



1. 通过空间句法模型分析
后生成的朝阳广场设计
效果图

1. Rendering of the
Chaoyang Square based
on the analysis of Space
Syntax model

基于空间句法模型的数据化城市设计 ——以吉林市朝阳广场设计为例

THE APPLICATION OF SPACE SYNTAX MODELING IN DATA-BASED URBAN DESIGN — AN EXAMPLE OF CHAOYANG SQUARE RENEWAL IN JILIN CITY

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项目背景

近年来, 轨道交通建设在中国各大中城市发展迅速。如何优化轨道交通站点周边的城市空间结构, 以数据空间模型为基础提升步行空间品质, 营造尺度宜人的街道、广场等空间, 是城市设计研究和实践领域的热点话题。空间句法作为一种积累了30余年实证研究经验的理论及设计方法, 因具有原理简单、操作高效等特点, 在大数据时代能够快速应用于数据分析与设计实践中^{[1]-[3]}。在中国近年来的城市规划、城市设计和建筑设计中, 已有一些以数据为基础, 运用空间句法建立空间模型进行设计方案评估和优化的实例^{[4][5]}。

2017年, 英国空间句法公司、吉林市城乡规划设计研究院和空间句法-北京交通大学联合实验室基于多源开放数据, 针对吉林市轨道交通线路及站点落位规划开展了研究。作为这一项目的后续, 设计团队对吉林市轨道交通沿线4个代表性站点周边的广场进行了设计。本文将吉林市朝阳广场设计方案为例, 介绍对各类交通流量数据进行收集

与分析并将结果应用于设计的过程。

朝阳广场位于吉林市中轴线——吉林大街和光华路的交点处, 毗邻繁华的东市场区(图2)。设计团队对场地展开了实地调研, 发现广场地表覆盖形式以绿地为主, 采用开放式管理, 周边有围栏但无人值守; 广场中央为大型草坪, 道路多沿广场边缘设置, 导致广场使用率极低(目前使用者主要为南面办公楼的工作人员), 4hm²的空旷空间与场地周边商业区中密集的步行流量形成了鲜明对比。

数据获取

将空间句法模型应用于研究和设计的理论基础在于从空间拓扑形态出发, 同时分析各类交通流量和功能分布的能力^[6]。该模型的行为学基础即为空间认知研究^{[7]-[9]}, 将以街道折转角度(而非街道长度)作为度量因素的算法引入到空间网络分析中, 来探究空间认知与导航过程的阻抗^[10]——通常, 人们的空间认知和导航阻抗主要为距离(因距离太长而不想前往), 而针对此项目的空间句

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摘要

空间句法是研究城市空间与社会经济活动之间关系的一系列理论与技术, 大数据时代便捷的数据获取使得空间句法研究成果能够快速应用于数据分析与设计实践。本文以吉林省吉林市轨道交通站点之一的朝阳广场为例, 通过应用线段模型以及视域模型中的多智能体模拟工具, 对广场内部及周边街道的交通流量和视域整合度进行了分析, 并呈现了将分析结果应用于广场设计及方案评价的全过程, 以期提升广场空间的使用率; 本文同时展望了机器学习和人工智能等新技术在推进空间句法基础研究和设计应用方面的前景。

关键词

空间句法; 数据化设计; 多源数据; 交通流量; 视域整合度; 多智能体

ABSTRACT

In the past decades, Space Syntax offers a series of theories and techniques to study the relationship between urban space and social-economic activities, and has been proved effective in analysis and design practices thanks to the open sources in the big data era. Taking the Chaoyang Square Renewal project in Jilin City, Jilin Province as an example, this article introduces the analyses of traffic volumes and visual integration of the square and the connected streets with modeling tools such as Segment Map and the intelligent multi-agent systems in Visibility Graph Analysis. All these analyses provided a basis for the full design process, from conceptual design to proposal evaluation, in order to activate this site through introducing pedestrian vitality. Prospects on new technologies in Artificial Intelligence, such as machine learning, are also explored to promote the research of Space Syntax and related application in urban design.

KEY WORDS

Space Syntax; Data-Based Design; Multi-Source Data; Traffic Flow; Visual Integration; Intelligent Multi-Agent System

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项目面积:72 680m²**项目委托:**

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Jilin City, Jilin Province

AREA (SIZE):72,680 m²**CLIENT:**

Jilin Rail Transit Construction Investment Co., Ltd.

PROJECT LEADER:

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PROJECT TEAM:

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法分析视街道的折转为阻抗（因道路不明而不想前往）。目前比较常用的空间句法软件工具包括Depthmap、Axwoman、sDNA和Place Syntax等。以Depthmap为例，在当代研究和设计实践中常用的分析模型包括线段模型和视域模型。线段模型经由轴线模型生成，后者按最长且最少的原则将街道空间抽象为一组彼此相交的直线段。该模型泛用性较强，可应用于上至国土疆域、下至建筑尺度范围的数据空间分析。视域模型则通过用户设定的解析度将空间抽象为网格，计算各网格节点间静态或动态的视域变化关系，也可用于反映交通流量。同时该模型自带多智能体模拟分析功能，可以在网格空间中随机生成或在指定区域内生成具有一定视域范围的智能体，以模拟步行者的运动，该功能主要被应用于建筑和街区尺度的分析和设计中。本项目在设计的不同阶段综合应用了线段模型和视域模型两种工具，以进行步行流量及视域整合度分析。

在该项目中，城市尺度空间分析的主要目标是分析广场周边各道路的连接性差异，以为未来的城市空间规划与设计提供依据。

为实现这一目标，建模区域范围往往需扩展至更广阔的城市区域尺度（图3）。项目进一步聚焦于街区尺度模型的分析，通过交通流量数据和可从网络上公开获取的兴趣点、大众点评数据等建立交通-功能-空间的回归方程，以为设计场地的商业开发潜力和交通分析提供量化模型。而无人机技术和网络开源数据的不断发展则降低了获取空间句法建模所需的精确数据的门槛，使空间句法的实践应用更加便捷。该模型还可用于对比评价各设计方案的公共空间使用率（图4）^②。

场地现状分析及流量建模研究

由于朝阳广场位于吉林市主要道路交通节点，人流及车流量极大，因而项目采用了以无人机航拍代替实地拍摄交通截面流量的方法来采集数据。具体操作方法为，选取平日和周末各一天中的4个时间段（上午8时、11时，下午1时、4时），在广场上空400m高度的4个位置俯拍视频。而后通过加权统计出各个街道截面周边机动车和步行者的通行情况（排除特殊事件的影响）。

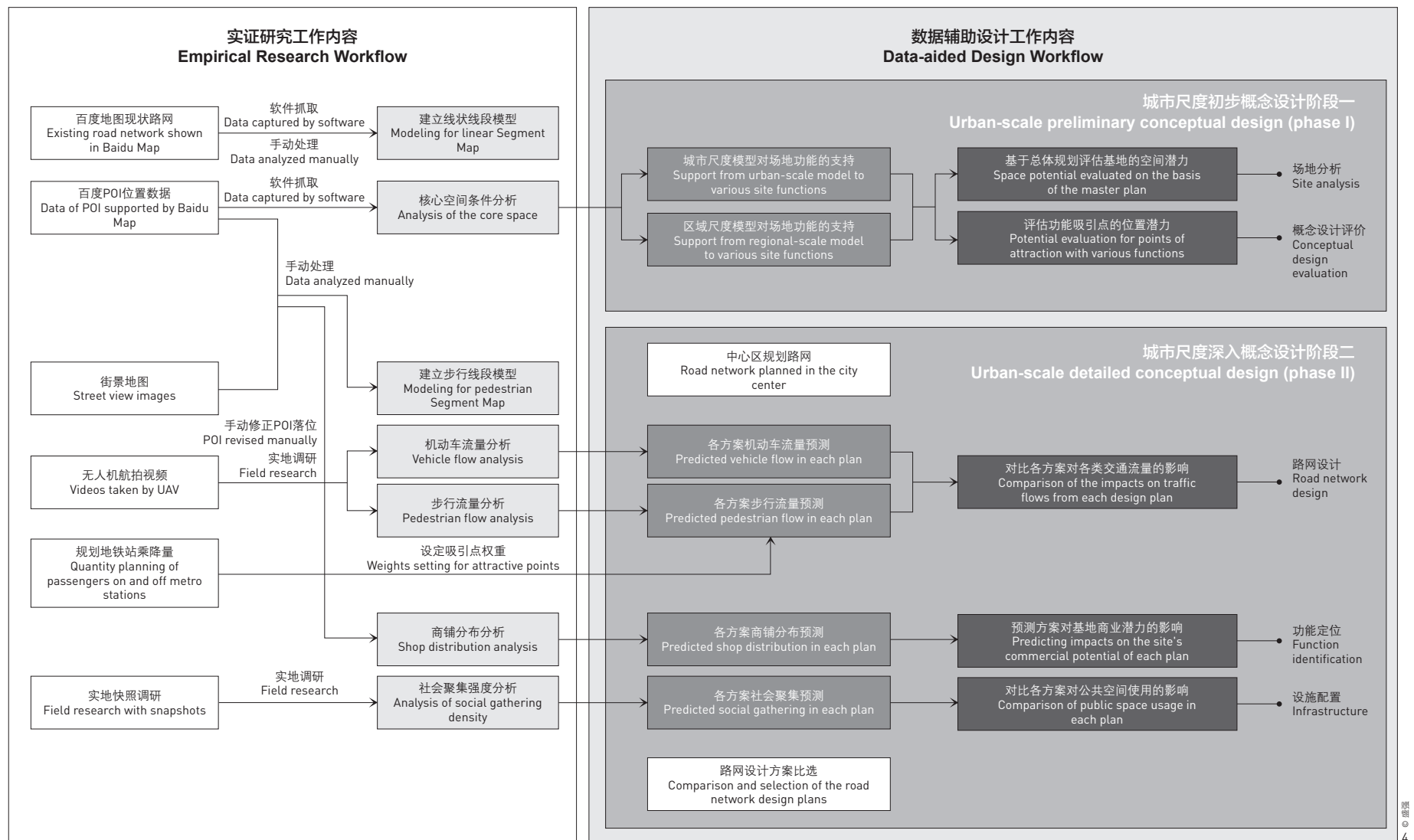
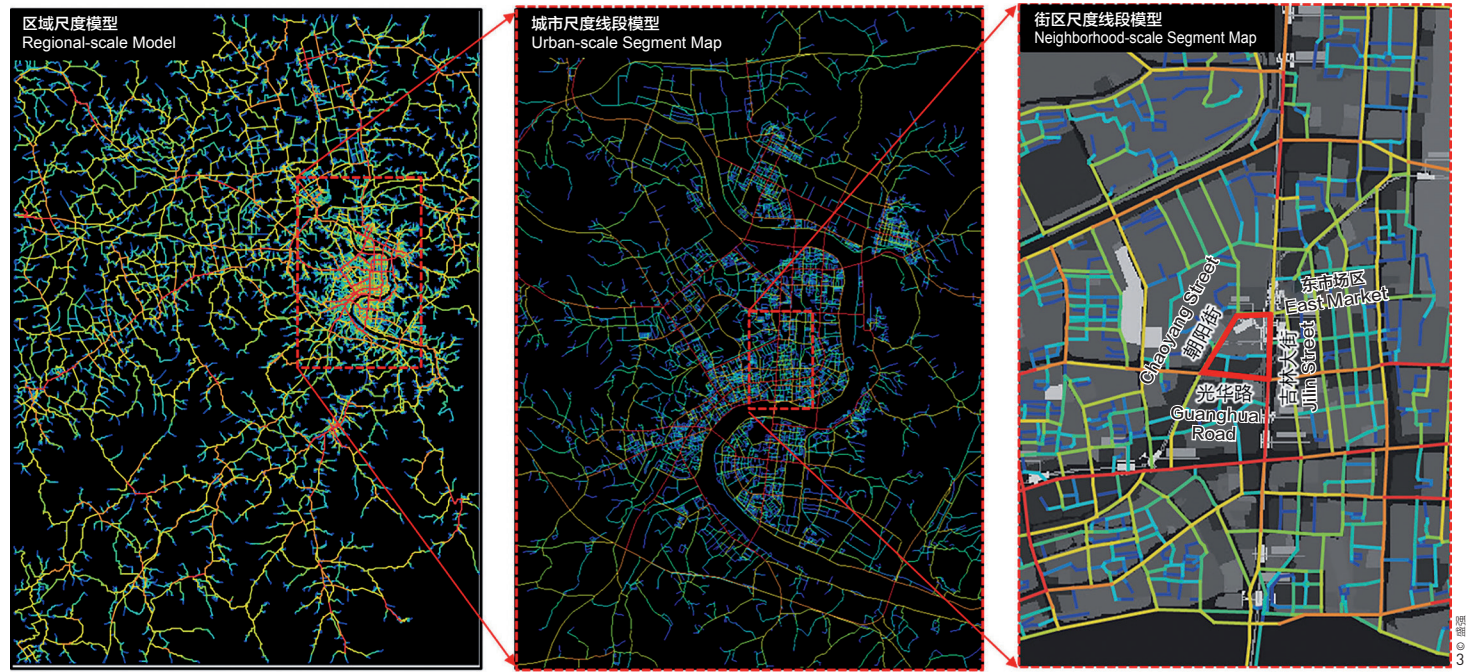
从视频数据可视化的结果来看，由机动车流量分布以及成都街与吉林大街交叉口处的转弯车流轨迹分布可以发现，利用下穿隧道的车流比例很低（图5-1）。从步行流量来看，东市场地区流量较大，而从广场中部穿越广场的流量极低（图5-2）。上述发现恰好印证了实地调研的结果。

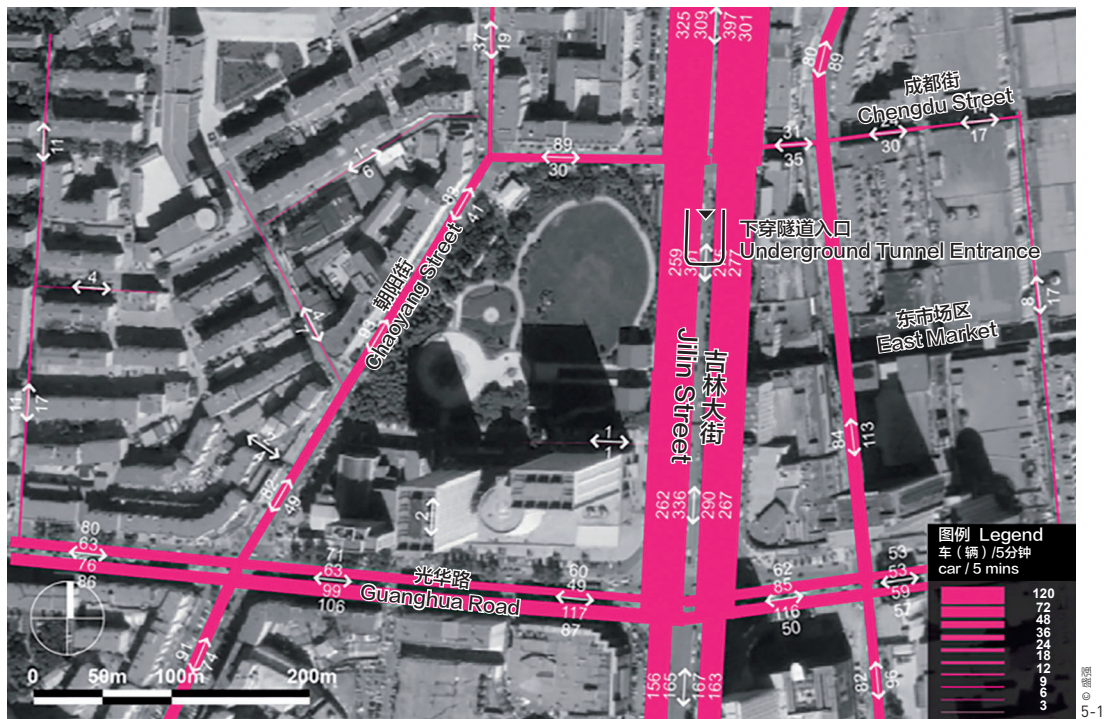
为了检验实测结果与模拟步行流量的拟合度并分析场地视域整合度，在Depthmap模型中多智能体模拟工具的帮助下，设计团队在项目范围内的公交站点和步行街等人流密集区域按比例集中投放智能体，并在其他区域随机生成并投放智能体。模拟结果显示，东市场区和光华路附近步行流量较高，而广场内部步行流量相对较低。该模拟结果与实测步行流量数据的拟合度在0.5左右，具有较高的相关性（图6）。视域整合度是指计算得出的从所有空间到特定空间的视觉距离，其反映了空间形态吸引流量的潜力。从现状分析结果来看，除光华路与朝阳街为既有的视觉焦点外，广场西北角也具有一定潜力；长沙路被吉林大街的车流阻断，因而潜力不佳（图7）。

② 更多内容可参见笔者近期发表的相关论文，详见参考文献[11]。

2. 朝阳广场区位图
3. 空间句法线段模型的尺度及精度示意图
4. 综合多源数据的空间句法模型在数据化城市设计中的应用流程

2. Location of Chaoyang Square
3. Accuracy comparison of Segment Maps at different scales in the Space Syntax analysis
4. Workflows of applying the Space Syntax model with multi-source data in data-based urban design





5-1



5-2

5-1. 基于无人机航拍视频获取的朝阳广场及周边机动车流量数据

5-2. 基于无人机航拍视频获取的朝阳广场及周边步行流量数据

5-1. Data of vehicle flow in and around the Chaoyang Square captured from videos taken by UAV

5-2. Data of pedestrian flow in and around the Chaoyang Square captured from videos taken by UAV

设计阶段的模型应用

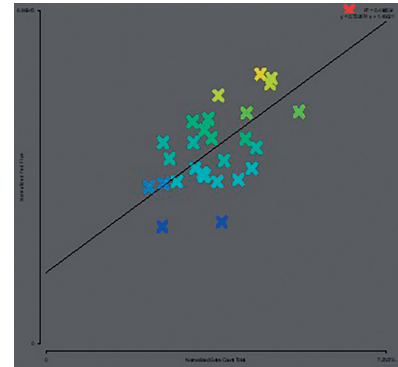
为了连接广场上的新建车站站房与周边道路，并赋予广场活力，设计团队需对广场的空间布局及道路网络进行重新规划。线段模型可快速探索广场周边地块所有可能存在的联系，有效促进设计初期概念的形成。图8展示了广场周边道路交叉口之间全部联系的预测结果，其中成都街与朝阳街之间的捷径（路径1）、长沙路延长线（路径2）、吉林大街与儿童医院西侧小路之间的捷径（路径3）均显示出较高的穿行度（路径1和路径2的预测流量略高于路径3），如能使这三条路径相互连接，广场内部将形成较高的步行流量。

基于以上预测结果，项目形成了初步的设计概念：将三条预测流量较高的道路相互连接形成穿越广场的三条主要流线；根据这三条流线的步行流量潜力及其划分的场地周边功能属性所带来的机遇与挑战，划定居民休闲活动区（西北部）、人流集散区（东北部）和文化展示区（南部）；提出未来将隧道出入口北移的远期方案（以降低广场东侧吉林大街路段机动车流量并提升广场与东市场的联系），进而将广场向东拓展（图9）。

在设计方案形成后，基于与现状分析中相同的参数设定，设计团队对方案的步行支持效果进行了量化评价。结果显示，多智能体预测的步行流量和视域整合度均有较大的提升（图10，11）——中部空间形成了明显的高步行流量区域，可充分利用景观和人流聚集效应开展文化展览活动；而广场西北角的步行流量略低，空间私密性较高，适宜作为周边社区居民的活动空间（图12，13）。结合吉林市“造船”的集体城市记忆，广场上的站房设计采用两艘相连船舱的架空形式，为其下方的儿童娱乐活动与游人集散提供了开敞空间（图1，14，15）。

空间句法研究和设计应用的前景

空间句法模型于20世纪70年代产生，在此后的几十年中，实证研究与软件技术的相



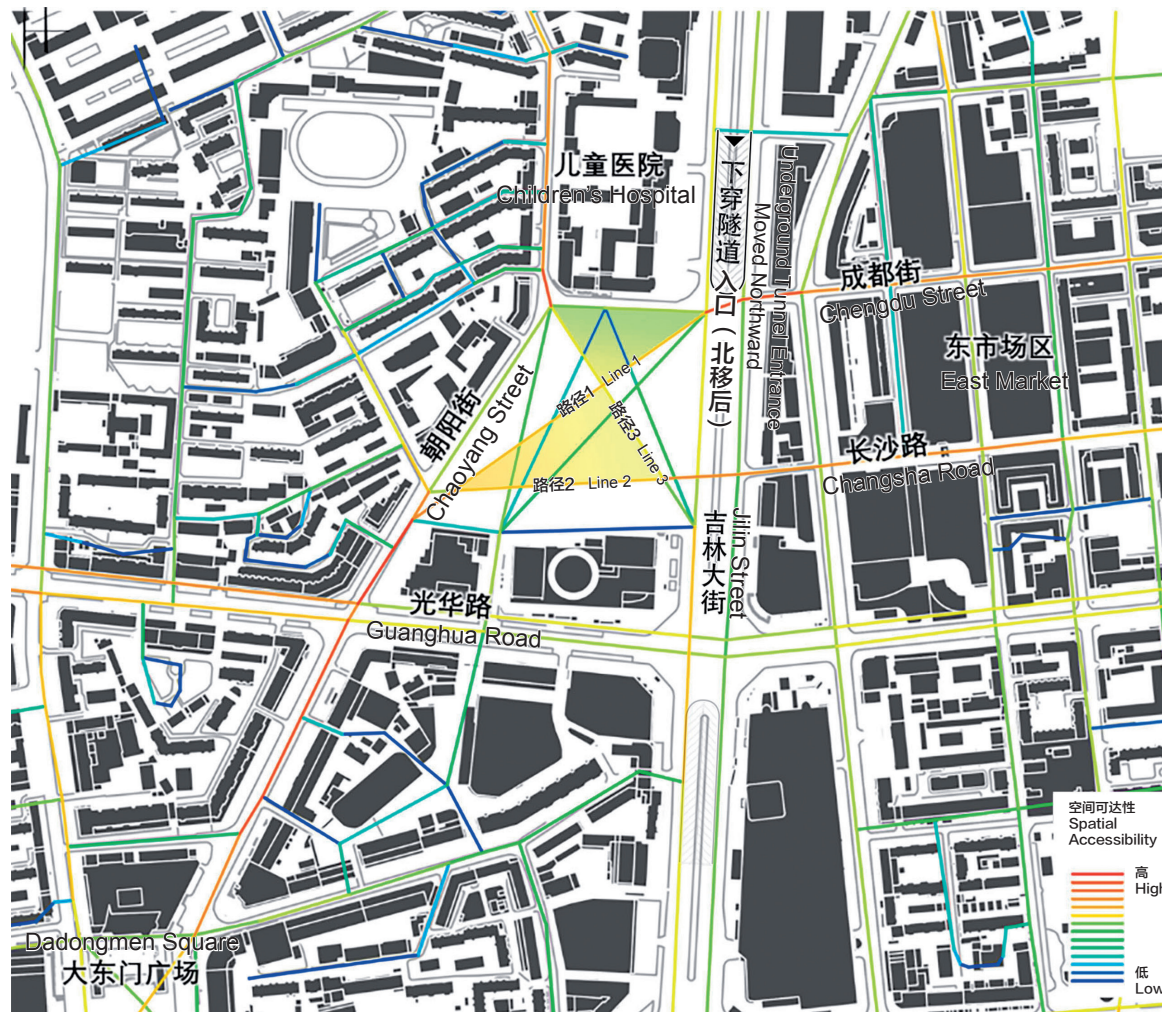
- 6-1. 应用Depthmap多智能体模型模拟广场及周边步行流量
 - 6-2. 步行流量模拟数据与航拍实测流量的回归分析图
 7. 朝阳广场视域整合度分析
- 6-1. Pedestrian flow in and around the Chaoyang Square simulated by the intelligent multi-agent systems in Depthmap
 - 6-2. Regression analysis result of the simulated pedestrian flow data and field measurement data
 7. Visual integration analysis of the existing Chaoyang Square

互促进一直是空间句法在城市设计领域前进的动力。信息时代为空间句法的实证研究提供了大量新数据源，近期比较具有代表性的包括兴趣点、点评数据和街景地图。前两者提供了城市活跃功能区的位置及使用情况，有助于发现各商圈细分业态空间分布的规律，实现精细化设计；而街景地图，特别是街景时光机对城市形态演变的图像记录，则为跨时间的城市功能演变分析提供了可能，也进一步降低了交通流量类数据的获取成本。笔者近期在“数据游骑兵”教学实践项目中测试了基于航拍图和街景地图获取车流量数据的方法^[12]，并初步测试了基于街景地图时光机获取步行流量数据的可行性^[13]。随着机器学习在图像识别方面日趋成熟，这个过程将迅速实现自动化，并进一步提升设计效率、降低成本，有力拓展空间句法模型在项目实践中的应用。LAF

致谢

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8. 基于线段模型的朝阳广场内部及周边各街道穿行潜力预测

8. Prediction of areas with high pedestrian flow in and around the Chaoyang Square in Segment Map

高步行流量路径围合区域
Areas enclosed by paths with high pedestrian flow

空间可达性
Spatial Accessibility

高
High

低
Low



0 50m 100m 200m

8

Project Background

In recent years, due to the rapid construction of urban railways and road networks, the accessibility of China's large- and medium-size cities has been largely improved. It has encouraged relevant research and practices to shift focus towards optimizing urban spatial design for transportation infrastructures (such as railway stations), to improve the quality of pedestrian space through data-based spatial modeling, and to create pedestrian-friendly public space, including streets and squares. Space Syntax, a theory and design method that has been developed for over 30 years, can help quickly

process these big data and promote design efficiency due to its simple principle and efficient operation^{[1]-[3]}. In recent years, Space Syntax has been proved effective in evaluating and optimizing urban planning, urban design, and architectural design through spatial modeling supported by data processing^{[4][5]}.

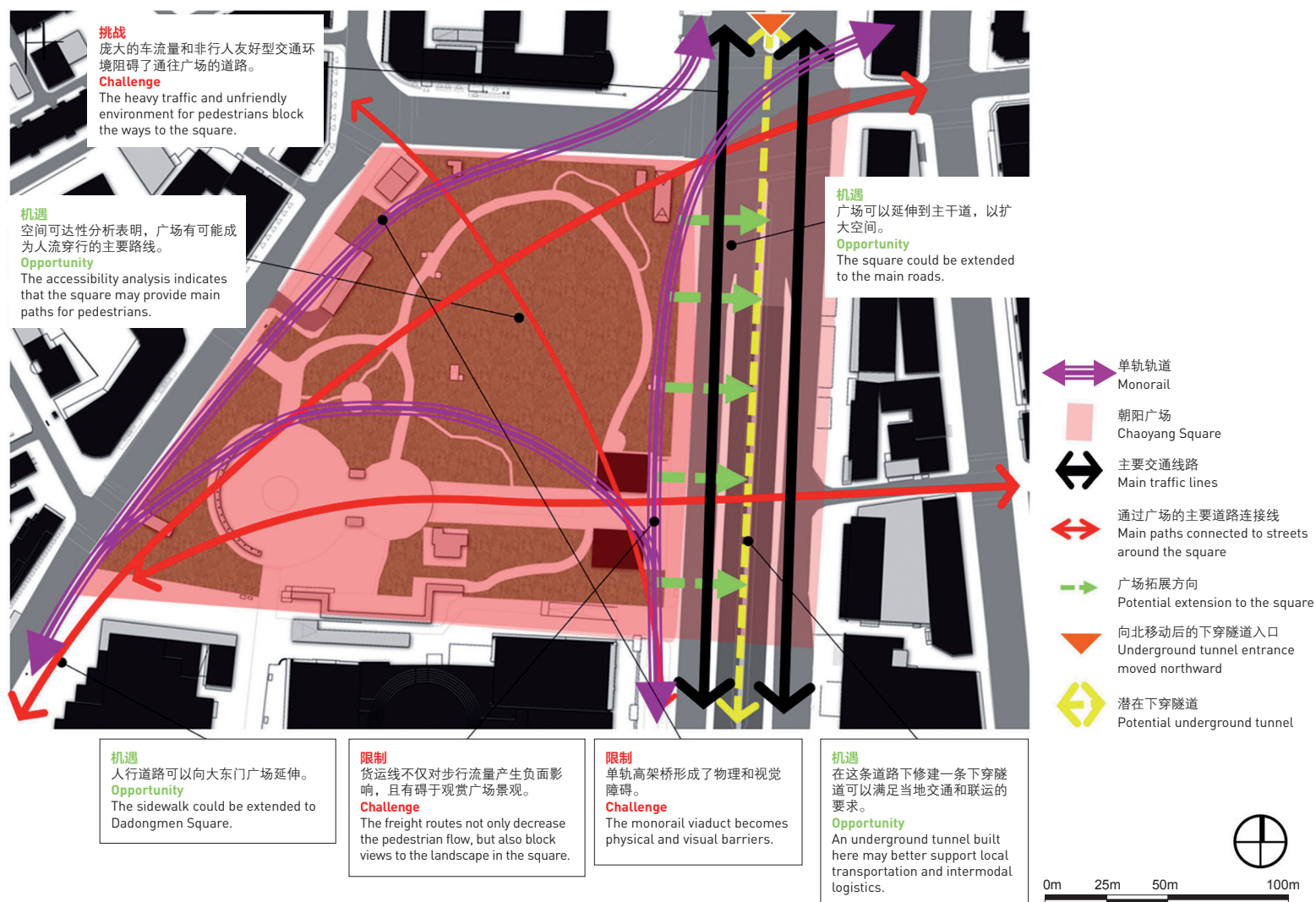
In 2017, Space Syntax Limited, UK, collaborated with Jilin Urban and Rural Planning and Design Institute and the Space Syntax-Beijing Jiaotong University Joint Laboratory, conducted a research on the railway network planning of Jilin City supported by available multi-sourced data. As a follow-up, the design team developed

individual urban design plans for four station squares. Taking the Chaoyang Square, one of the squares to be designed, as an example, this article introduces the processes of data collection and analysis of vehicle and pedestrian flows, and the application of the processed results in spatial design.

Chaoyang Square covers an area of 4 hm² and is located at the intersection of the Jilin Street and the Guanghua Road, on a focal axis of the downtown, adjacent to the bustling East Market (Fig. 2). In field investigations, the design team found that, though the square is of large area of green scape and open to the public, the railings enclosing and the loop path along the border

9. 概念设计阶段图解分析

9. Conceptual design which indicates challenges and opportunities for the Chaoyang Square



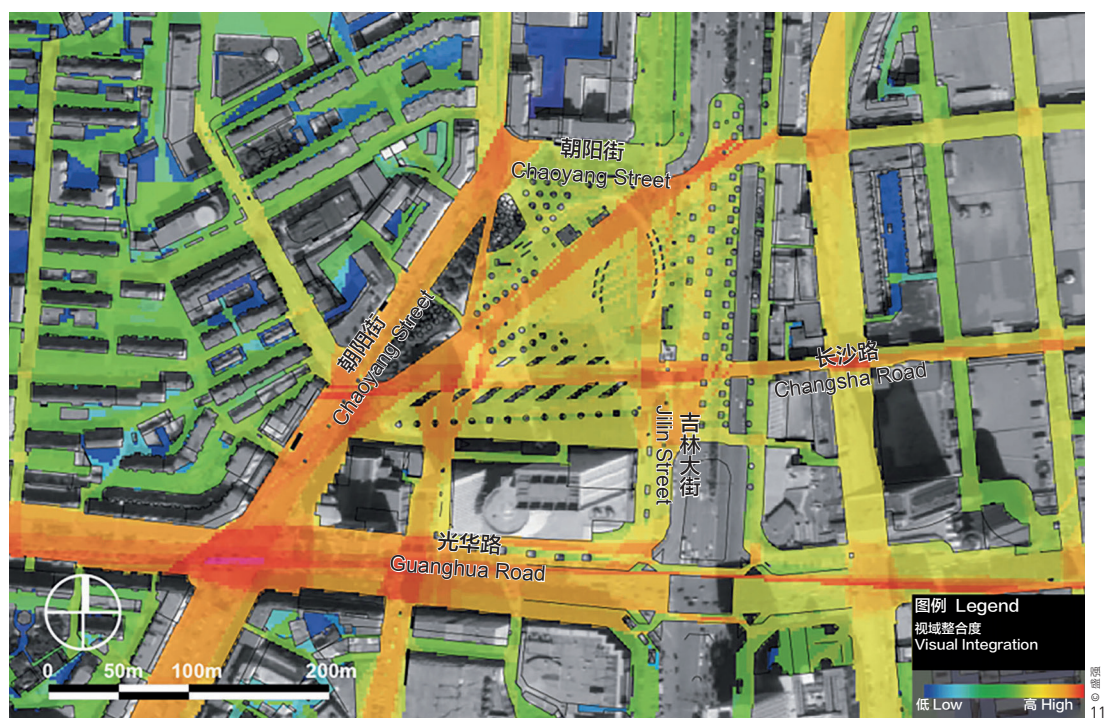
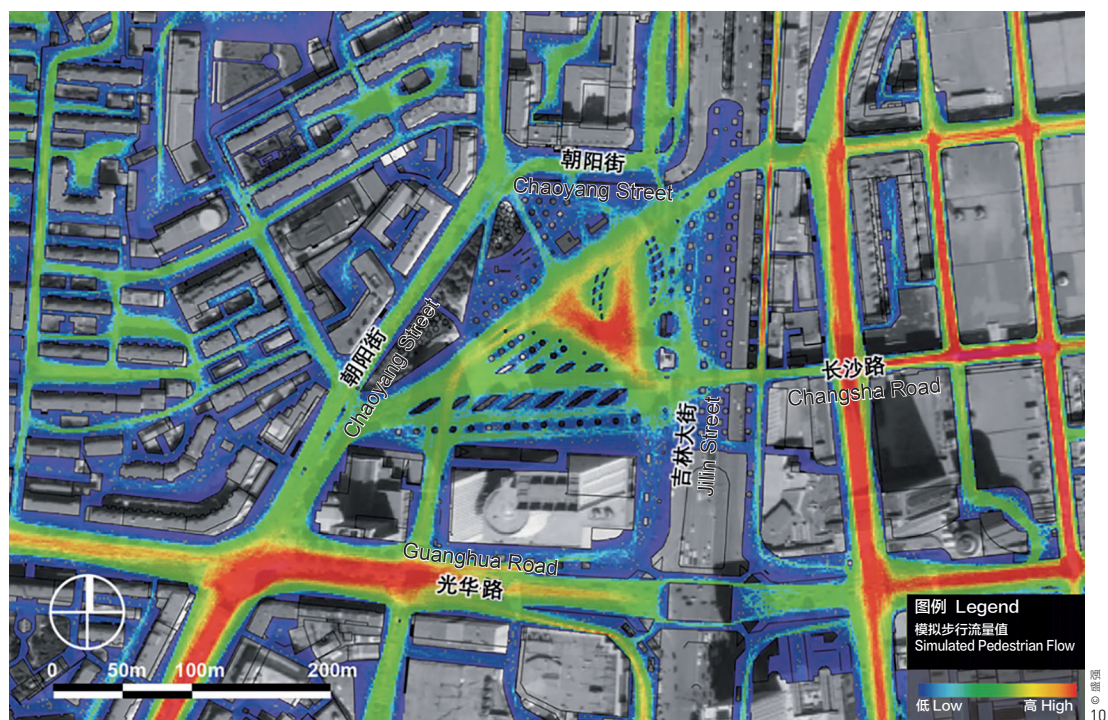
make the square less attractive to citizens, leaving it a place for the staff from the office buildings in the south. The low pedestrian vitality of the site is in stark contrast to the dynamic traffic of the neighboring commercial areas.

Data Collection

Theoretically, the application of Space Syntax modeling in urban research and design mainly includes generating analyses on various traffic flows and spatial function arrangement in topological forms^[6]. The human behavioral studies of this modeling is based on spatial cognition^{[7]-[9]}, which can

identify the obstacles in spatial perception and wayfinding^[10]. For example, in spatial network analysis, the algorithm adopts the angle between two streets (instead of street length) to measure accessibility and to predict humans' desire to go. At present, software kits such as Depthmap, Axwoman, sDNA, and Place Syntax are often used. In Depthmap, for example, the analyzing models of Segment Map and Visibility Graph Analysis (VGA) are widely used in urban research and design. A Segment Map is generated by an axial model which abstracts street space as a group of intersected straight-line segments under the algorithm that takes the longest

length yet the minimum segments. As one of its advantages, Segment Map can be extensively used in data-based spatial analysis at different scales, from territorial to architectural. VGA, on the other hand, allows users to scan space into grids in different resolution levels and to compare the changes in visual domains with the shifts of grid nodes in static or dynamic states. It can also be used to indicate the traffic flows. More importantly, the intelligent multi-agent systems equipped in VGA may simulate pedestrians' movement within a certain area, randomly or particularly designated. This model is usually applied in architectural or neighborhood-scale spatial analysis and



② For more information of the authors' publications, please see Ref. [11].

10. 朝阳广场设计方案步行流量预测
11. 朝阳广场设计方案视域整合度预测
12. 依据空间句法模型分析结果设计的朝阳广场总平面图
13. 更新后的朝阳广场景观系统分析图

10. Pedestrian flow prediction of the renewed Chaoyang Square
11. Visual integration prediction of the renewed Chaoyang Square
12. Site plan of the Chaoyang Square renewed on the basis of the analysis results from the Space Syntax model

13. Landscape systems distributed in the renewed Chaoyang Square

design. In the Chaoyang Square project, these two models, Segment Map and VGA, were both applied throughout the whole design process.

In this project, the urban-scale spatial analysis was to compare the accessibilities of different roads connected with the square. To achieve this goal, the model studied a larger-scale urban area (Fig. 3). With regard to the collection of data, a transportation-function-space regression equation is established based on traffic flow data, POI (points of interest), and public comments from open sources, providing a quantitative model for the commercial potential estimation and traffic analysis of the site. Thanks to the rapid development of Unmanned Aerial Vehicle (UAV) and open information on the Internet, the collection of required data is much easier, which greatly facilitated the modeling process in this project. Moreover, this model can also be used to compare and evaluate the public space usage of each design proposal (Fig. 4)^②.

Site Analyses and Research on Traffic Flow Modeling

Due to the heavy traffic of the site, the vehicle and pedestrian flows of the streets were recorded by UAV, instead of section flow shoots. UAVs recorded the traffic flow in videos at four different locations from 400 meters above the square, in four time frames of a day (8:00 and 11:00 am, and 1:00 and 4:00 pm), on both weekdays and weekends. The data of vehicle and pedestrian flows of each street were collected from the videos and calculated in weights. The impact caused by traffic incidents was excluded.

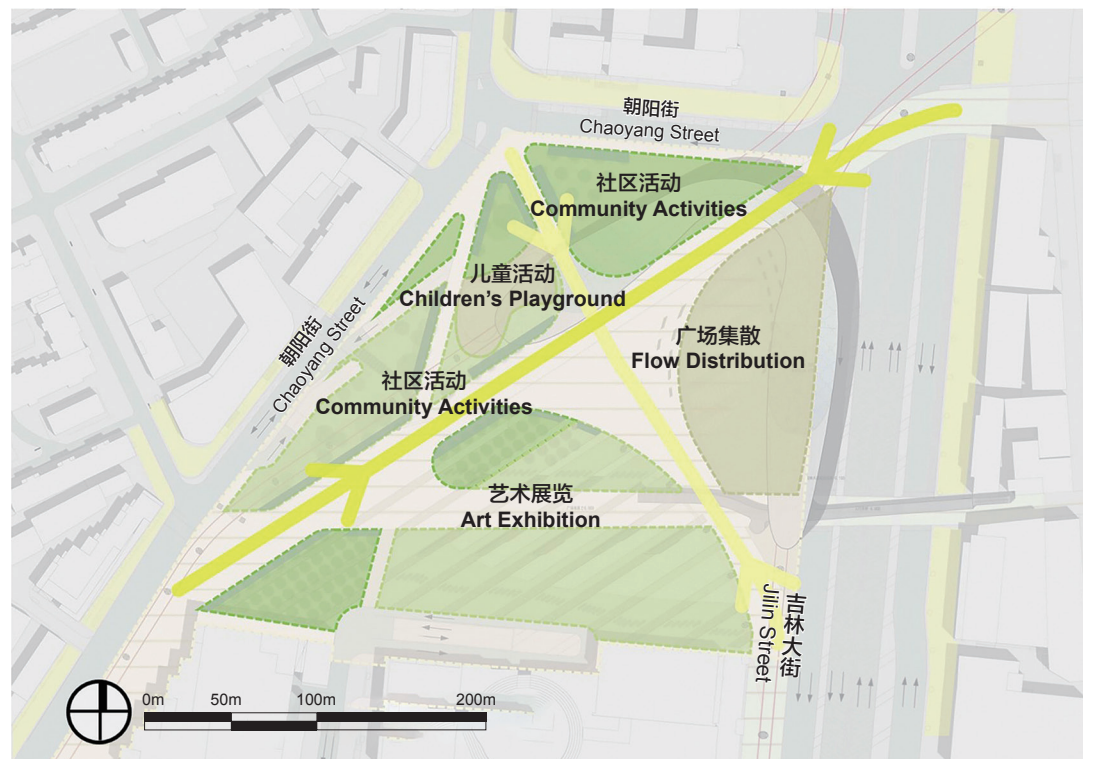
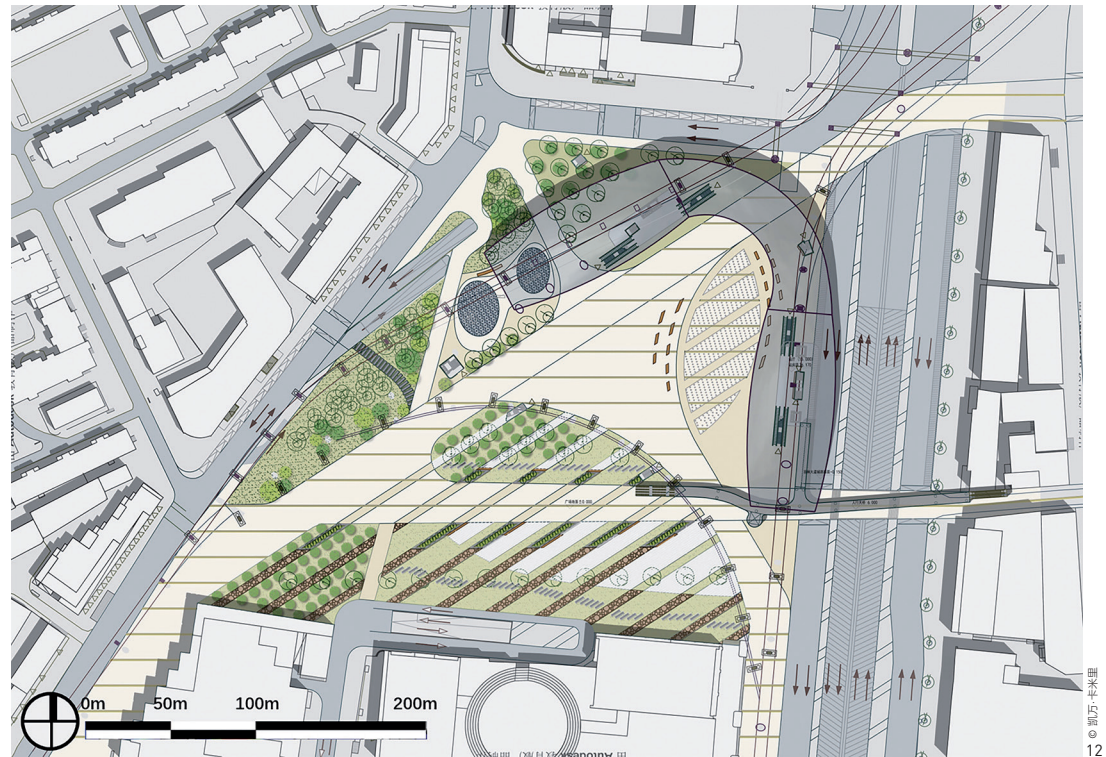
The visualized results of the vehicle flows and the traffic tracks at the intersection of the Chengdu Street and Jilin Street showed that the underground tunnel was rarely used (Fig. 5-1). The statistics results of the existing pedestrian flow proved that the East


Market attracts the most pedestrians, and less people chose to walk through the center of the square (Fig. 5-2).

To test the fitting degree of the existing pedestrian flows with the simulated results and to integrate visual domains, the design team proportionally put the intelligent agents from VGA in Depthmap at the bus stops, pedestrian malls, and other places of high traffic, and put the agents randomly at the rest area of the site. The simulation results is shown as in Figure 6: the East Market and Guanghua Road attracted more pedestrians, in comparison to the lower usage inside the square. The result indicated a goodness of fitness of 0.5, which meant the model is effective and quite accurate in simulating traffic flows. The analysis on visual domains was to evaluate the visual distance between spaces which is used to reveal the potentials to attract traffic flow. According to the analysis, the existing visual focuses at Guanghua Road and Chaoyang Street, as well as the northwest corner of the square, were identified as main focuses, while the Changsha Road blocked by the traffic flow from Jilin Street was less attractive to pedestrians (Fig. 7).

Modeling Application in Design

The design team was asked to develop a renewal plan for the spatial organization and path network of the square in order to improve the connectivity between the planned station house with the streets around and to increase the vitality of the site. The Segment Map applied to quickly dig the connection possibilities between the streets around the square helped form the early design ideas. The predicted results (Fig. 8) show that three lines might be of high pedestrian flows, including the shortcut connecting Chengdu Street and Chaoyang Street (Line 1), the extension of Changsha Road (Line 2), and the shortcut connecting Jilin Street and the path on the west side



- | | | | |
|---|---|---|--|
|  | 场地内主要人行流线
Main pedestrian flow in the site |  | 可达景观空间
Accessible landscaped space |
|  | 场地内硬质铺装
Hard pavement inside the square |  | 不可达景观空间
Inaccessible landscaped space |
|  | 集中式开放空间
Central open space |  | 场地外部硬质铺装
Hard pavement outside the square |

of the Children's Hospital (Line 3). The predicted flows of Line 1 and 2 were slightly higher than the Line 3. It supported the idea that if the three lines can be connected, pedestrians might be directed into the center of the square which is poorly used at present.

On the basis of these analyses, a conceptual design was proposed. First, the square can be activated by connecting the three pedestrian lines of high predicted traffic flows. Secondly, a zone for recreational activities at the northwest, a large zone for gathering at northeast, and a zone for cultural events at the south were designed according to the projected attractions and traffic flows on the three lines, and the opportunities and challenges defined by the physical settings and their various functions. Thirdly, the design team proposed a long-term plan according to which the existing tunnel mouth will be relocated to the north, which would help

disperse the heavy vehicle flow in the Jilin Street, improve the connection between the square with the East Market, and leave space for future programs in the east of the square (Fig. 9).

Evaluations on the increase of pedestrian flows were also conducted. By setting the same modeling parameters, the comparison between the existing usage and projected scenarios revealed that there would be a greater improvement in both the pedestrian flow and visual integration (Fig. 10, 11). The square center could be designated as a highly visited area with attractive landscapes and cultural programs. While the pedestrian flow in the northwest corner would be quite low that provides a good possibility to create a place for daily and recreational activities for residents from the surrounding communities (Fig. 12, 13). In addition, a twin-cabin-shape station house was designed to celebrate the city's history of shipbuilding. Its elevated structure could provide space for

children's playground and people gathering (Fig. 1, 14, 15).

Further Research and Application of Space Syntax

Space Syntax was first developed in the 1970s. Along with the fast development of Artificial Intelligence, Space Syntax has leveraged the mutual promotion between empirical research and software technology, and their research has greatly benefited from open data sources, such as POI, public comments, and street view applications — POI and public comments that provide the location, usage, and other real-time information of certain places may contribute to extract the spatial distribution characteristics of various commercial activities and help develop more precise designs on urban space; Street view applications, especially the "Time Machine" application that is designed to present



14. 朝阳广场设计效果图。更新后的广场中部空间步行流量较大，适宜开展艺术展览等活动。
15. 朝阳广场设计效果图。位于船型交通站房东侧底部的进出站口直接与通向长沙路的过街天桥相连，便捷的快轨交通可进一步提升东市场区的商业活力。

14. Rendering of the Chaoyang Square. The renewed square center will attract a large amount of pedestrians to support activities such as art exhibitions.
15. Rendering of the Chaoyang Square. The entrance and exit located at the east bottom of the cabin-shape transport station are connected to the skywalk to the Changsha Road, where the East Market will be more bustling with visitors travelling from afar by the convenient rail transit.

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historical images of a city, are expected to offer bases for studies on urban identity and image evolution, and to support traffic data collection. The authors' other research efforts, including the "Data Ranger" teaching program, have tested the method applied in traffic data collection by UAV and street view applications^[12] and the feasibility of pedestrian flow data collection by the "Time Machine."^[13] As Machine Learning becomes more and more mature in image recognition, the automation of data collection will be realized in a near future, which would further improve efficiency and reduce cost, and effectively promote the application of Space Syntax model in urban research and design. **LAF**

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