, often causing the squeeze of connections or even cutting off those connections from their normal original supply. This results in 2 realities:

(1) inefficient operation of space – other usage types & variations do not come up in ways to function normally in the original location, thus are forced to operate in ways of hindered operations/efficiently;

(2) spatial overflow– some demands of usage were forced to overflow into adjacent spaces, achieving ends on complete detour or substitution.

An important premise is: the spatial demand usage itself will not disappear. When the spatial usage demand is insufficient supply, the demand must be satisfied or concluded in some manner. The overload mechanism expresses the historical damage in the physical space supply confronted with intensity of demand to the order of overall operational order of space.

4.3 Mismatch mechanism

The "mismatch mechanism" is defined as the mapping of spatial usage demands to spatial supply that is either neglecting to develop, or misaligns with that type of constraint of operation or characteristics of behavior, and produces decreased efficiency and potential chaos of sorts. Again, mismatch is not necessarily attributed to errors at the design phase, but more often occurs due to regeneration of displaced demand, and functional overlaps during the operation of spatial matter. When demands of usage are present in space, consistent without regularity and occurring on whatever original constraint are left over, some use of demand will display mismatched behavior, because of one or several of the points: misplacement of new demand due to search from crowd in original supply, no guidance system to direct new demands, or even the operators are unaware or poorly based in the decision making of supply-usage relationship.

For example, placing high-mobility distribution activities in areas primarily designed for landscape stays not only fails to achieve efficient distribution but also diminishes the environmental quality and user experience of the landscape space.

The mismatch mechanism essentially reflects the mismatch between the update speed of spatial demands and the adjustment capability of spatial supply, representing an important manifestation of structural operational problems in high-intensity districts.

5 Optimization Strategies for Open Space in High-Intensity Districts

Based on the preceding mechanism analysis, this study proposes three systematically targeted optimization strategies aimed at reshaping stable matching relationships between spatial supply and actual demands through comprehensive adjustments to spatial structure and functional organization.

5.1 Restructuring through Flow Rationalization: Reconstructing spatial boundaries and behavioral flowlines to reduce interactive conflict

Restructuring through Flow Rationalization primarily responds to the structural problems revealed by the "conflict mechanism". In districts with high usage density, there can often be significant divergence among varying types of usage in growth rates, with expanding uses reaching out into surrounding supply spaces, resulting in surprising overlaps and interferences. Restructuring via Flow Rationalization is about more than simply “cutting off” or “isolating,” and instead providing an opportunity to evaluate and screen for **new/upcoming** pairing arrangements - to collectively achieve a recalibration of the supply-coordinate - use relationship through a bi-directional means of intervention(Yu et al., 2023).

(1) From the supply side: Redefining boundaries and micro-update site structure

Assess the rationality of the expanding demand periphery extending to the adjacent spaces, determine which of the "new connections" has actual necessity; orient the demand flow into more appropriate supply units utilizing re-adaptive spatial boundary adjustments, changing scale configurations, and buffer zones/categories; and finally, repair spatial structure utilizing micro-update approaches to reinforce stability and physical condition of existing necessary "new pairings."

(2) From the use side: Rectifying/unpacking and channeling unreasonable connections

Through management, flow organization, or behavioral guidance, "break the chain" of unreasonable usage overflow; Using directional measures (one way flows, time based guidance, directional guidance signs) or some other measure to reduce behavioral entanglement; and if necessary use flexible channeling measures to re-direct some actors back to appropriate supply units.

Through combined rectifying interventions from both the supply and use side, we accomplish an effective re-organization of behavioral logic, and the potential for the spatial structure to adjust appropriately in the face of dynamic growth.

5.2 Three-Dimensional Expansion: Building a multi-level spatial system to alleviate ground-level overload

Three-Dimensional Expansion seeks to deregulate supply-and-demand misalignments created by unprecedently rapid short-term increases in single usage types in the "overload mechanism." In high demand areas, organizing public spatial systems fully on the ground often will not provide sufficient expansion capacity to meet periodic and/or event-induced demands for expansion, and there needs to be some integration of vertical space as part of the overall supply system (Zhang et al., 2022).

(1) From the supply-side: Adjacent fixed-structure building into a composite spatial structure with vertical feed availability

Add public space capacity through underground connecting corridors, through elevated floors and second-level pedestrian systems; fix the public space at different vertical levels into the same supply system so that and "routinely" needs can be "comfortably connected" on the ground when needed, but that the peak need can orderly "overflow" through a parcel of space vertically in a certain direction; and fix into a composite three-dimensional supply structure to minimize the total exclusive occupancy of space during the overflow usage events.

(2)From the user-side, "orderly" promote distribution of peak usage

Through flow guidance, layered emptiness of entrance functioning, and line-of-sight and functional overflow path design, allow the expanding characteristic of demand to form "orderly large connections" in the functional working order; avoid peak use on the ground that fully occupies the ground level supply and creates obstruction, chaos, or underlining paralysis of the public supply and functional system.

The essential premise of Three-Dimensional Expansion is creating spatial reassignment of supply capacity across vertical dimensions, which allows the area to develop its own resilient spatial bearing structure so that sudden usage does not create an external shock that constrains the supply and demand usable relationship.

5.3 Precise Embedding: Building a new flexible response spatial adaptation mechanism

Precise Embedding mainly targets a supply-use mismatch issue exposed by the "mismatch mechanism." When new demand streams continually arise, and activity types rapidly change, high-intensity areas require a spatial mechanism that is capable of dynamic adjustment to achieve reasonable matching of supply and demand.

This strategy does not rely on large-scale reconstruction of permanent spatial infrastructures but introduces flexible and temporary mechanisms to maintain adjustable space for up-and-coming usage demands.

(1) For long-term new demand: steady-state embedding through spatial guidance

Recognizing the existing supply-use interaction relationships, new routine activities are cautiously configured; utilizing path organization, boundary adjustment, and node optimization, new demands are accommodated without upsetting the existing stable structure.

(2) For short-term, temporary demands: create institutionalized spaces for “temporary supply”

Small-scale open spaces that can be drawn upon should be requisitioned on demand, and not fixed to any existing type of spatial supply; as demand arises, temporary construction, rearranging, or spatial conversion should occur quickly to shift the open space to assemble adjustable space with ‘‘temporary vitality.’’ Rather than crowding non-routine demand into unsuitable spatial units, this process avoids the mismatches or conflict.

Precise Embedding allows the district to adjust to demand updates at long-term minimal structural costs by constructing flexible, convertible spatial mechanisms to uphold long-term stability of supply-use relationships.

5. Summary and Discussion

As cities accelerate toward high-density and high-intensity development, the functional boundaries, usage intensity, and behavioral structures of open spaces are being dramatically reshaped. A systematic analysis based on "supply-use" interaction logic helps reveal operational mechanisms and provides a knowledge basis for future optimization and governance. The analytical framework highlights that relationships between open space supply structures and usage demand are not static, but rather a continually adapting, dynamically evolving process — one that may better address the prominent issues of conflict, overload, and design mismatch, increasing overall spatial resilience and adaptability.

The "supply-use" interaction mechanism holds strong scalability and growth potential. While this study focuses on resident population needs, the interaction logic is not limited to existing paradigms. Future research could incorporate broader user types and goal orientations, including ecology protection, carbon sink management, and other non-human dimensions of demand. Multi-objective analysis and design may thus support open space optimization pathways, promoting landscape design toward broader systematic collaborative optimization.

6.Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant No. 52178034).

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