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基于空间潜力和社会行为多源数据分析的城市绿道规划研究——以北京市海淀区城市绿道选线规划为例

STUDY OF URBAN GREENWAY PLANNING BASED ON MULTI-SOURCE DATA ANALYSIS OF SPATIAL POTENTIAL AND USER BEHAVIORS — THE GREENWAY ROUTE PLANNING OF HAIDIAN DISTRICT, BEIJING

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摘要

城市绿道对于鼓励城市慢行交通出行、缓解城市交通拥堵具有重要意义。目前，中国绿道研究和规划实践主要集中在具有生态、历史、文化和休闲服务功能的、位于郊区的区域绿道；而对于服务于城市慢行交通、满足市民日常通勤和休闲需求的城市绿道研究较少。相比前者，城市绿道的选线和建设更加需要考虑建成区空间现状条件和市民的实际使用需求。因此，本研究着重探讨在大数据涌现的背景下，运用多源数据，构建基于GIS空间分析（绿道建设潜力空间评价）和大数据社会行为分析（居民绿道日常使用需求评价）的城市绿道选线规划方法，并以北京市海淀区为例开展实证研究。随后，研究针对海淀区城市绿道建设涉及的道路、河道、铁路廊道和带状绿地等主要空间类型，提出具体改造模式策略，将绿色空间网络与慢行系统相结合，以实现城市线性空间的功能优化。

关键词

慢行交通；城市绿道；选线规划；构建模式；大数据

ABSTRACT

Urban greenways play a key role to a city's non-automobile commuting and help alleviate traffic congestion. Currently, China's greenway planning research and practice focuses mostly on suburban areas where greenways provide ecological, historical, cultural, and recreational services, while fewer studies explore urban greenways that serve citizens' daily non-automobile commuting and recreational needs. Compared with suburban ones, urban greenways often face more spatial limits in the built-up areas and need to respond to more challenging demands. Supported by multi-source data and the rise of big data technologies, this research explores the methods of urban greenway route planning that are underpinned through GIS spatial analyses (potential evaluation on spatial construction conditions of greenways) and big-data-based user behavior analyses (of citizens' daily use of greenways). Demonstrating the authentic planning case for Haidian District, Beijing, the research proposes a series of construction strategies to urban corridors of roads, waterways, and railways, respectively, which integrate green spaces with non-automobile system, in order to improve the services of linear spaces in cities.

KEYWORDS

Non-Automobile Traffic; Urban Greenway; Route Planning; Construction Strategies; Big Data

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EDITED AND TRANSLATED BY Tina TIAN

1. 管理混乱的城市慢行交通服务设施

1. Urban non-automobile commuting facilities in a poor management

1 城市绿道相关研究

近年来，在以机动车为主导的城市道路发展模式下，中国城市的交通拥堵问题日益严重，慢行交通（步行和自行车）的使用率不断降低[1]。究其原因，随着城市规模的扩大，慢行交通出行的时间成本不断提升，而且道路环境的慢行友好性也较差，缺乏必要的安全性和便利性[2][3]。

城市绿道的一个重要职能就是承载城市慢行交通[4]，是城市多功能慢行交通系统的重要组成部分。其强调慢行优先，通过环境改造增强慢行舒适性和安全性，并通过与公共交通系统和重要公共服务节点的便利联系，吸引更多的人使用慢行公共交通方式出行，进而缓解城市交通拥堵问题。目前，世界上越来越多的城市都开始通过构建“绿色、慢行”的交通网络系统来鼓励市民慢行交通出行[5][6]。

当下，越来越多的中国城市居民开始选择自行车、步行和公共交通换乘的方式出行，尤其是在北京、上海等大型城市，共享单车的出现极大地推动了慢行交通出行的发展。而且，自20世纪90年代开始，中国的绿道建设发展非常迅速[7]~[9]，在一定程度上鼓励了慢行交通出行。但是，目前也存在一些迫切需要解决的问题：长期以来，受到中国城市扩张发展趋势和绿道建设实施难度的影响，对于郊区和城市边缘地区绿道的研究和规划实践远多于城市建成区[10][11]。相较而言，前者承载的生态、历史和文化保护与假日休闲功能更加显著，而后者才更多服务于市民的日常通勤和休闲需求。而且，目前城市慢行交通出行网络建设的合理性和覆盖度都严重不足，很多城市绿道由于不符合市民的日常出行实际需求而使用率很低。即使在一些步行和自行车使用率非常高的城市路段，亦存在服务设施严重不足且管理混乱的问题，这也在一定程度上抑制了城市慢行交通出行的发展（图1）。

相比其他绿道类型，城市绿道受到的空间制约更加显著，与市民日常工作、生活的联系也更加紧密。因此，在复杂的城市建成环境

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1 Review of Existing Studies of Urban Greenways

Traffic issues become increasingly prominent in Chinese cities along with the promotion of vehicle-based transportation construction, while non-automobile commuting modes, such as walking and bicycling, and related transportation facilities are less utilized[1]. City sprawls that increase citizens' commuting time and the poor non-automobile commuting environment that is deficient in safety and convenience all contribute to the status quo[2][3].

Urban greenways, as places accommodating non-automobile activities[4], are an important component to a city's multi-functional non-automobile commuting system. Urban greenways are expected to serve the public as comfortable and safer corridors for non-automobile commuting, and to link up public transportation system with key public service facilities in order to encourage non-automobile traveling and relieve cities' traffic pressure. Today more and more cities are promoting non-automobile commuting combining with the construction of urban greenway system[5][6].

At present, a growing number of Chinese urban residents resort to cycling, walking, and public transportation methods, particularly in metropolises such as Beijing and Shanghai where sharing bikes greatly boost the popularity of non-automobile travelling. Since the 1990s, China's greenway construction has seen a strong momentum[7]~[9], which helps create favorable conditions for the promotion of non-automobile commuting. However, there are now pressing issues to be tackled with: subject to urban expansion and the difficulties in greenway construction in Chinese cities, research and planning practice concentrates more on suburban areas than to their urban counterparts[10][11]. Comparatively, suburban greenways often serve for ecological, historical, cultural protection, and recreational purposes while those in urban areas are expected to meet citizens' daily commuting and recreational needs. However, many existing urban greenways see a low usage due to their failure to meet citizens' actual commuting needs. Much needs to be done to improve the planning practice and the coverage of non-automobile commuting systems. Although walking and bicycling are frequently adopted alternatives in some areas, supporting services and facilities are in a poor management, posing challenges to the promotion of urban non-automobile commuting system (Fig. 1).

Compared to other types of greenways, those in cities are designed to meet more specific daily needs but often faced with more constraints in physical construction. Considering such complexity, urban greenway planning needs to respond to two core issues: what urban spaces can be utilized for greenway

中，城市绿道规划建设重点需要解决利用哪些空间和如何满足社会使用需求两大问题。

从空间利用角度而言，如今，建成区的空间利用难度巨大，城市绿道建设最主要的机会是结合城市更新[12]，利用城市现有的空间网络和尚未充分开发的空间来开展城市绿道系统的建设。既有研究对城市绿道的空间载体进行了探索，包括城市带状绿地，以及道路、铁路、水渠等城市线性基础设施的附属空间等，这些都是建设城市绿道的主要可利用空间[13][14]。在实施技术层面，诸如巴塞罗那、纽约、巴黎等欧美城市都在不影响原有空间功能的前提下复合新的绿道功能，创造了一系列具有影响力的城市更新项目[6][14]-[17]。未来研究需要针对城市绿道可利用的潜在空间特征对其选线规划进行优化，并结合具体城市空间特征探索设计改造途径。

从社会使用需求角度而言，如何反映复杂的日常通勤和休闲需求是城市绿道选线的关键和难点。土地适宜性分析是目前绿道选线规划运用的主要方法[18]，且在大尺度非建成区的区域绿道选线中应用较多。该方法主要从生态、社会、文化等方面设立了绿道建设适宜性指标[19][20]。但是，由于建成区城市绿道的功能及尺度与区域绿道有着显著差异，因而区域绿道的评价指标无法很好地适配市民的日常通勤和休闲需求。而且，由于城市建成环境非常复杂，通过分析建成环境特征来获知社会使用需求也存在较大难度。今天，大数据技术的发展使得越来越多的研究开始通过大量的个人移动设备和互联网数据来反映社会生活的实际状况[21]，进而有效反映当前的交通出行行为模式[22][23]。这些数据除了可以反映居民的行为状态外，还带有空间和时间属性，可以用来描述空间在不同时间段所承载的使用行为特征[24][25]；相比调查问卷、访谈等传统抽样方法所得数据，大数据信息更为科学和全面；并且，随着数据挖掘、捕捉和解读技术方法的不断发展，数据有效性也将得到显著提升[26]。目前，大数据（包括共享单车[27]和公交刷卡大数据[28]）已经开始运用于绿道选线规划中的通勤目的地分析[29][30]。大数据在绿道选线规划，尤其是城市建成区绿道选线规划方面的应用潜力巨大。因此，对将传统空间数据与大数据相结合的城市绿道选线规划方法框架的探究是接下来的一个重要研究方向。

2 基于多源数据的城市绿道选线规划思路和框架

本研究针对城市建成区，以服务市民日常通勤和休闲需求为目标，着重探讨运用多源数据，构建基于GIS空间分析（绿道建设潜力空

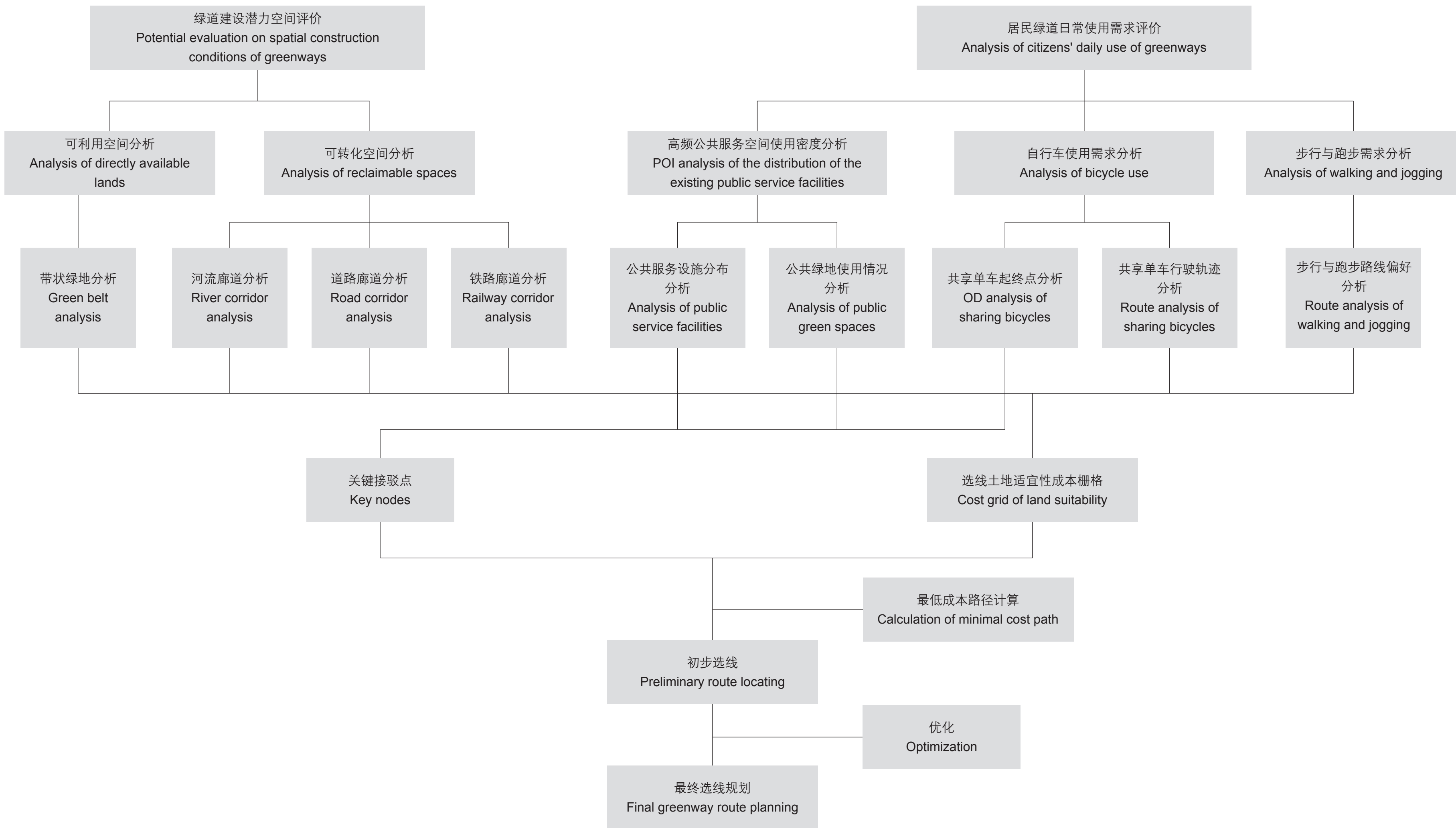
construction, and how to meet citizens' needs in their daily life.

In terms of the challenging spatial utilization in cities, most urban greenways are built through urban renewals in built-up areas[12], by leveraging the existing urban space network and the underdeveloped spaces. Existing studies explore the potential spaces for urban greenway construction, including urban green belts and the ancillary green spaces of linear infrastructure such as roads, railways, and waterways[13][14]. Contemporary urban renewal practices in cities such as Barcelona, New York, and Paris have integrated various urban services with existing greenways[6][14]-[17]. Future studies should focus on the greenway route improvement based on the spatial characteristics of potential sites, and the development of renovation solutions accordingly.

Another challenge to urban greenway route planning lies in how to meet the variety of commuting and recreational needs. Land suitability analysis is employed the most in greenway route planning[18], particularly in the ones in non-urban areas at regional scales. This method assesses the suitability to build greenways with ecological, social, and cultural metrics[19][20]. However, these metrics cannot well reflect urban residents' commuting and recreational needs due to the significant differences in the expected functions and scales between urban greenways in built-up areas and the regional ones. In addition, it is also difficult to identity citizens' real needs because the complexity of urban built-up environment makes analyses of physical characteristics unable to well indicate the patterns of user behaviors. The advance of big data technologies makes it possible to record citizens' real-time living activities with massive mobile devices and Internet data[21], which can be used as a tool to study the patterns of people's commuting behaviors[22][23]. Besides, such data also offers a lens to examine the spatial-temporal attributes of commuting behaviors[24][25]. Compared with traditional sampling methods such as questionnaires and interviews, big data analysis offers a more scientific and inclusive perspective which keeps advancing in data collection, accuracy, and interpretation over time[26]. Particularly, data collected from cities' sharing bikes[27] and bus passes[28] can be useful for identifying the hotspots of commuting destinations in the greenway route planning[29][30]. Given the promising potential of big data in greenway route planning for built-up urban areas, more efforts are expected to be invested in the development of the greenway route planning framework by combining traditional spatial data collection and big data analysis.

2 Urban Greenway Route Planning Framework Based on Multi-Source Data

This paper aims at developing a technology framework for greenway network identification for built-up urban areas (Fig. 2)



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2. 基于绿道建设空间潜力评价和居民绿道日常使用需求评价的城市绿道选线规划方法框架

2. Urban greenway route planning framework based on potential evaluation on spatial construction conditions of greenways and analysis of citizens' daily use of greenways

间评价）和大数据社会行为分析（居民绿道日常使用需求评价）的绿道网络识别技术框架（图2）。该框架可以随着相关数据源的增加而进一步扩展。

绿道建设潜力空间评价是在建成区空间结构基础上，找出最适宜建设的城市可利用空间（主要包括可直接利用的现有带状绿地）和可转化空间（主要包括现状河流、道路、铁路等各类线性基础设施的附属空间，这些空间可通过部分复合使用的手段转化为城市绿道建设空间）。

通过城市出行行为大数据分析，可得到市民目前在通勤和休闲方面的实际使用偏好，包括：1）高频公共服务空间使用密度分析，主要是通过公共兴趣点（POI）大数据分析城市现有公共服务设施分布和公

through a combination of GIS analysis (potential evaluation on spatial construction conditions of greenways) and big-data-based user behavior analysis (of citizens' daily use of greenways). The framework would work to meet citizens' commuting and recreational needs and can be further improved and upgraded along with the increase of related data sources.

Based on spatial structure and physical characteristics of built-up areas, potential evaluation on spatial construction conditions of greenways is to identify the lands that are directly available for greenway construction (including existing urban green belts) and convertible spaces that can be built into greenways through (partly) functional renewals (including affiliated green spaces of linear infrastructure such as rivers, roads, and railways).

Analysis of citizens' daily use of greenways is based on big data profiling of commuting behaviors and recreational preferences. Major public service and recreational nodes of

园绿地的使用情况，确定城市绿道的主要公共服务和休闲节点；2）共享单车起止点（OD）和行驶轨迹大数据分析，以获知目前市民自行车出行的主要公共服务节点和道路路线偏好；3）健身应用程序大数据分析，以获知目前市民在城市中的步行和跑步路线偏好。

基于以上分析，利用高频公共服务空间使用密度和自行车OD分析数据选取绿道关键节点；并通过绿道建设潜力空间评价以及共享单车、步行、跑步喜好轨迹评价建立绿道选线土地适宜性成本栅格；接下来，通过最低成本路径的循环计算，获得从每一栅格单元到其最近节点的最小累计成本距离与成本距离方向，并获得不同节点之间的最低成本路径，生成绿道初步选线方案；最后，对选线方案进行现场踏勘和空间校准，并对重叠路径进行合并，最终完成城市绿道选线规划。

3 北京市海淀区城市绿道选线规划实证

3.1 数据来源

3.1.1 潜力空间数据

以北京市海淀区高分二号遥感影像为潜力空间分析的主要数据源，通过监督分类目视解译收集所需的海淀区绿地和可转化的潜力空间分布信息，主要包括公园绿地、防护绿地，以及道路、河道、铁路等城市线性基础设施附属空间。

3.1.2 公共服务空间使用行为大数据

（1）公共服务空间使用密度数据

公共服务空间代表着市民日常出行中的主要城市空间，也是绿道规划建设的主要节点。本研究于2018年10月9日从Bigemap地图下载器上下载海淀区POI数据，通过空间匹配以及重分类后得到有效POI数据共计50万条，由此可获知海淀区现状商业、医疗、文化和办公等潜在慢行节点的分布情况。

（2）公园绿地使用活力数据

公园绿地是城市绿道连接的重要空间节点。高德地图热力图大数

urban greenways can be identified through POI (point of interest) analyses of the distribution of the existing public service facilities and the utilization of urban parks and green belts; analyses of OD (Origin to Destination) and traveling routes of sharing bikes reveal the public's preferences on service node usage and traveling routes; and, data collected from fitness Apps is used to analyze the walking and jogging routes preferred among most citizens.

Accordingly, based on the key nodes of greenways identified through the above analyses, a cost grid of land suitability can be roughly mapped out. The minimal cost distance between each cell and its nearest node(s), the direction of each cost distance, and the minimal cost path between each pairs can be identified with a loop calculation of minimal cost path. A greenway route can thus be primarily located. Through an on-site survey and spatial calibration, an urban greenway route planning can be completed after merging the overlapping sections.

3 Demonstration: The Greenway Route Planning in Haidian District, Beijing

3.1 Data Source

3.1.1 Data of Potential Spaces

The remote-sensing images of Haidian District from the GF-2 Satellite were used as the major data source for the analysis of potential spaces. Information on the distribution of green spaces and convertible spaces, including parks and green belts, green buffers, as well as ancillary spaces of linear urban infrastructure such as roads, waterways, and railways, was collected through supervised classification and visual interpretation.

3.1.2 Big Data of the Usage of Public Service Facilities and Spaces

(1) Data of the usage of public service facilities and spaces

The public service facilities and spaces are important to citizens' daily commuting, which should also be considered the major nodes of greenways. The POI data of Haidian District from Bigemap on October 9, 2018 was collected for this study and obtained 500,000 pieces of valid data, outlining the distribution of potential non-automobile nodes in commercial, medical, cultural, and office areas of Haidian District.

(2) Data of the usage of parks and green belts

Parks and green belts are important spatial nodes to

据可利用手机定位坐标信息实时反映某区域的用户数量与密度。本研究通过高德地图开放数据获取2018年4~10月期间海淀区公园绿地的使用人数，随后使用VBA语言对高德地图进行抓包统计，并导入ArcGIS软件生成空间栅格数据。

（3）共享单车数据

数据来自摩拜科技有限公司2016年9月30天的单车使用数据，在剔除与研究内容无关的信息后，获取了包括摩拜单车的OD数据及基于行驶轨迹数据的拟合道路数据。在本研究数据截取时段，摩拜单车有着北京市共享单车最大的用户群体和稳定可靠的定位数据，数据真实可信且具有代表性。

（4）跑步与步行道路偏好数据

对北京市民的跑步和步行热点线路进行分析，本研究对Keep应用程序中北京市海淀区在2018年12月9日的相关数据进行采集，共采集到推荐慢行路线330条，数据频次约25万次。这些推荐线路是用户长期以来使用频率最高的跑步线路，是平台自动计算后推荐给其他用户的一个累计优化的结果。在本研究数据截取时段，Keep使用用户超过2亿[31]，数据具有代表性。

3.2 绿道关键连接节点选取

3.2.1 公共服务空间使用密度分析

本研究首先将公共服务空间划分为商业、办公、医疗和文化4个类型，并分别选取每一类型的POI数据，随后运用ArcGIS软件进行可视化处理，得出海淀区这4种类型的公共服务空间分布密度热力图。本研究认为这4种类型空间同等重要，对分别计算出来的核密度进行重分类后等权叠加，最终得出海淀区综合公共服务空间分布密度热力图（图3）。

3.2.2 公园绿地使用活力分析

通过将海淀区各绿地的累计访问人数进行收集分析，并运用

the connectivity of urban greenways. The hotspot map from Amap reflects the real-time user amount and density in a certain area based on the mobile GPS. The study team obtained the user amount of the parks and green belts in Haidian District from April to October, 2018 based on the open data of Amap. The acquired data was then calculated through packet-capture calculation with VBA (Visual Basic for Applications) and processed into spatial grid data with ArcGIS.

(3) Data of sharing bikes

In this research, data from the Mobikes in Beijing was collected from September 1 to 30, 2016, including ODs and the fitting data of roads acquired based on travelling trace analyses. As of the time when the data was collected, Mobike had the largest user population and owned dependable positioning data, which is considered an authentic and reliable data source.

(4) Data of preferred running and walking routes

To identify the preferred running and walking routes, the authors collected related data (approximately 250,000 pieces) on December 9, 2018 from Keep App and obtained 330 recommended non-automobile routes. The recommended routes ranked top in terms of the long-term travelled frequency based on an automatic and cumulative computation. As of the time when the data was collected, the user amount of Keep was more than 200 million[31], which is considered an authentic and reliable data source.

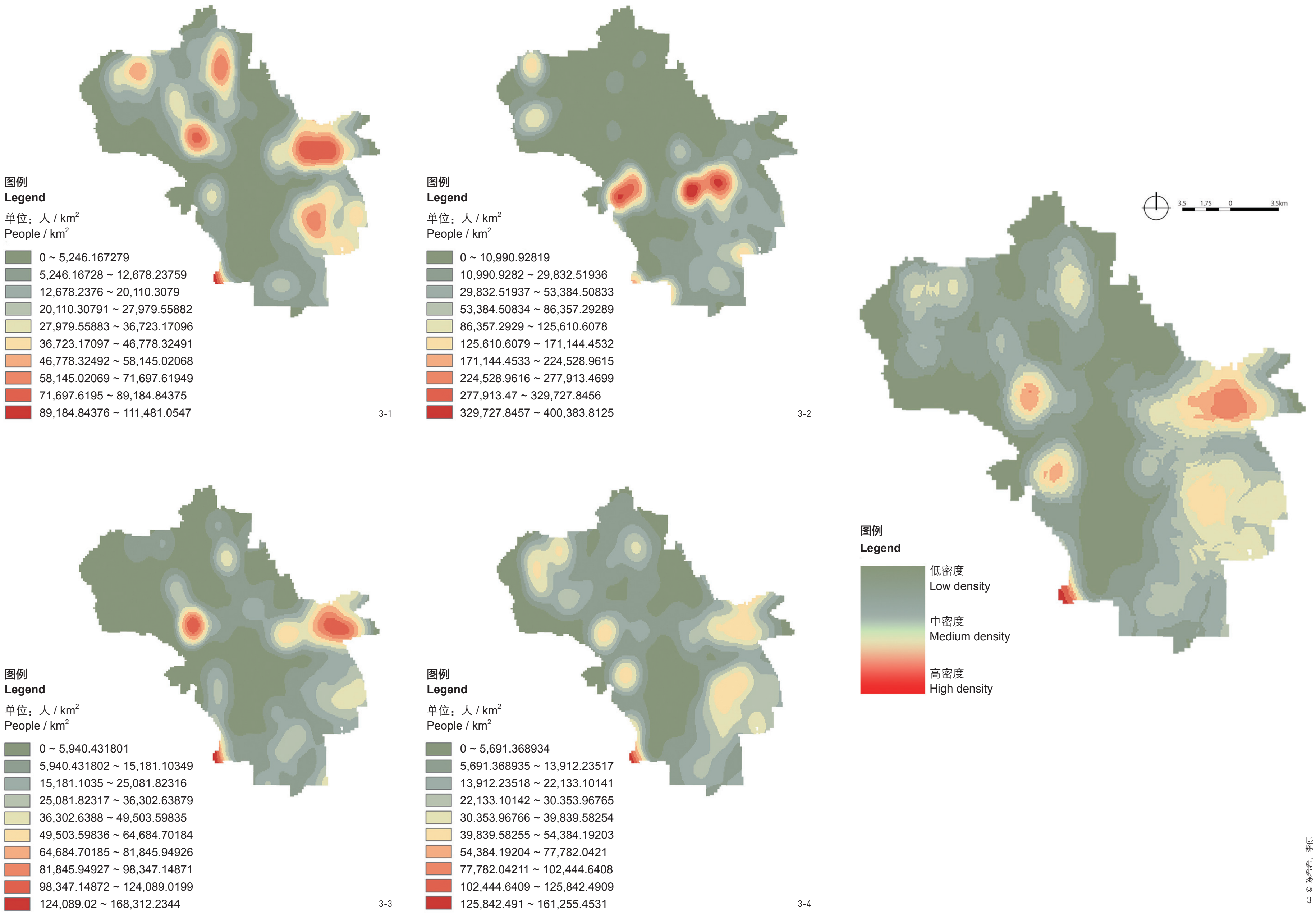
3.2 Identify Key Nodes of Greenways

3.2.1 Analyses of the Usage of Public Service Facilities and Spaces

This study classified the public service facilities and spaces into four categories, namely commercial, office, medical, and cultural, and then by visualizing the POI data of each category with ArcGIS, four hotspot maps of the distribution of public service facilities and spaces were obtained. The research attached equal weight to the usage density of each category, re-categorized kernel density after a weighted-stack calculation, and generated the hotspot map of the distribution of the public service facilities and spaces in Haidian District (Fig. 3).

3.2.2 Analyses of the Usage of Parks and Green Belts

Based on the statistics of the total visits of each park or green belt in Haidian District, the research weighted the usage intensity in these areas with ArcGIS and obtained an overall hotspot map of usage intensity of parks and green



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ArcGIS软件为各绿地内的活动强度赋值，得出海淀区绿地活力等级分布图（图4）。绿地使用人数越多，活力等级越高。

3.2.3 共享单车OD数据节点分析

共享单车OD数据可以反映出市民自行车出行和换乘公共交通的目的地热点，这些节点将是城市绿道需要重点考虑的驳接服务点。本研究将海淀区划分为10m × 10m的网格，通过统计每个单元栅格中的共享单车数量，得到研究区域内共享单车OD栅格数据；而后通过数据可视化分析，得到日均共享单车使用空间分布热力图（图5）。

belts in the district (Fig. 4), the more visits a green space had, the higher usage intensity it had.

3.2.3 OD Analyses of Sharing Bikes

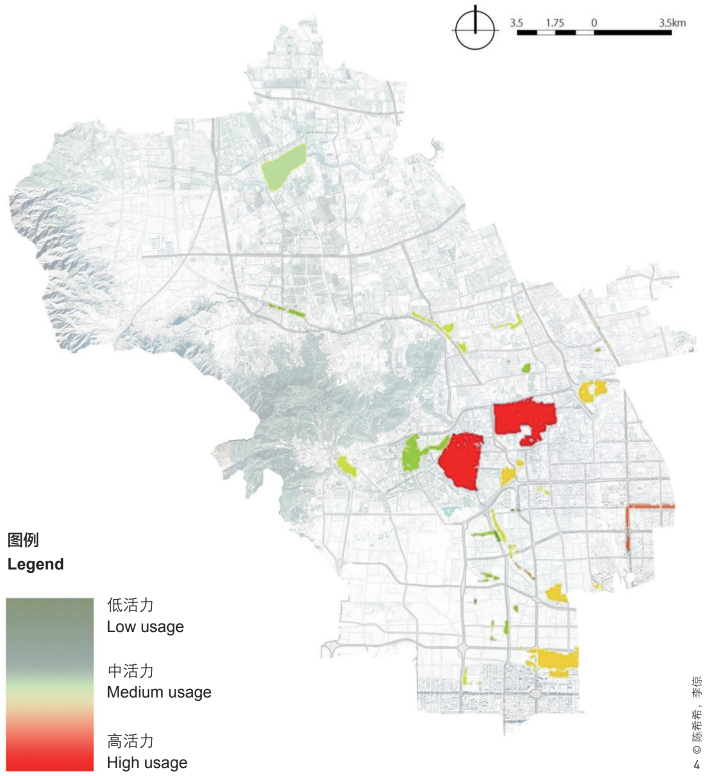
The OD data of sharing bikes reveals the hotspots of destinations that connect the city's cycling and other public transportation rides. Such destinations are considered key nodes of urban greenways. In this research, the district was divided into 10 m × 10 m grids, and the amount of sharing bikes in each grid was counted so as to obtain an overall OD statistics of the study

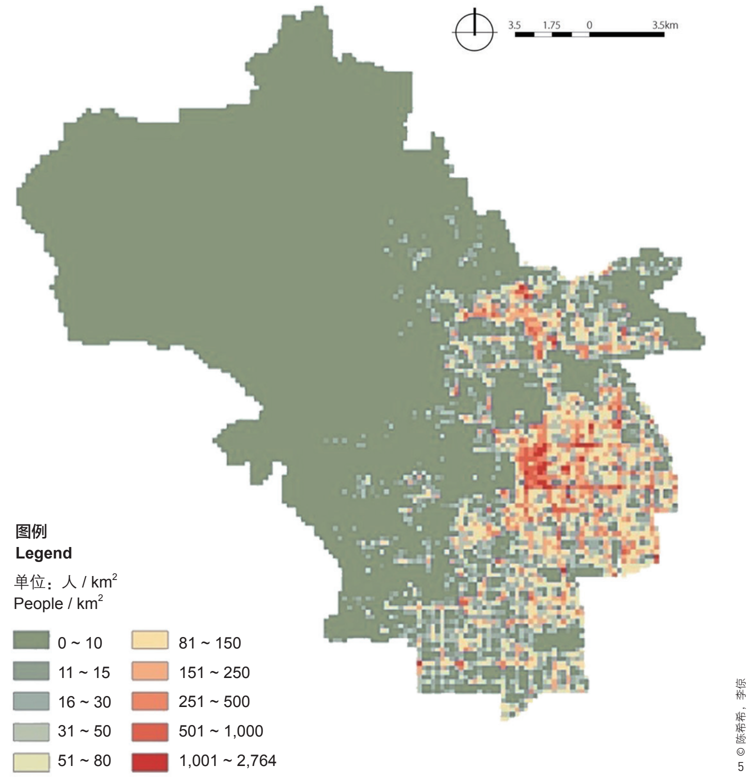
3. 海淀区综合公共服务空间分布密度热力图（4种类型的公共服务空间依次为商业、办公、医疗、文化）

3. Hotspot map of the distribution of the public service facilities and spaces in the commercial, office, medical, and cultural areas in Haidian District

4. 海淀区绿地活力等级分布图
5. 海淀区共享单车OD空间分布热力图

4. Hotspot map of usage intensity of green spaces in Haidian District
5. Hotspot map of the distribution of the OD data of sharing bikes in Haidian District





3.2.4 关键连接节点分析

运用ArcGIS软件分别对以上三组分析数据进行重分类，划分为10个等级，分别赋值1~10；热力等级越高，表示该节点越为关键。随后通过将重分类后的等级进行等权叠加分析，重新得到10个等级（图6），最终筛选出热力等级为10的40个核心连接节点（图7）。由于海淀区的中心建成区和城郊区发展不均衡，这种无差别化的活力分布分析标准，导致核心连接点全部位于海淀区中心建成区，城郊区无连接节点覆盖。因此，考虑到绿道建设公平性因素，本研究对模型进行了优化：将城郊过渡区的连接节点热力等级筛选标准调整为7，最终在城郊区得到5个新增连接节点（图8）。

3.3 绿道关键潜力空间分析

3.3.1 绿道建设潜力空间分析

现状带状绿地和线性基础设施附属用地具有绿道建设的利用和转化潜力，是建成区内城市绿道建设的核心可利用空间。通过应用遥感影像数据并监督分类目视解译收集所需的海淀区绿地空间分布信息，对海淀区中的水系廊道、线性绿地和铁路廊道等城市线性空间类型进

area. The OD data was then visualized into a hotspot describing the distribution of citizens' daily use of sharing bikes (Fig. 5).

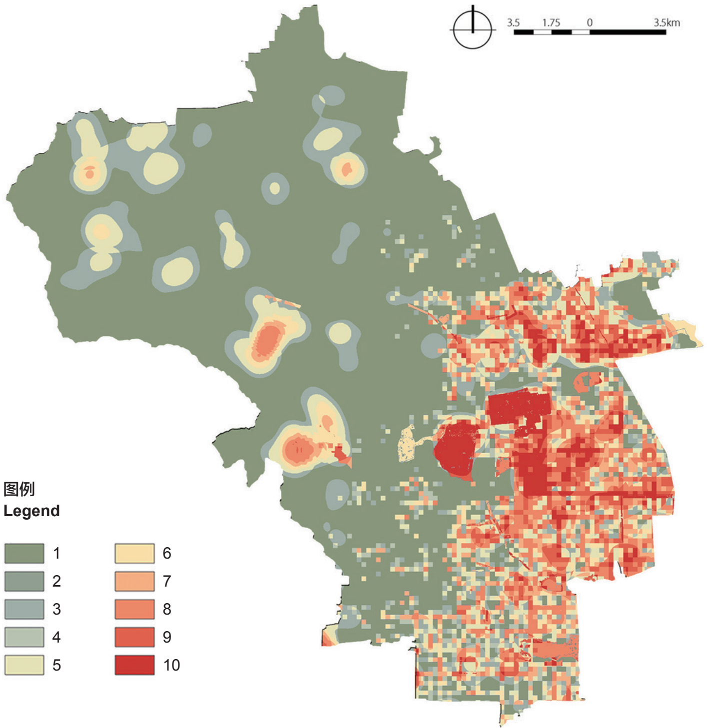
3.2.4 Key Nodes

ArcGIS was employed to re-classify the data on the usage of public service facilities and spaces, parks and green belts, and sharing bikes and valued all the spatial elements into 10 grades, the higher grade a spatial element has, the higher usage level it has. By re-classifying the findings through the weighted stack method, ten grades were re-overlaid (Fig. 6) and a total of 40 key nodes (at the grade of 10) were identified (Fig. 7). Given the uneven physical development among central built-up areas and suburban areas in the study area, an undifferentiated analysis standard of the distribution of usage levels of spatial elements resulted in all the key nodes in the urban areas and no one in the suburban. To ensure the social equality, the research lowered the screening standard in suburban areas to grade 7 and five new key nodes were identified (Fig. 8).

3.3 Potential Evaluation of Key Space of Greenways

3.3.1 Potential Spaces for Greenway Construction

To built-up areas, existing green spaces and ancillary spaces of linear infrastructure are ideal spaces that can be used directly or reclaimed into greenways. Data on the distribution of green spaces in Haidian District was collected through supervised classification



将核密度进行重新分类，划分为10个等级，分别赋值1~10
By re-classifying the findings, ten grades were re-overlaid and valued from 1 to 10 respectively

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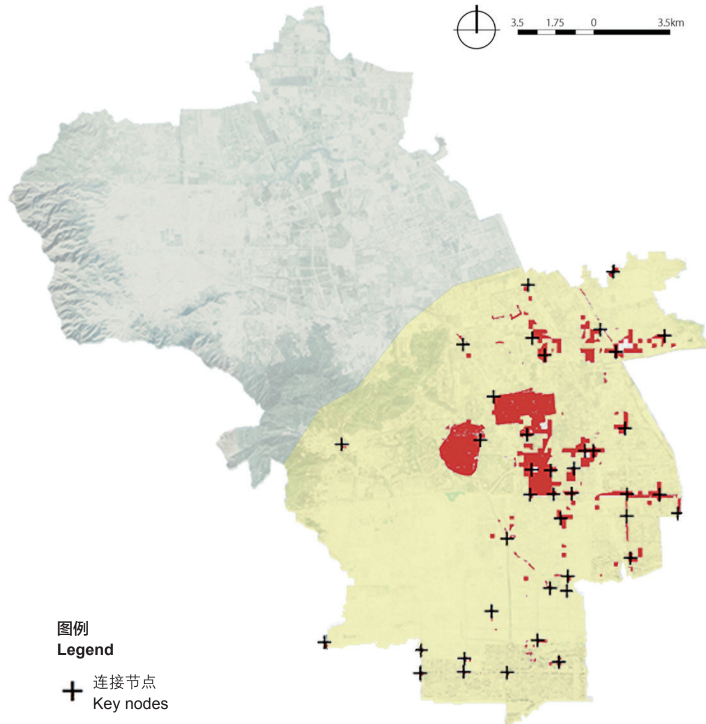

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6. 海淀区绿道空间节点热力图
7. 海淀区中心建成区绿道连接节点选点图
8. 海淀区城郊区绿道连接节点选点图

6. Hotspot map of spatial elements along the greenways in Haidian District
7. Key nodes of the greenways in urban areas of Haidian District
8. Key nodes of the greenways in suburban areas of Haidian District

行了提取，并分别生成了水系廊道分布图、线性绿地分布图及铁路廊道分布图（图9~11）。

3.3.2 慢行高频使用道路空间分析

（1）共享单车骑行道路偏好分析

研究通过将共享单车GPS轨迹点与实际路网匹配，获得目前共享单车骑行轨迹信息，并分析市民的路线偏好；随后通过ArcGIS软件进行可视化分析，生成共享单车道路使用热力图（图12）。研究分析所得的高频率空间在绿道选线中具有更高的慢行交通出行服务改造优先级。

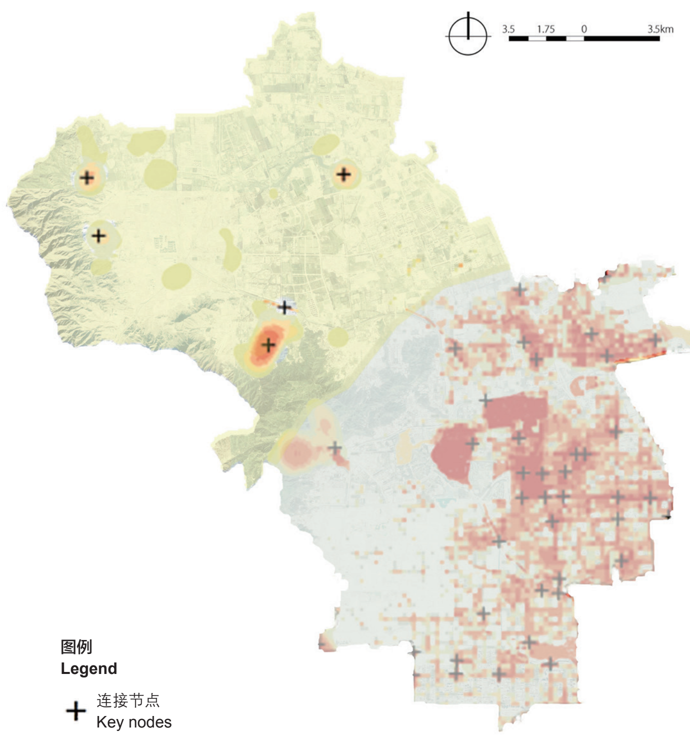
（2）步行与跑步道路偏好分析

研究根据Keep提供的数据，获得了目前市民步行、跑步的路线偏好（图13）。这些路线在城市绿道的选线中具有更高的土地适宜性。

3.4 最低成本路径选线和优化

运用ArcGIS软件分别对以上数据进行重分类和等权叠加，得到绿道选线土地适宜性成本格栅图（图14）。运用“成本路径”工具，以确定的45个绿道重要连接节点作为起点与终点，以绿道选线适宜性地图作为成本栅格图层，获得连接节点之间的最低成本路径（图15）。

为了提升城市绿道的连通性，在研究所得的绿道最低成本路径选线的基础上，结合现场调研（重点考察城市现有路网及建筑布局等客观限制因素），并通过与现状空间拟合及合并，最终形成一个连贯的城市绿道网络，完成了研究区域内的城市绿道选线规划（图16）。



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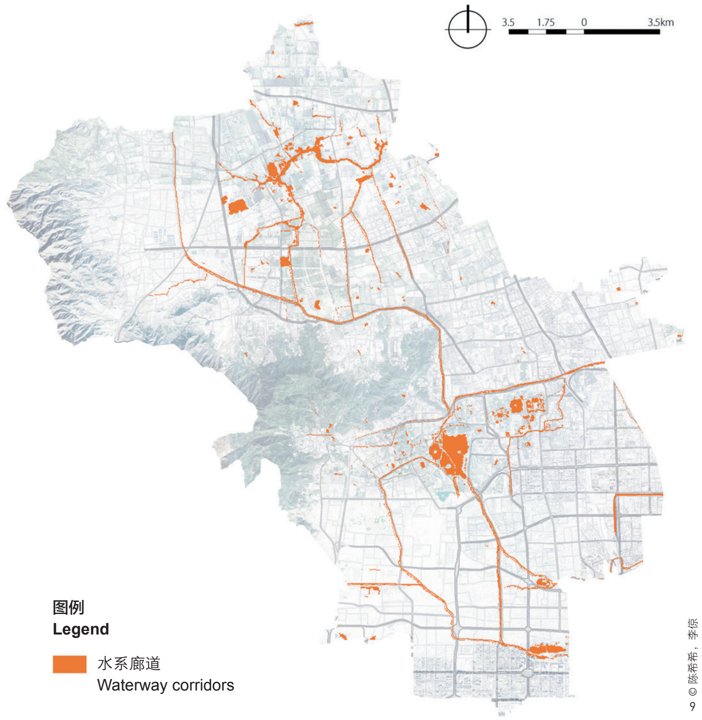
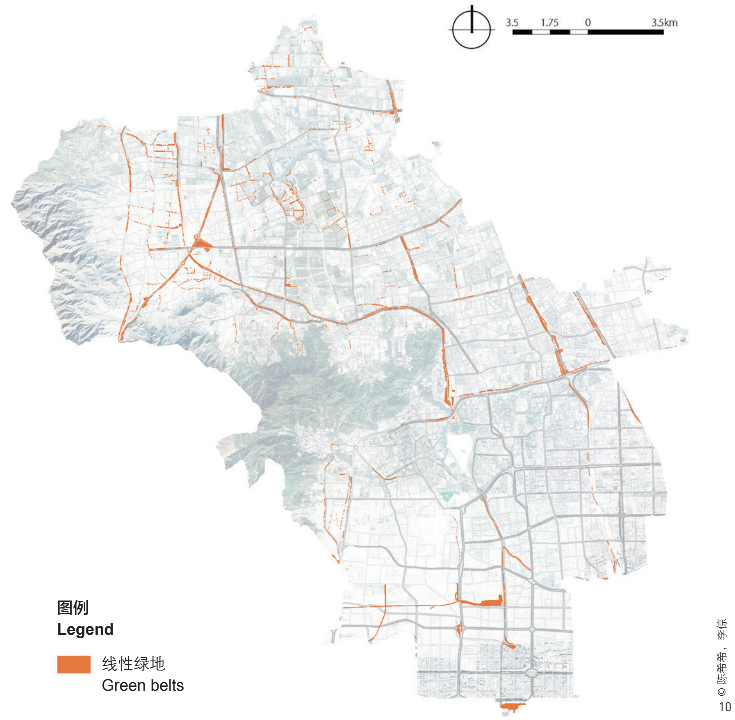
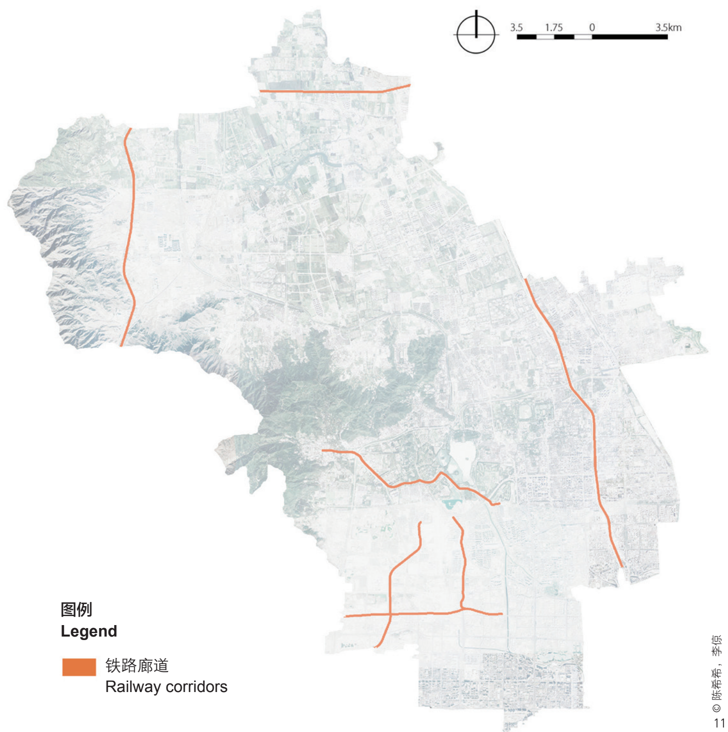
9. 海淀区水系廊道分布图
10. 海淀区线性绿地分布图
11. 海淀区铁路廊道分布图

9. Potential waterway corridors for greenway construction in Haidian District
10. Potential green belts for greenway construction in Haidian District
11. Potential railway corridors for greenway construction in Haidian District







and visual interpretation based on the remote-sensing images to identify the potential linear spaces for greenway construction, ranging from waterway corridors, green belts, and railway corridors, which are shown as Figure 9, 10, and 11, respectively.

3.3.2 Analyses of the Distribution of Frequently Used Roads for Non-Automobile Commuting

(1) Preferred routes of sharing bike rides

Match the GPS traces of sharing bikes with actual city roads to map out the preferred routes of sharing bike rides. The data was then visualized with ArcGIS in form of a hotspot map (Fig. 12). The frequently used roads are the ones of higher priority to be re-constructed into greenways for non-automobile commuting.

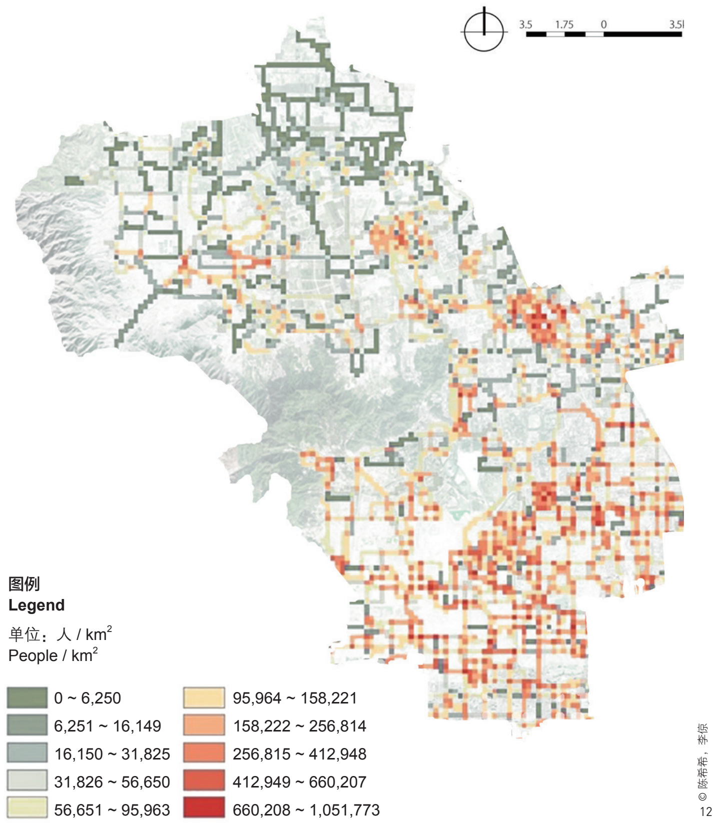
(2) Preferred routes for walking and jogging

Analyses of the data from Keep was used to identify the preferred routes for walking and jogging (Fig. 13), revealing the roads that are of higher land suitability to construct urban greenways.

3.4 Route Locating and Optimization Based on Minimal Cost Path Calculation

The cost grid of land suitability to construct greenways was generated by re-classifying and equally weighting the data with ArcGIS (Fig. 14), based on which the minimal cost path calculation among the 45 key nodes was conducted (Fig. 15).

As the final step of the route planning process, based on the minimal cost path calculation above, the research combined with on-site surveys



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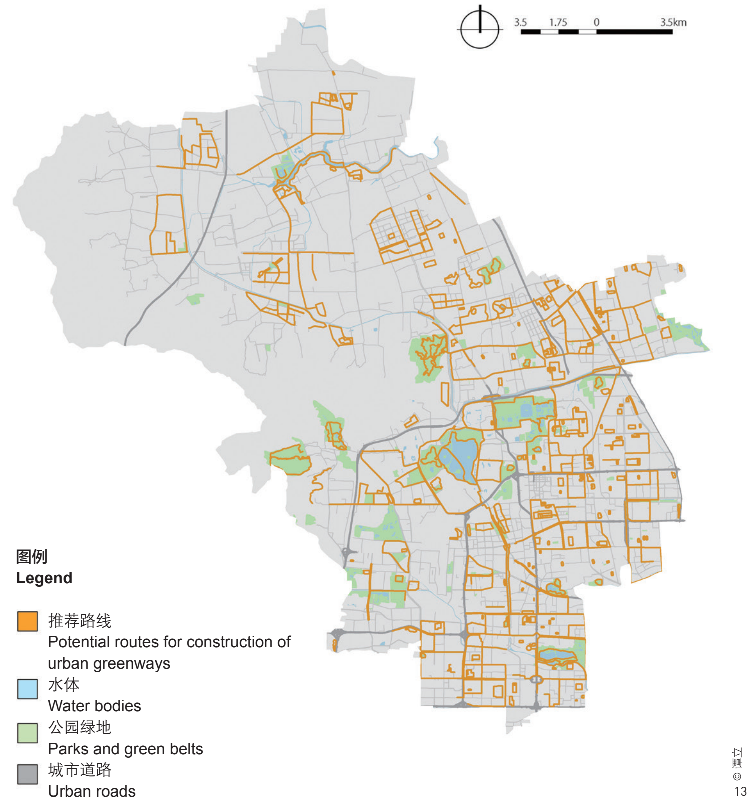

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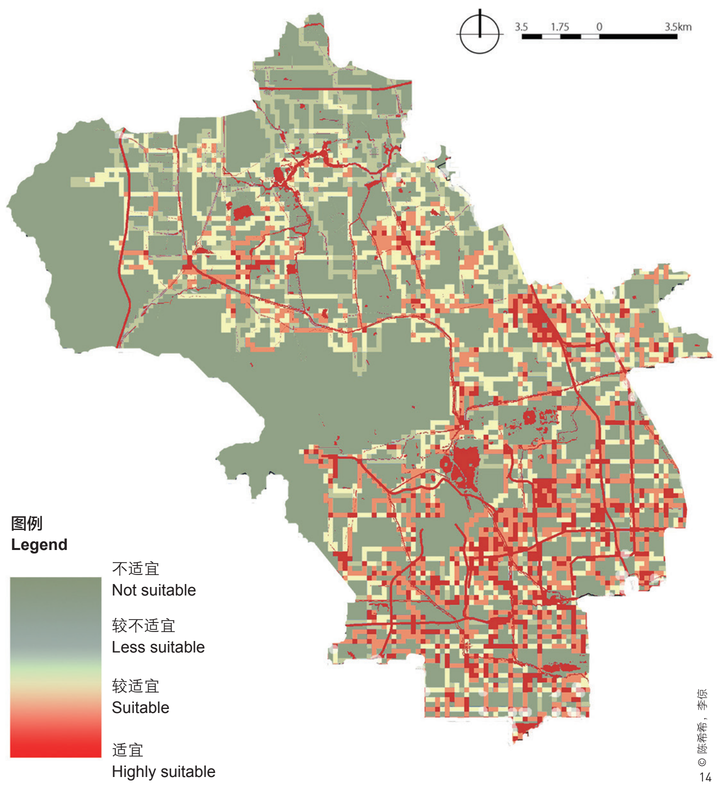

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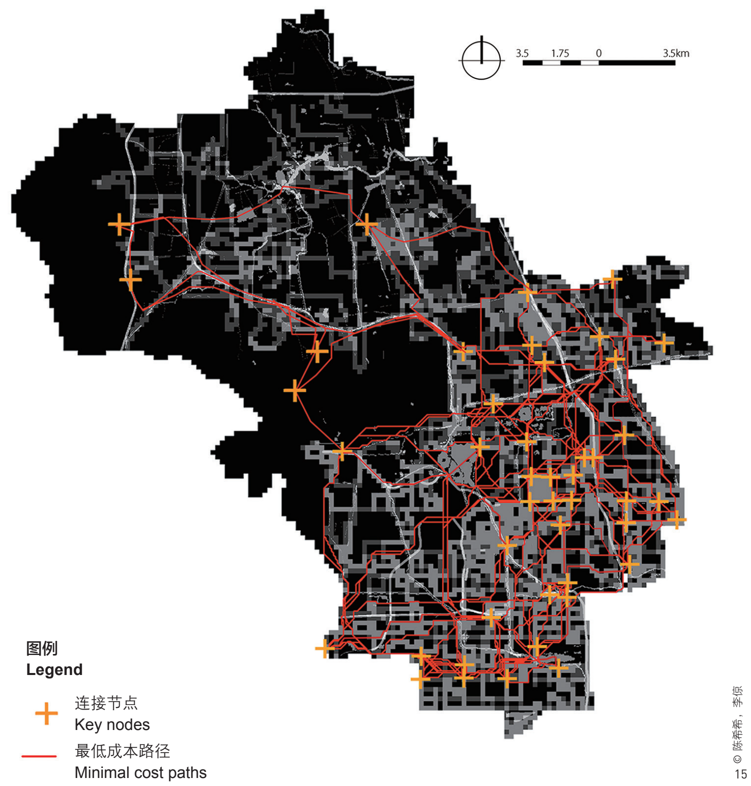

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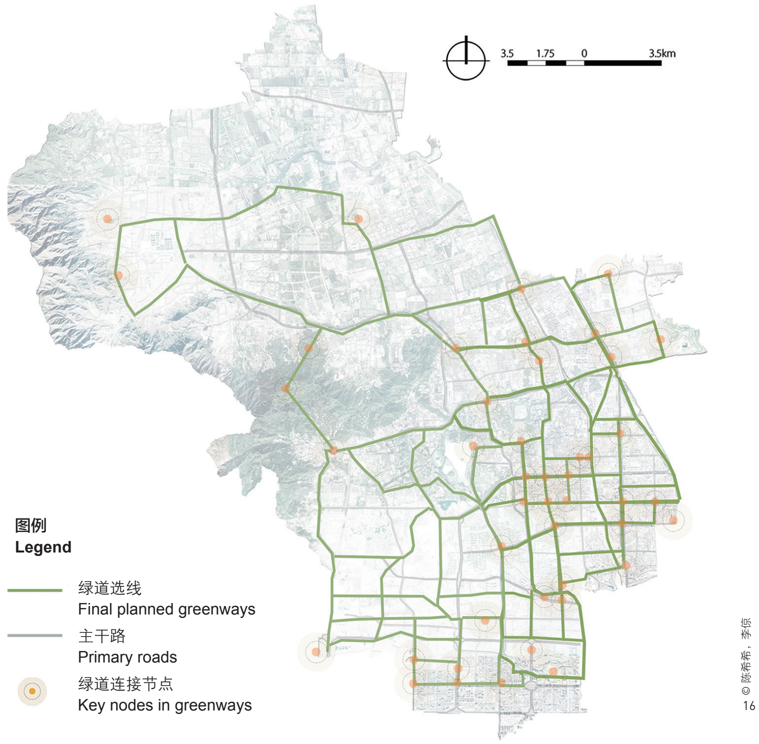
12. 海淀区共享单车道路使用热力图
13. 海淀区步行、跑步喜好道路分布图
14. 海淀区绿道选线土地适宜性成本格栅图
15. 海淀区绿道最低成本路径选线计算结果图

12. Hotspot map of the frequently used roads of sharing bike rides in Haidian District
13. Preferred routes for walking and jogging in Haidian District
14. Cost grid of land suitability for greenway construction in Haidian District
15. Minimal cost path calculation in greenway locating for Haidian District

16. 优化后的海淀区城市绿道选线规划图

16. Optimized urban greenway route planning for Haidian District



4 海淀区城市绿道构建模式

根据选线规划，海淀区城市绿道建设主要依托现有的城市道路、河流和铁路廊道。道路廊道是未来海淀区城市绿道建设最主要的空间，通过复合利用和路权的重新分配，部分现有城市道路廊道可以转化为城市绿道的重要潜力空间；部分河道廊道和各类防护绿地也可直接纳入或改造为城市绿道。随着城市的发展，铁路附属绿地具有绿道建设潜力，部分废弃铁路空间可通过改为地下通行等方式转化成为绿道潜力空间；这些现状潜力空间变化丰富和复杂，因此本研究对这些空间的特征进行了梳理，并针对不同的空间类型提出了多种可供选择的构建模式，以为规划实践提供更具针对性的指导建议。这些构建模式策略不仅适用于海淀区城市绿道建设，对其他区域实践也具有较高的借鉴意义。

4.1 依托道路的城市绿道构建模式

道路改造的核心目标是为市民的慢行交通出行创造更加安全、舒适的环境。改造主要采用地面路权重新分配和道路分层两种形式（图17）。

地面道路路权重新分配的改造模式强调以步行和骑行为主的慢行交通路权的回归，是一种城市道路交通发展思路的转变。路权重新分配有多种组合方式：对于可利用空间较少且缺少慢行系统的道路，可以将部分机动车道作为慢行空间；对于可利用空间较大且景观较好的道路，可在道路中间设置多功能的步行道和自行车道；对于景观或商业集中在道路单侧的情况，可仅将慢行交通系统设置在同侧。通过这种道路路权重新分配模式，城市慢行交通系统得以保障，道路公共活

(on the physical constraints in the existing road network and building layouts), as well as the fitting between the candidate and actual routes, a connected urban greenway network in the study area was identified (Fig. 16).

4 Construction Strategies of Urban Greenways for Haidian District

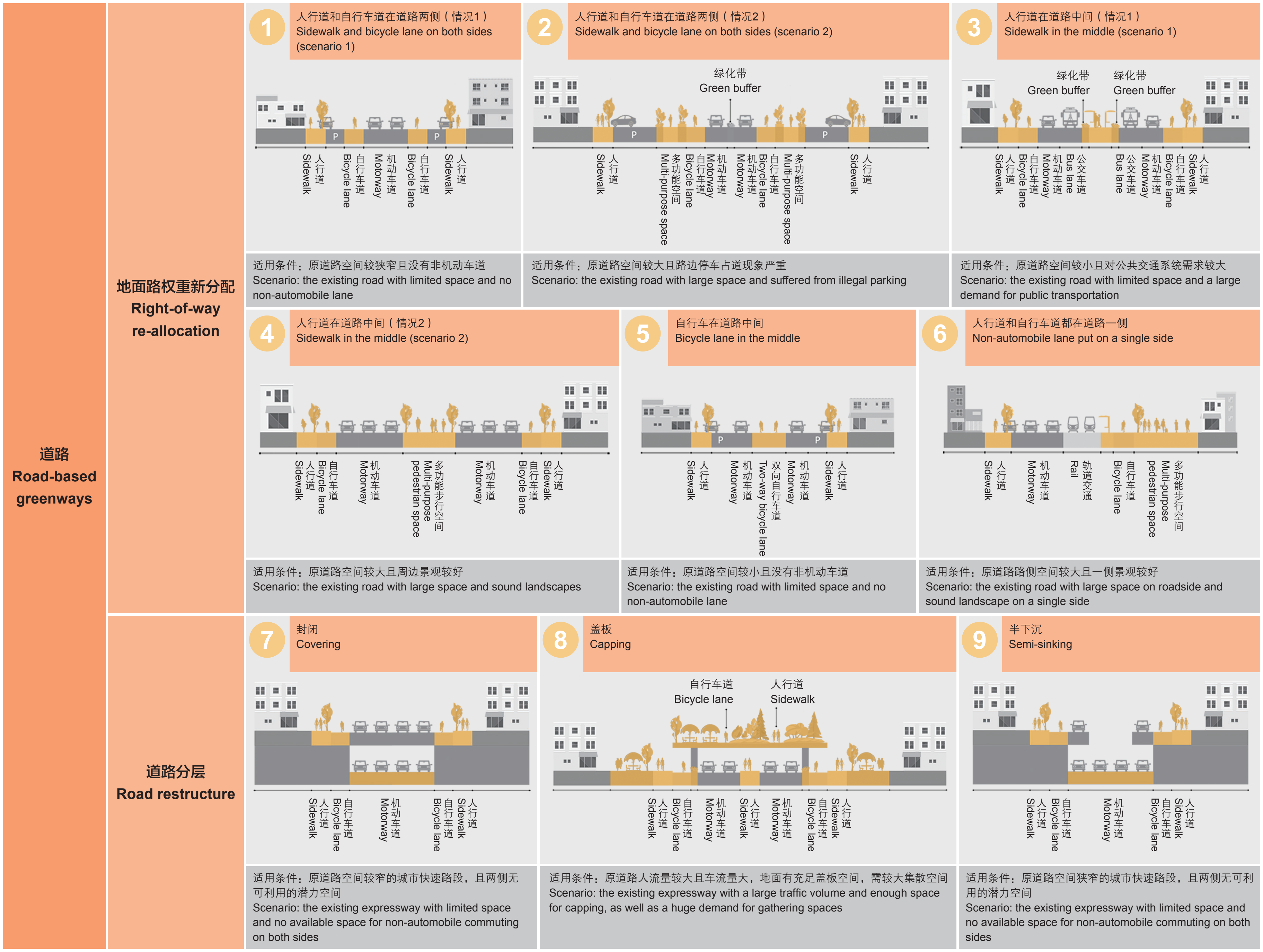
In the planning scheme, urban greenways in Haidian District would mainly employ the existing corridors of roads, railways, and waterways. Particularly, road corridors are the most important spaces for urban greenway construction, parts of which are of great potential to be reclaimed by adding new functions of the roads and re-distributing the right-of-way. Several waterway corridors and green buffers are sound for transformation into urban greenways. Ancillary green belts in railway corridors are also of high potential in contemporary context of urban development, and parts of derelict railways can be re-constructed into sunken or underground greenways. The potential spaces for greenway construction in the study area saw a variety of spatial characteristics that are continuously changing over time. The research ranged them and proposed different construction strategies accordingly. These strategies might offer references for both Haidian District and other similar planning practices.

4.1 Construction Strategies for Road-Based Urban Greenways

The core goal of such transformation is to create safe and convenient non-automobile commuting environment for citizens, and in the forms of right-of-way re-allocation and road restructure (Fig. 17).

Transformation through right-of-way re-allocation is to re-introduce or enlarge the right-of-way for non-automobile commuting, in line with the ideological change in transportation construction in cities. Specifically, for roads with no non-automobile lanes and limited space available for greenways, part of existing motorways can be converted into non-automobile lanes; for roads with good landscapes and larger available spaces, multi-purpose walkways and bikeways can be set up; and for roads with landscapes or stores on a single side, non-automobile lane(s) can be put in place along. Such right-of-way re-allocations not only ensure the validity of non-automobile commuting system, but also help activate public urban spaces. In the long run, more diverse and environment-friendly non-automobile commuting modes would be created and help reduce vehicle traffic.

For the urban roads with large traffic volumes, such as



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力得以提升。长远来看，这将促进城市发展出更加多元、环保的慢行交通方式，降低机动车使用量。

此外，对于城市快速路等交通流量较大的城市道路，可以采用封闭、盖板、半下沉三种途径实现道路空间的分层利用，在城市中创建更多的慢行空间。此种改造模式往往耗资较大，且技术难度较高，但目前这种模式也正在被越来越多的城市，尤其是高土地价值的城市所采用。针对城市中心区内对周边产生噪音、污染等影响的城市快速

urban expressways, the transformation can be realized through road restructure such as covering, capping, and semi-sinking so as to create more non-automobile spaces. This might require larger investments and sophisticated technological supports. But it has gone popular among more cities, especially those which have a higher land price. City expressways in downtowns that might cause air or noise pollution can be fully or partially covered to make more room for greenways. For expressways with limited room for sinking, the capping measures might be applicable.

17. 海淀区依托道路的城市绿道构建模式图
18. 海淀区依托河道的城市绿道构建模式图

17. Construction strategies for road-based urban greenways for Haidian District
18. Construction strategies for waterway-based urban greenways for Haidian District

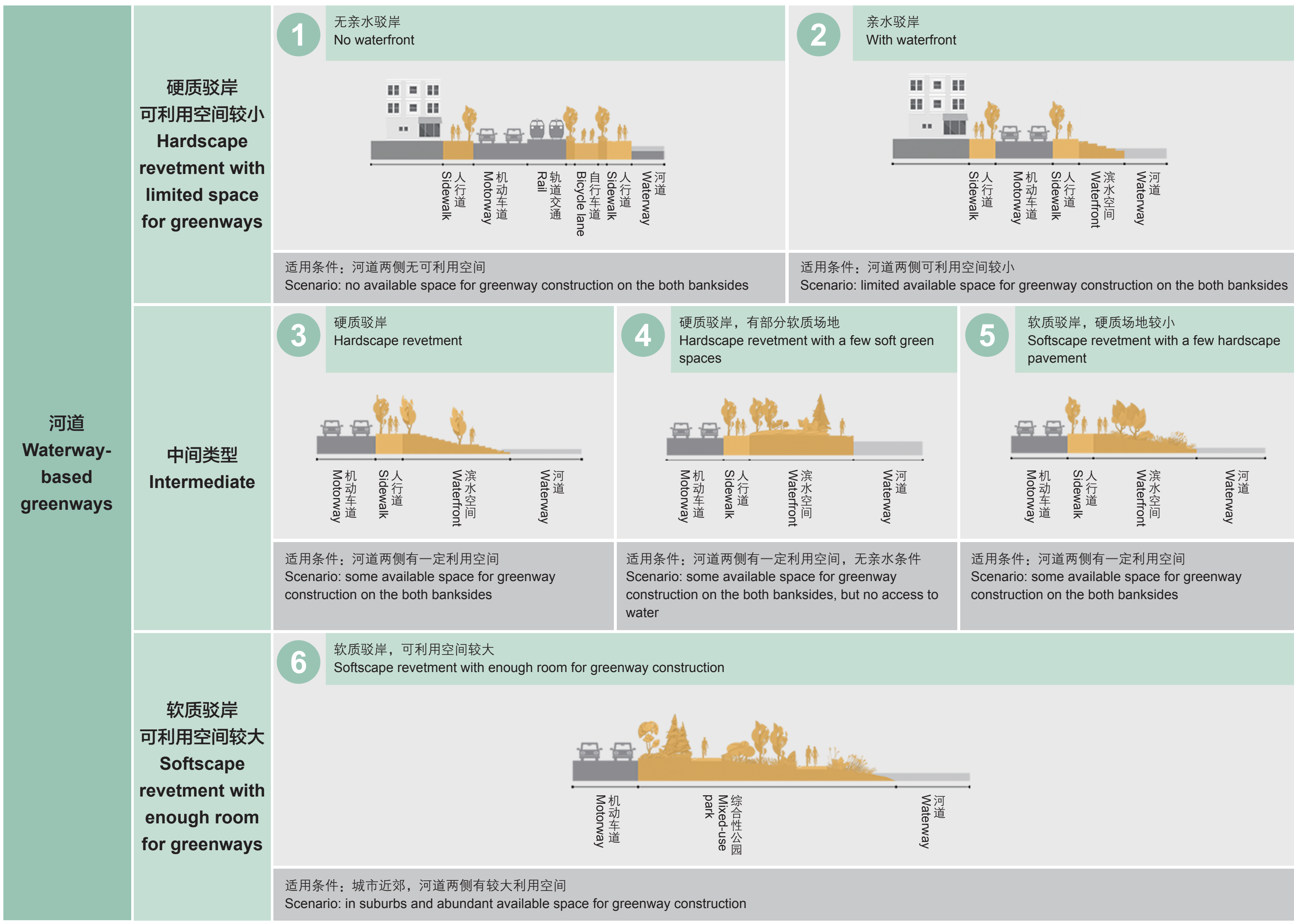
路，可以采取全覆盖（封闭）或半覆盖（半下沉）的方式增加可用于绿道建设的空间。在一些快速路下沉受限的区域，也可以采用盖板的方式来增加绿道建设可利用空间。

4.2 依托河道的城市绿道构建模式

根据研究区域内渠化河道断面情况（图18），对于河道两侧无可利用空间的河段，可以调整城市市政道路断面，增设滨水步道和自行车道；对于河道两侧可利用空间较小的河段，可视具体条件建设亲水型驳岸（如亲水台阶）。当河道两侧有一定的可利用空间时，可视具体条件以台阶和步道相结合的方式设置硬质亲水驳岸或建造滨水绿化带形成软质生态驳岸。河道两侧可利用空间较大的情况多出现于城郊地区，可通过建设带状公园的方式与城市绿道相结合。

4.2 Construction Strategies for Waterway-Based Urban Greenways

Transformation strategies for the canalized waterways in the study area vary according to their cross-sections (Fig. 18). For waterways with no available space on banksides, the adjacent road can be partly converted into greenways while waterfront sidewalks and / or bikeways can be built; for waterways with limited available space on banksides, revetments (such as waterfront terraces) can be built, depending on specific conditions; for waterways with some space available for greenways construction on banksides, hard waterfronts can be built by combining terraces with walkways, or ecological soft revetments can be built by creating landscaped waterfronts; and for waterways with enough room for greenways (mostly in suburbs), belt-shaped parks can be introduced and integrated into urban greenways.



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4.3 依托铁路廊道的城市绿道构建模式

根据城市铁路断面情况，研究区域内的铁路廊道分为高架铁路、地面铁路、地下铁路三类（图19）。对于高架铁路，主要利用桥下空间建造绿道和公共休闲空间；对于地面铁路，需要在铁路周围加设防护隔离设施，而高速铁路可采用铁路盖板，并在其上建设绿道；对于地下或半地下铁路，可以合理利用其地上的线性空间进行绿道建设。

利用铁路廊道进行绿道设计是时下国际实践的一大热点，且实践发现上述策略不受铁路沿线建筑物高度的影响。城市规划者对于不同项目案例所选用的策略与措施需视场地具体条件而定。

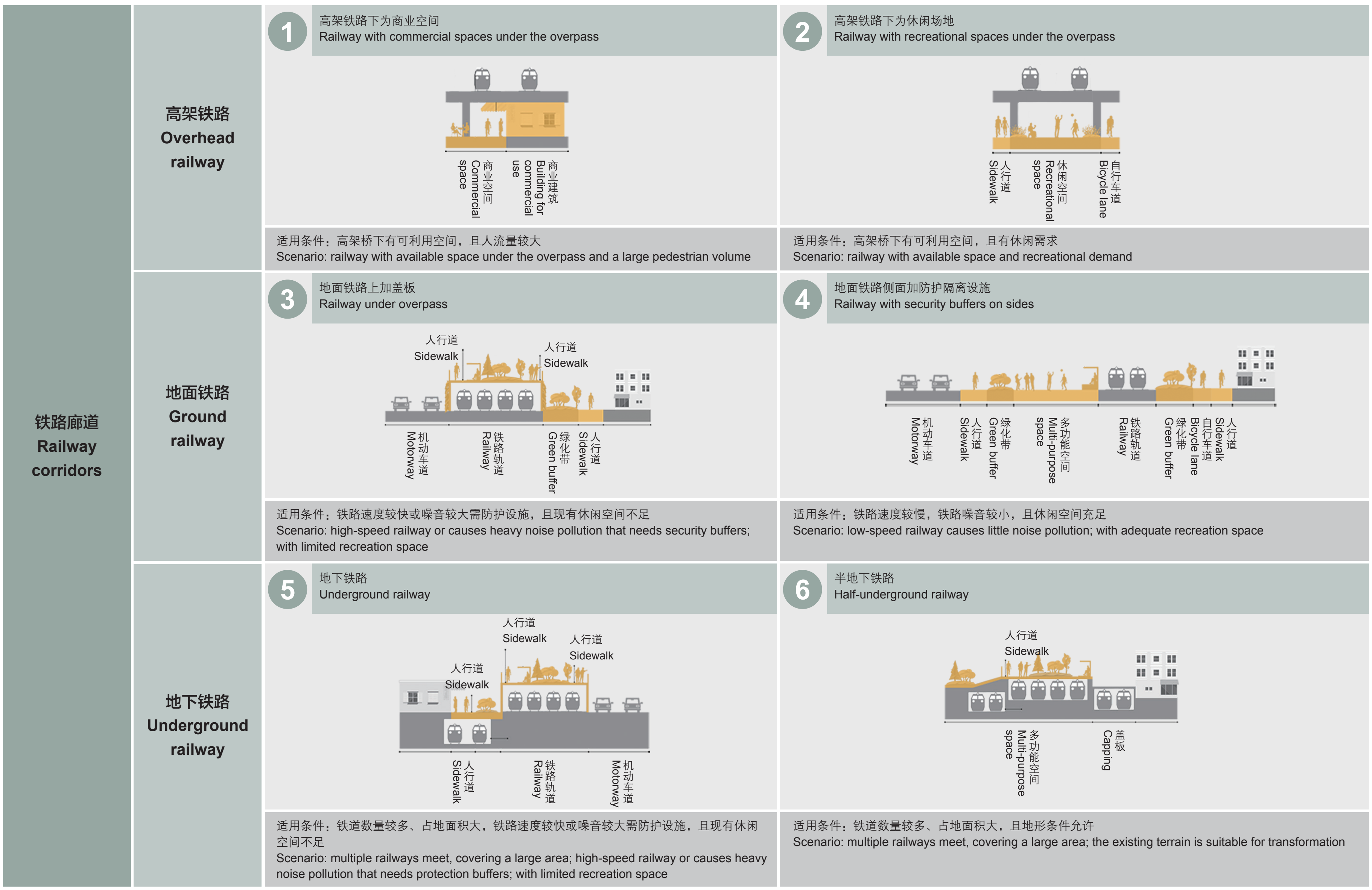
4.3 Construction Strategies for Railway-Based Urban Greenways

Overhead railways, ground railways, and underground railways are found in the study area (Fig. 19). For the first, the space under overpasses can be adopted as greenways and other public recreational spaces; for the second, security buffers or facilities must be in place, and capping measures can be employed over the high-speed railways to create elevated greenways; and for the third, be it fully-underground or half-underground, the linear ground space above the railways can be used for greenway construction.

Railway-based greenways are popular worldwide. Relevant practices suggest that the strategies discussed above are little impacted by the height of buildings in the surroundings. The strategies and specific measures should be smartly adopted to the actual conditions of sites.

19. 海淀区依托铁路廊道的城市绿道构建模式图

19. Construction strategies for railway-based urban greenways for Haidian District



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5 讨论与总结

本研究基于市民的日常慢行通勤和休闲活动需求，从空间潜力和社会行为两方面分析在城市建成区建设绿道的空间利用要求，探索复杂城市建成环境中的城市绿道选线规划方法；之后以海淀区为例，对规划框架方法进行实证研究，并针对研究区域内城市绿道建设可利用的道路、河道、铁路廊道和带状绿地等主要空间，提出了一系列改造模式策略，将绿地与慢行系统相结合，以实现城市线性空间的功能优化。

虽然目前大数据的产生主要来源于使用智能手机应用程序的人群，但也能在一定程度上反映社会的实际使用特征。未来随着这类使用人群的不断扩大，数据覆盖度和精度都将不断提高；而且，随着更多数据的加入，可以不断扩充和完善本研究提出的选线框架方法，提升其科学性和准确性。本研究针对研究区域现状场地条件的差异性所提出的改造策略，亦可随之得到进一步优化和拓展，并有可能产生更具创造性的解决方案，进而应用于其他地区的城市绿道建设之中。**LAF**

5 Discussion and Conclusion

This research, by analyzing citizens' daily needs in non-automobile commuting and recreation opportunities, explores how to build greenways in built-up urban areas from aspects of spatial potentials and social behaviors and arrives at a framework for such urban greenway route planning practice. Demonstrating the authentic planning case for Haidian District, Beijing, the research proposes a series of construction strategies to urban corridors of roads, waterways, and railways, respectively, which integrate green spaces with non-automobile system, in order to improve the services of linear spaces in cities.

App-generated big data shows its representative significance nowadays though most Apps are smart phone borne. Along with the increase in the amount of App users, the data coverage and accuracy would see a remarkable improvement. Also, the increasingly diversified data sources would help enrich and improve the proposed route planning framework and methods in scientificity and accuracy. The according strategies would be optimized as well. More innovative solutions are expected in future research and practice of greenway construction for urban areas. **LAF**

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