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城市新陈代谢视角下的以减慢城市资源流动为目标的城市设计决策支持框架

DECISION-SUPPORTIVE FRAMEWORK FOR URBAN DESIGN BASED ON THE TARGET OF SLOWING DOWN URBAN RESOURCE FLOWS: FROM THE PERSPECTIVE OF URBAN METABOLISM

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摘要

城市新陈代谢理论以解析城市资源流动的视角，为可持续城市设计提供了量化设计方法及策略的可能性。本文以改善城市生活环境为出发点，选取了4类与居民生活相关的城市资源（水、能源、有机废物、食物）作为评价对象，以其流动速率作为评价指标，以设计情景模型作为核心建立设计决策支持框架。整个框架包含4个基本部分，包括城市现状分析、设计情景设定、设计选项清单，以及设计评价。该框架可实现方案的快速呈现并对其预期效果做出模拟和评价，为设计实践提供决策依据。通过将北京市国贸区域作为初步应用案例，框架为该地区提出一系列城市设计导则，阐明了其对设计实践的支持作用。最后，本文指出，框架的最终输出结果并不意味着某一种设计方案或设计策略即是最优选项，而是帮助设计决策者建立对该设计方案的直观认识，并更深刻地理解其将对城市环境造成何种影响。

关键词

城市设计；城市新陈代谢；城市资源；城市设计决策支持框架；设计情景；城市空间工作平台

ABSTRACT

The Urban Metabolism theory makes it possible to quantify design methods and strategies for sustainable urban design based on analysis of urban resource flows. Aiming at improving the urban environment, this paper takes four types of urban resources closely related to residents' lives (i.e., water, energy, organic waste, and food) as evaluation objects and their flow rates as the evaluation indicators, and operates with design scenario models as the core to establish the decision-supportive framework for urban design, which consists of four basic parts: urban status analysis, design scenario setting, design alternatives, and design evaluation. This framework could quickly present design proposals and evaluate their expected performances, providing a basis for decision making in design practice. Then, China World Trade Center area in Beijing is taken as an example to interpret the practical value of the framework by providing guidelines for urban design practices of this area. Finally, the paper points out that instead of showing the optimal design strategy, the final output of the framework just provides decision makers an intuitive understanding of a specific design proposal and the impacts the design intervention would bring to the urban environment.

KEYWORDS

Urban Design; Urban Metabolism; Urban Resources; Decision-Supportive Framework for Urban Design; Design Scenario; Urban Space Platform

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1 城市新陈代谢与城市设计

城市设计最重要的目标之一就是通过设计干预缓解城市环境压力并提升其韧性。城市设计对于城市环境，尤其是居住环境具有直接且显著的影响，因此其在缓解城市污染、降低能源消耗，以及减少温室气体排放等方面往往被寄予厚望。近年来，随着环境监测技术和分析技术的发展，许多学者都尝试将城市资源的消耗和产出整合为闭环，

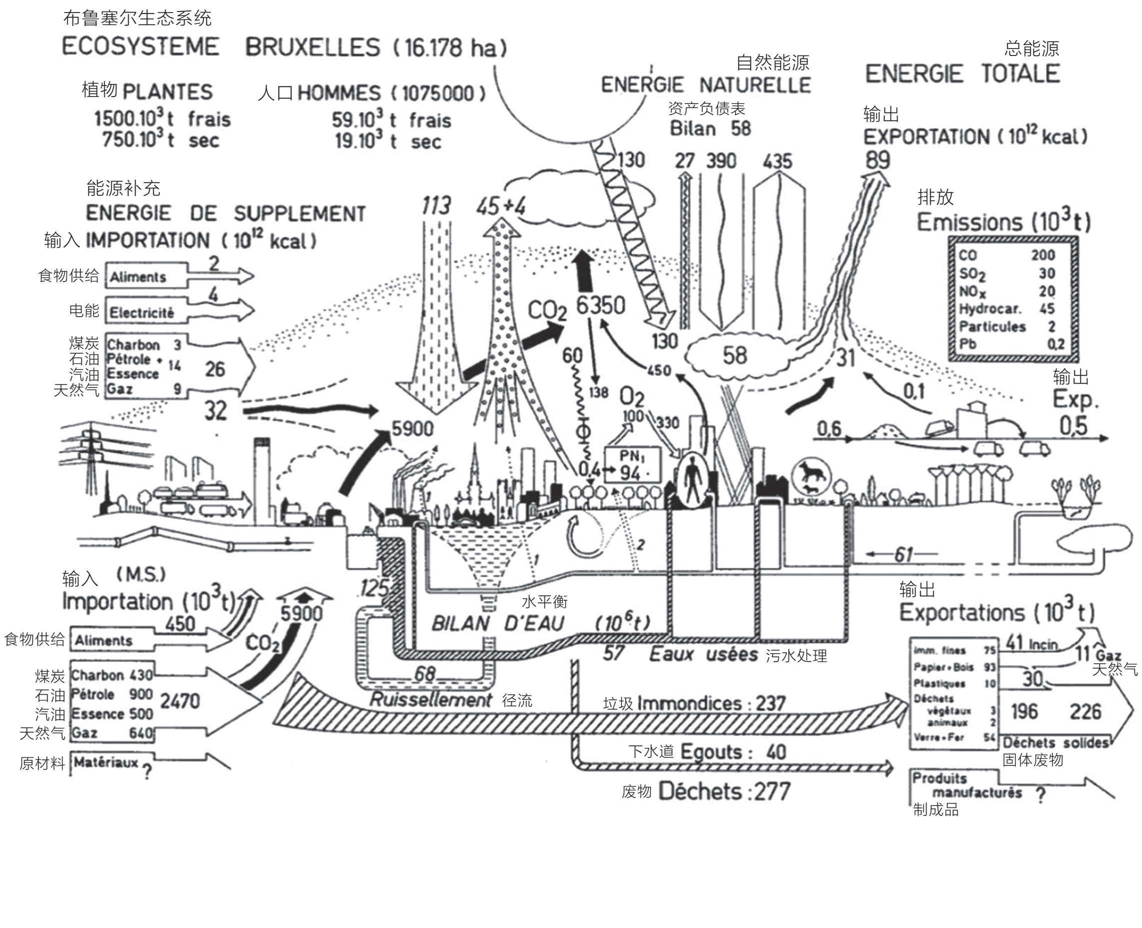
以代替开放的、线性的城市资源流动模式，并期待将这些成果应用于设计实践。得益于技术和方法的革新，新的可持续城市理念层出不穷，例如共生系统[1]、可持续生态系统城市[2]、城市共生[3]，以及无废城市[4]。虽然这些理念所描述的城市形态不同，但其核心理念具有关联性，即以减少城市的废物排放和能源消耗为目标，改善城市资源的循环系统。

“城市新陈代谢”（Urban Metabolism）概念最初由亚伯·沃尔曼于1965年提出[5]，并被认为是构建可持续城市和社区的基础。1999年，彼得·W·G·纽曼基于对资源投入和废弃物输出的分析，将城市新陈代谢重新定义为一种城市生物系统模型，并认为城市新陈代谢重新始于建筑和城市基础设施内的一系列资源输入。在这个过程中，产生的能量以热能的形式被分配到环境中，最终，大部分生活垃圾和工业垃圾会被转移到城市周边区域[6]。克里斯多夫·肯尼迪等人于2007年将城市新陈代谢重新定义为“城市中发生的技术和社会—经济过程的总和，其推动着城市的增长、能源的生产，以及废弃物的排放”[7]。上述学者认为，与自组织平衡系统内部的生产、消耗和降解过程不同，现代城市的新陈代谢是一个线性的、无特定方向的过程。改善城市的新

1 Urban Metabolism and Urban Design

One of the most important goals of urban design is to alleviate pressures of urban environment and make it more resilient. Considering its direct impact and obvious significance to improve urban environment, especially the living environment, urban design has been highly expected to reduce pollution, energy consumption, and greenhouse gas emissions, etc. In recent years, the development of environmental monitoring and analytical technologies has helped scholars reshape the linear and open-ended flow pattern of urban resources into a closed loop by integrating resource consumption and production, which is expected to be applied to urban design practices. Benefiting from the advance in technologies and methodologies, new city concepts associated with the idea of sustainability are emerging, such as symbiosis[1], cities as sustainable ecosystems[2], urban symbiosis[3], and zero-waste cities[4]. These concepts actually share the same core idea, that is, to build a more efficient cycling system for urban resources with less waste emission and energy consumption.

The concept of Urban Metabolism, first proposed by Abel Wolman in 1965[5], is considered offering a basis for building sustainable cities and communities. In 1999, Peter W. G.



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1. 20世纪70年代早期的比利时布鲁塞尔城市新陈代谢概念示意图（来源：参考文献[14]）

1. A diagram of the Urban Metabolism of Brussels, Belgium in the early 1970s (Source: Ref. [14])

陈代谢则意味着提高城市居民的适应性、促进城市资源循环、减少自然资源消耗，并降低城市活动对气候造成的影响[7]。迄今最大尺度的城市新陈代谢研究于1971年在中国香港启动[8]，并于1997年进行了升级[9]。这项研究对香港的原料消耗和废物排放进行了全面分析，并从多个尺度探究了城市新陈代谢与当地经济增长之间的联系。世界银行城市发展与地方政府部门自2010年起对全球7座城市的新陈代谢情况展开了研究，并通过研究结果中反映的城市气候变化唤起人们对于城市资源消耗模式的重视[10]。

1991年，彼得·巴奇尼和保罗·布鲁纳提出了4项主要城市行为：滋养和恢复、清理、居住和工作、交通和交流[11]。这些行为被用于分析城市新陈代谢中4种主要资源（水、食物和废物、建筑材料、能源）的生产与消耗，为城市新陈代谢理论在城市设计中的应用提供了重要参照。最早将城市新陈代谢框架应用于城市设计研究的是弗兰兹·奥斯沃德和彼得·巴奇尼，他们运用形态学和生态学工具设计整个城市重建过程，并提出了城市环境的4项主要原则（承受力、可持续性、重建能力、责任）和5项城市环境质量标准（可识别性、多样性、灵活性、自给自足、资源效率）来指导城市设计[12]。2007年，由约翰·E·费尔德兹教授指导的麻省理工学院团队将基于城市新陈代谢理论的设计方法应用到“网状城市”新奥尔良的飓风灾后重建规划中[13]。

在城市新陈代谢理论的视角下，城市环境被看作一个不断与外界进行资源交换的系统，城市则如同一台巨大的机器，不断消耗着水、能源和食物等资源，同时排出废气、废水和其他污染物。如果把城市内部的资源循环看成一个整体，其与外部环境的资源交换频率便反映了城市发展的可持续性——频率越高，可持续性越差，城市自身及外部环境所受影响也越大。而以改善城市资源流动为目的的城市设计正是通过降低城市与外界环境的资源交换频率，使该系统更加健康。例如，借助分散式生态水处理设施，城市能够降低对外部饮用水的依赖，并减少污水排放，使城市与外界间的水资源流动慢下来；采用节

Newman defined Urban Metabolism as a model for urban biological system based on analysis of resource input and waste output, and deemed that Urban Metabolism begins with a series of material inputs within buildings and urban infrastructure, in the process of which energy, as heat, is produced and distributed in the environment, and ends with the massive domestic and industrial waste transported to suburbs[6]. In 2007, Christopher Kennedy et al. redefined Urban Metabolism as “the sum total of the technical and socio-economic process that occur in cities, resulting in growth, production of energy, and elimination of waste”[7]. These scholars believed that unlike the production, consumption, and degradation in a balanced self-organized system, the metabolism of modern cities is linear and non-directional. Therefore, improving metabolism means a higher adaptability of urban residents, more efficient urban resource circulation, lower consumption of natural resources, and a reduced impact on climate caused by urban activities[7]. The world’s largest-scale study on Urban Metabolism was conducted in Hong Kong in 1971[8], then upgraded in 1997[9]. In this study, the raw material consumption and waste emission of Hong Kong were comprehensively analyzed with multi-scale tools to figure out the relations between the metabolism of Hong Kong and its economic growth. Since 2010, the Urban Development and Local Government Unit of the World Bank started a study on metabolism of seven client cities around the globe, and the research results reflecting climate changes of these citie can be used to arouse people’s attention to the urban resource consumption patterns[10].

In 1991, Peter Baccini and Paul Brunner proposed four major behavioral types in cities, namely nourishment and recovery, cleaning, living and working, and transportation and communication[11]. These behaviors are used to analyze the production and consumption of four main resources of Urban Metabolism: water, food and waste, building materials, and energy, providing an important reference for applying framework to design practices. The framework was first applied to urban design studies by Franz Oswald and Peter Baccini, who used morphological and ecological tools in the long-term design process of the entire city’s reconstruction, and proposed four leading principles (shapability, sustainability, reconstruction, and responsibility) and five indicators of urban environmental quality (identification, diversity, flexibility, self-sufficiency, and resource efficiency) as guidance[12]. In 2007, an MIT team led by Professor John E. Fernandez designed a “mesh

2. 城市设计决策支持框架

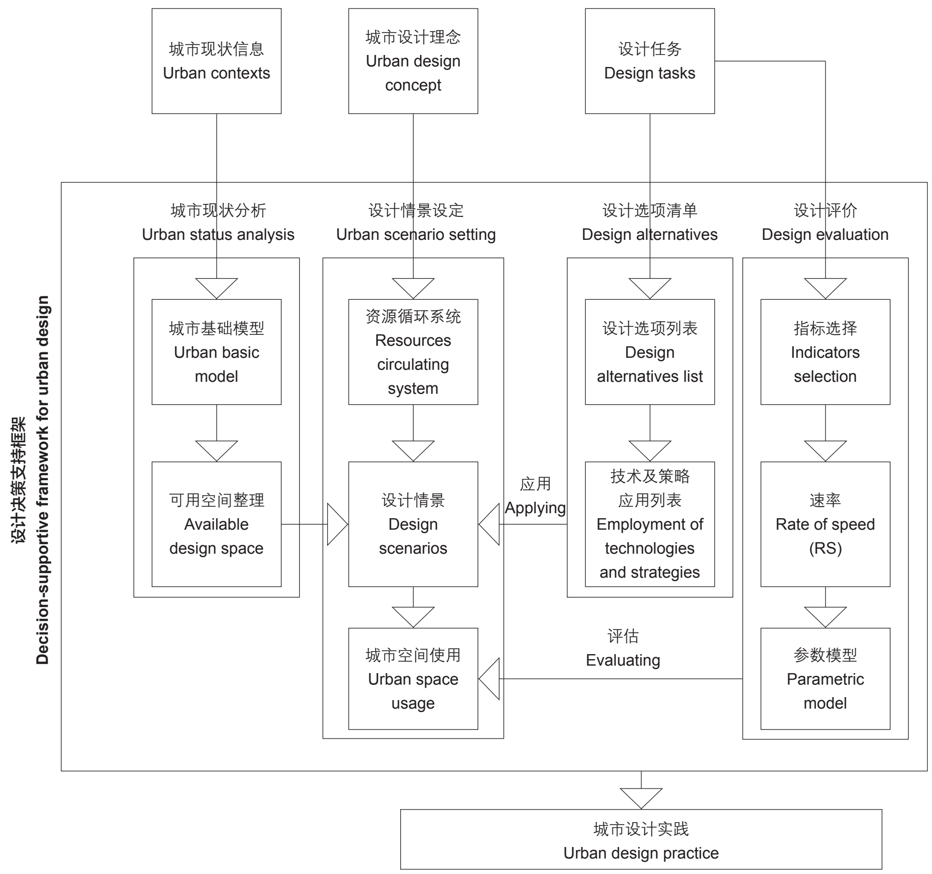
2. The decision-supportive framework for urban design

能措施和可再生能源设施可减少城市的能源消耗，亦可以减慢城市与外界的能源交换。本文以城市新陈代谢为视角，以改善城市资源流动为目标，探讨一种新的城市设计决策支持框架，并以此指导设计实践。

2 城市设计决策支持系统

近年来，城市设计领域主要有两个发展方向：一个是通过数据分析、云服务和移动技术对城市运行现状进行深度了解，从而制定设计策略[15]；另一个是以实证的方式，通过总结过去实践项目的经验和教训推导出新的设计策略[16]。本文应用的设计方法属于后者，其核心是将一系列现有技术和策略以工具包的形式应用于城市空间中。这种城市设计方法与城市现状高度关联，具有较高的复杂性和不确定性，涉及大量其他相关学科（如市政工程、水污染与大气污染治理、交通规划等）的专业知识，导致设计决策面临诸多困难。因此，建立一个能将基础信息进行量化和简化，并可有效整合多专业知识的设计决策支持框架非常必要。

本文选取4类与居民生活相关的城市资源（水、能源、有机废物、食物）作为评价对象，以其流动速率作为评价指标，以设计情景模型作为核心建立设计决策支持框架。整个框架包含4个基本组成部分：城



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city" for the post-hurricane reconstruction of New Orleans based on urban metabolism ideas[13].

From the perspective of Urban Metabolism, a city can be seen as a system running with constantly resource exchange with the external environment: The city itself operates as a huge machine continuously consuming water, energy, food, etc. while producing waste gas, waste water, and other pollutants. The frequency of resource exchange between the city and its external environment indicates the sustainability level of the city's development — a higher frequency implies a poorer sustainability, as well as a greater impact on both the city and the external environment. Urban design by means of optimizing resource flows is exactly to slow down this frequency, thus making the entire system healthier. For example, through decentralized ecological water treatment facilities, cities can reduce dependence on external water supply and cut down sewage discharge to slow down water resource exchange; similarly, energy-saving measures and renewable energy facilities contribute to decreasing the city's energy consumption, so that the energy exchange would be slowed down. Based on Urban Metabolism, this article focuses on a decision-supportive framework of urban design with a goal of optimization of resource flows of the city, and exemplifies its application with a pilot of urban practice case.

2 The Decision-Supportive Framework for Urban Design

In recent years, there are mainly two approaches to develop urban design strategies: One is based on deep understanding of the city's operating status through data analyses, cloud services, and mobile technologies[15]; the other relies on empirical studies from previous practices[16]. The approach applied in this paper is the latter one, proposing a toolkit of existing technologies and strategies for urban design. In the consideration of high complexity and uncertainty of a city, as well as trans-disciplinary collaboration with Civil Engineering, Water and Air Pollution Management, Transportation Planning, etc., it is necessary to develop a decision-supportive framework, which could simplify and quantify complex basic information and integrate diverse professional knowledge, in order to help planners and designers to make decisions.

The decision-supportive framework takes four types of urban resources closely related to residents' lives (i.e., water, energy, organic waste, and food) as evaluation objects and their flow rates as the evaluation indicators, and operates

市现状分析、设计情景设定、设计选项清单、设计评价。它们都可接入外部模块，并可通过引入新的技术工具和研究方法进行改进升级。下文将依次对这4个部分的主要功能进行介绍。

2.1 城市现状分析

城市设计的对象及目标问题往往高度依赖各种信息，故而需首先通过城市现状分析，将复杂的城市空间、人口、气候等信息进行选择、过滤、量化与整合，转换为更易于设计者理解的工作平台，作为下一步情景模型设定的基础。该工作平台不仅要包含市容积率、建筑密度、建筑覆盖率等城市基础信息，还要包含建筑层数、建筑高度、立面面积等单体建筑信息。街道、空地、屋顶和绿地等重要的设计可用空间也需要被包括在内。

2.2 设计情景设定

本文的核心理念是通过设计干预减慢城市资源流动，从而改善城市环境。因此，需要通过设定相应的设计情景来预测干预方案对未来城市发展的影响，从而将不确定的城市未来路径化。为便于对不同设计干预的预期影响进行比较，需要将城市现状或施加某一干预后的预测结果作为参照。

2.3 设计选项清单

这一部分主要收集各种以优化城市资源流动为目标的既有设计策略和技术信息，并基于经验性研究方法将其归纳为一系列输入、输出参数，以生成设计干预选项清单。其中，输入参数主要包含各种设计策略和技术的空间应用情况，以及各种城市资源的单位时间输入量；输出参数主要包含各种设计策略和技术的实际环境绩效，以及各种城市废弃物的单位时间输出量。作为整个框架的开放部分，这一部分还可引入气候和地理条件等对输入与输出参数进行调节，其包含的设计策略和技术信息也可随时更新。

with design scenario models as the core. It consists of four basic parts: urban status analysis, design scenario setting, design alternatives, and design evaluation. They are open to external modules, and can be upgraded with new technical tools and research methods. Functions of the four parts will be introduced in the following sections.

2.1 Urban Status Analysis

Since the objects and key issues of urban design are usually defined by multiple complex information such as urban space, population and climate, this information needs to be sorted, screened, quantified, and integrated through urban status analysis to form a basic platform, which is easier for designers to understand. Basic data of urban construction like the floor area ratio, building density, and building coverage ratio, parameters of an individual building such as the number of building storey, building height, and facade area, as well as the available design space including streets, idle lands, roofs, and green spaces should be all included in this platform.

2.2 Design Scenario Setting

The core concept of this paper is to improve the urban environment by slowing down the resource flows, the performance of which should be simulated by setting corresponding scenarios. In this way, the uncertain impacts of different urban design proposals on a city's development would be clarified. The city's current situation or a predicted outcome after applying a design intervention can be used as a reference for comparison.

2.3 Design Alternatives

This part is to collect the information of existing design strategies and technologies aiming at optimizing urban resource flows, and induce a series of input and output parameters based on empirical analyses to form a list of design alternatives. The input parameters include the spatial application of various design strategies and technologies, and the amount of various city resources input a city per unit time, while the output parameters mainly include the environmental performance of those design strategies and technologies, and the amount of various waste from the city per unit time. Factors such as climate and geographical conditions can be added to adjust the input and output parameters, and the information of strategies and technologies in this part can be updated at any time.

2.4 设计评价

框架提出了城市资源流动率（RS）这一新指标来评价城市发展的可持续性，其计算公式为

$$RS = \frac{C - P}{D} \times 100\%, \qquad (1)$$

其中，C代表资源的消耗量，P代表资源的产生量，D代表资源的总需求量。RS取值范围为0～1。RS为1时，表示城市对资源的需求完全依靠外部输入；RS为0时，表示城市能通过内部自我循环满足全部资源需求。在对每个设计情景的实际绩效进行评价时，需使用上述公式分别计算每一种资源的RS，再以加权法估算出该情景下城市资源总体的RS。

3 城市设计决策支持系统总体框架

3.1 城市空间工作平台

在研究城市设计策略时，很多学者都倾向于将城市形态信息类型化、数据化和量化。例如，菲利普·斯特德曼等尝试将建筑形态作为一种量化参数分析城市能耗[17]；妮可·米勒和邓肯·卡维斯等通过统计学方法将城市形态进行分析归类[18]。城市设计本身是一个全程可视化的决策过程，而将城市中多种各具特色的空间形态进行可视化非常重要。二维平面一般只能表达街道形式、建筑占地面积、城市密度和容积率等信息，而建筑立面、屋顶形式、地下室和建筑悬挑等信息则需要在三维模型中体现。本文提出的设计决策支持框架将全三维城市空间基础模型作为工作平台，并将城市密度、建筑覆盖率、建筑形态、开放空间、街道属性、用地功能和地下空间7项基础参数整合其中：

1）城市密度包括发展密度和容积率；

2）覆盖率分为居住覆盖率、工作覆盖率和人口覆盖率；

3）建筑形态包括：建筑物形态、平面形状、建筑高度、屋顶面积、墙面面积、建筑层数、阳台面积等；

2.4 Design Evaluation

The framework proposes a new indicator, namely the rate of speed (RS) of urban resources, to evaluate the sustainability of urban development. The formula is:

$$RS = \frac{C - P}{D} \times 100\%, \qquad (1)$$

where, C, P, D represent the consumption, production, and demand of resources respectively, and the value of RS ranges from 0 to 1. 1 means that all resources a city demands is provided by the external environment; 0 means that the city is totally self-sufficient in resources. When the performance of a design scenario is evaluated, RS of each type of resource should be calculated respectively, then given a weight and estimated the overall RS of the scenario.

3 Overall Framework of Decision-Supportive System for Urban Design

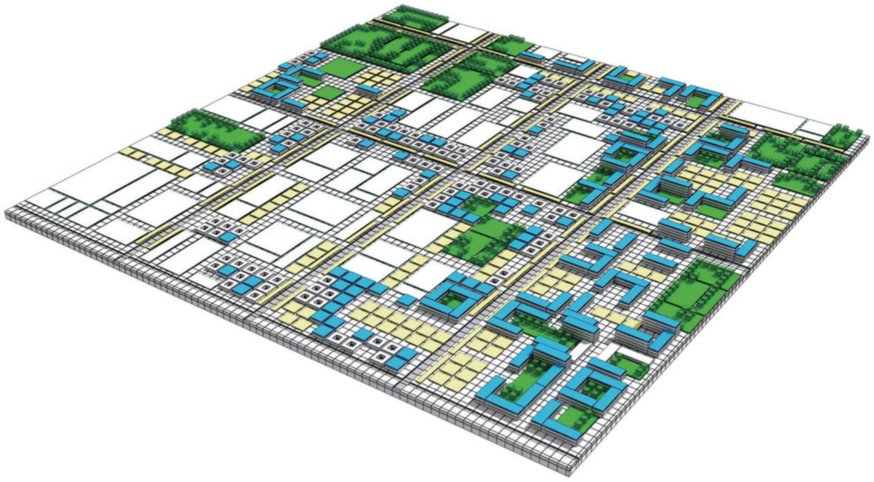
3.1 Urban Space Platform

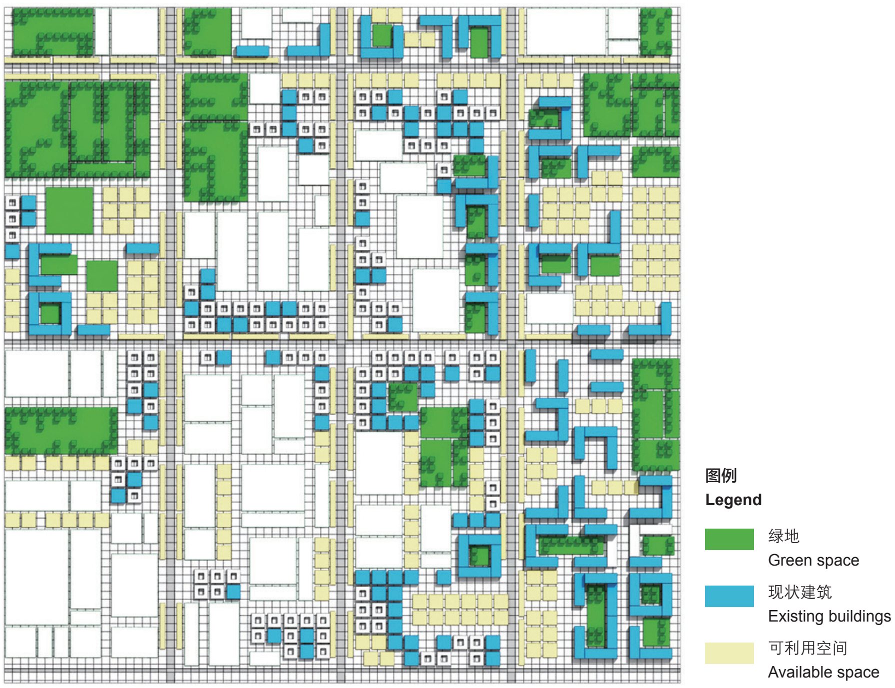
Many scholars are inclined to categorize, digitize, and quantify urban form information in studying urban design strategies. For example, Philip Steadman et al. regarded the building form as a quantitative parameter to analyze urban energy consumption[17]; Nicole Miller and Duncan Cavens et al. used statistical methods to analyze and classify the urban forms[18]. In the decision-making process of urban design, visualization of various urban space forms is very important. Street fabrics, building areas, urban density, floor area ratio, etc. have been shown through two-dimensional plans; however, a lot of detailed information such as building facades, roof structures, basements, and building overhangs can only be presented in three-dimensional models. Therefore, the decision-supportive framework in this paper proposes a three-dimensional urban space model as the fundamental working platform, in which seven basic parameters, namely urban density, rate of coverage, architectural form, open space, street attributes, land use, and underground space are integrated:

1) Urban density is described through development density and floor area ratio;

2) Ratio of coverage contains that of residence, working place and population;

3) Building morphology includes building form, plane shape, building height, area of roofs, area of walls, number of floors, area of balcony, etc.;





Category	Number	Unit	Category	Number	Unit
Building morphology	NA	NA	Rooftop of institutional-hospital	NA	m^2
Building form	Single floor; multiple	NA	Rooftop of utility corridor	NA	m^2
Building height	4-24	NA	**Ground parking space**	**73,530**	m^2
Number of floors	1-8	NA	Ground parking space of commercial-retail	NA	m^2
Land use	**2.5**	km^2	Ground parking space of office	2,400	m^2
Residential	0.7	km^2	Ground parking space of institutional	NA	m^2
Retail	0.01	km^2	Public ground parking space	47,320	m^2
Industrial	0.07	km^2	Road and street side park	11,400	m^2
Community and educational	0.01	km^2	**Open space**	**220,723**	m^2
Underground	**0**	m^2	Public parks	101,300	m^2
Underground of commercial-retail car	0	m^2	Playgrounds	64,600	m^2
Underground of residential car	0	m^2	Nature preserves	NA	m^2
Underground of office car	0	m^2	Cemeteries & amusement areas	NA	m^2
Underground of institutional car	0	m^2	**Urban infrastructure**	**1,640**	m^2
Underground of utility	NA	m^2	Railway	NA	m^2
Underground of public transport	NA	m^2	Railway station	NA	m^2
Underground of civil facility	NA	m^2	Bus station	120	m^2
Streets and roads	**94,300**	m^2	Public facilities	1,320	m^2
Street	23,800	m^2	**Vacant land and gardens**	**932,500**	m^2
Sidewalk	17,500	m^2	Vacant land for development	490,200	m^2
Pedestrian	21,700	m^2	Vacant land for non-development	434,500	m^2
Highway	NA	m^2	Private garden	NA	m^2
			Public garden	NA	m^2
			Facades and walls	**0**	m^2
			Facades and walls of commercial-retail	0	m^2
			Facades and walls of residential	0	m^2
			Facades and walls of office	0	m^2
			Facades and walls of institutional	NA	m^2

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4）开放空间包括广场用地、活动场地、绿地、草地、林地、保留用地、农业用地、停车场等；①

5）街道属性包括街道、公路和步行道等；

6）用地功能包括居住用地、商业用地、工业用地、社区及教育用地等；

7）地下空间包括地下停车、地下商业和地下设施。

4) Open space includes plaza space, activity space, green space, grass space, grove space, reserved space, agricultural space, parking space, etc.;①

5) Street properties include streets, roads, pedestrian path, etc.;

6) Land uses include residential land, retail land, industrial land, community and educational land, etc.

7) Underground space includes underground parking, underground commercial, and underground facilities.

① 此处的广场用地和活动用地具有不同的性质；在实际统计中，广场用地不计入可改造用地，而活动用地则可计入。类似地，绿地将计入可改造用地中，草地和林地则不计入。

① In this paper, plaza space and activity space are different. In actual open space investigation, plaza space would not be regarded as reclaimable land while activity space belongs to it. Similarly, green space would be regarded as reclaimable land but grass space and grove space not.

3. 低密度城市空间工作平台示意图（左上为三维模型图，左下为平面图），以及模型中包含的部分城市空间信息

3. A schematic diagram of the urban space platform showing the 3D model of a low-density city (upper left) and its master plan (bottom left), as well as part of urban space information of the model

3.2 指标选取

新陈代谢指标体系被用于描绘城市运转情况。一般来说，指标作为单项参数，不能直接用于描述现状环境条件，但"可以用于衡量一个系统的（部分）运行情况"[19]并量化数据。在选取城市资源流动指标时，应将其与城市居民生活的关联密切度以及对设计干预的敏感度作为主要标准。与城市居民生活最密切相关的三种城市资源是水、能源、食物。此外，不同于成分复杂的工业废物，有机废物（主要指生活有机废物和城市农业有机废物）更容易被追踪和处理，向外部环境输出频繁，因此也是一种有待进一步利用的重要城市资源。随着城市人口的增加，城市中水、食物、能源的输入和有机废物的输出在近几十年内呈几何级数增长，成为城市资源枯竭和城市病频发的主要原因。

不同资源类型之间也存在紧密联系。例如，食物的生产过程消耗了全球约70%的清洁水资源，食物的供给过程又消耗了全球约30%的能源[20]。因此，我们无法将其中任何一种资源从整个系统中隔离开来以衡量其流动情况对环境的影响，而是需要建立一个指标体系进行整体评价。虽然框架以水、食物、能源和有机废物为主要评价指标，但也可根据每个城市的具体情况进行增减。例如，在水资源丰富而矿产资源贫乏的区域，可以删去水资源指标并新增金属和碳足迹指标。

3.3 设计情景模拟

设计情景模拟分析方法为城市设计决策提供了新思路。这一分析方法并非旨在预测城市未来发展的确定情形，而是通过呈现不同可能性，帮助规划设计师明确现阶段的城市发展方向[21]。设计情景模拟法全面考虑了城市中与设计干预相关的因素，将不确定影响因子进行分类并结合进去，从而帮助设计者制定更好的设计方案。更重要的是，情景模拟可以在明确的发展限制下对不同的环境变量进行量化，因此也具有定量分析功能。该框架中的设计情景模拟以文字描述的形式呈现，包含内容、挑战、理论框架、事件、行为、结果以及反应。此外，设计情景还可判断某一设计干预是否会为城市带来预期结果，以及设计策略是否符合城市未来发展的条件。在制定设计情景时，应最大限度地反映实际需求，并遵循以下原则：

3.2 Indicator Selection

Indicator system of metabolism is used to reflect the city's operating status. Generally speaking, as a single parameter, indicators cannot describe the current environment situation, but it "is a measure used to express the behavior of a system or part of a system"[19] and is useful to analyze quantitatively. The indicators should be highly correlated to urban life and sensitive enough to design interventions, and three types of urban resources, namely water, energy, and food are most closely related to residents living. In addition, organic waste (mainly refers to domestic organic waste and urban agricultural organic waste) is also included because it can be tracked and processed more easily than industrial waste with a close relationship with urban life and high output frequency. In recent decades, the input of water, food, and energy and the output of organic waste of cities have increased exponentially due to urbanization, which is the main reason of resource exhaustion and urban diseases.

Different resource types are relevant. For example, food production consumes approximately 70% of the clean water in the world, and food supply chain consumes about 30% of global energy[20]. Therefore, the flow of any type of resource cannot be isolated from the urban system to measure its impact on the environment, making it necessary to establish an indicator system to evaluate holistically. Notably, the indicator system can be adjusted according to the specific conditions of different cities: For example, in an area with rich water resources and poor mineral resources, indicator of water can be replaced by those of metal and carbon footprint.

3.3 Urban Scenario Simulation

The design scenario simulation provides a new method for urban design decisions. It aims to show the possibilities of different development modes, rather than to predict a specific prospect of a city, helping planners and designers clarify the orientation of city development[21]. By using this method, factors related with design intervention and those with uncertainty can be comprehensively considered to create better solutions. More importantly, it is an ideal tool to quantify different environmental variables with specific constraints. The design scenario in the framework is described by its content, challenges, theoretical frameworks, events, behaviors, results, and responses, helping estimate whether a design intervention brings the desired results to the urban environment, or whether the adopted design strategy fits the conditions of future development. The design scenario setting should consider city's real demands as much as possible, and follow the following principles:

1）设定设计情景不是为了将最优选项呈现给设计者，而是帮助设计者理解设计干预与影响因素之间的关系；

2）需要设定一个合理的特定时间轴，以体现设计的可操作性；

3）须保证每个设计情景都有可能在未来的环境中实现；

4）须确保设计情景可通过现有设计手段实现。

以水、食物、能源和有机废物为指标，框架设定了6种基础设计情景：

1）线性发展情景：以现状发展模式类推未来发展情景，作为其他情景的参照；

2）绿色发展情景：将提高城市绿地率、增加城市建筑屋顶绿化面积作为城市未来发展的最重要方向；

3）城市农业优先发展情景：将城市农业作为城市未来发展的最重要方向，在城市可利用空间内主要种植农作物，减少城市对食物输入的依赖；

4）可再生能源优先发展情景：将利用可再生能源作为城市未来发展的最重要方向，在城市可利用空间内大量铺设太阳能板，并进一步推广风能和生物能利用；

5）慢交通优先发展情景：通过减少停车空间和机动车道面积限制私家车的使用，发展公共交通并提倡步行；

6）高技术优先发展情景：利用已有的先进技术（如垂直农场、无土栽培），在忽略前期高投入的情况下对城市空间进行设计干预。

3.4 参数模型

框架采用参数模型对各设计情景下一系列评价指标的绩效进行计算模拟，此类模型近年来在城市设计和规划领域广受欢迎[22]。模型采用设计者较易理解和操作的简单参数公式来模拟城市资源的输入量和输出量，并可以将模拟结果从已有模型转换到新模型上，对于指导不同项目的设计实践具有很强的实用性。未来，设计者可以根据需要将更高级、更精确的模拟工具（例如水资源和能源模拟计算工具）整合到该模型中以完善其分析和评价功能，提高参数模拟的准确性。

4 框架对设计实践的支持案例

建立框架的目标是指导城市设计实践。城市设计不仅要对城市现状进行分析，更需要对城市的未来发展进行预判，因此对框架本身提

1) The purpose of setting design scenarios is not to find the best option for designers, but to help them understand the connection between design interventions and influence factors;

2) An appropriate timeline should be set specifically to show the operability of the design;

3) To ensure that each scenario is likely to be realized in the future;

4) To ensure that each scenario can be realized through existing design methods.

Taking water, food, energy, and organic waste as indicators, the framework sets six basic design scenarios:

1) Linear development scenario, in which the city would develop under the current mode as a reference for comparison;

2) Green-oriented scenario, which focuses on increasing the green space coverage and the area of roof greening;

3) Urban agriculture-oriented scenario, in which most available urban space would be used for agricultural production, in order to reduce city's dependence on food import;

4) Renewable energy-oriented scenario, which prioritizes renewable energy utilization by installing solar panels widely in available urban space and expanding the use of wind energy and biomass energy;

5) Slow traffic-oriented scenario, which limits the use of private cars by reducing parking lots and motor roads, develops public transportation, and advocates traveling by walking;

6) High-tech-oriented scenario which uses existing advanced technologies (e.g., vertical farming and soilless culture) to design urban space in spite of the high cost.

3.4 Parameter Model

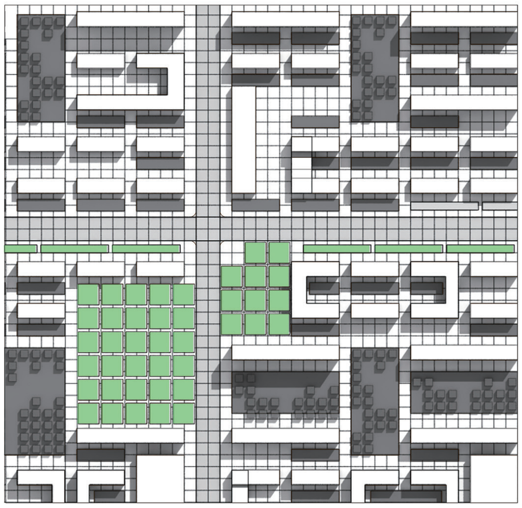
The framework is equipped with a parameter model to calculate the performance of a series of indicators for specific design scenarios, which has become increasingly popular in recent years in the field of urban design and urban planning[22]. With simple parameter formulas, the input and output of urban resources can be easily simulated, and transformed from an existing model to another one, which would be quite efficient in practice. In future, more advanced and accurate simulation tools (such as those for water resource and energy) can be integrated into the model to improve its analysis and evaluation functions with higher accuracy.

4 A Case Study of the Framework's Support for Design Practices

The decision-supportive framework is established to guide urban design practice. However, it is such a demanding task for

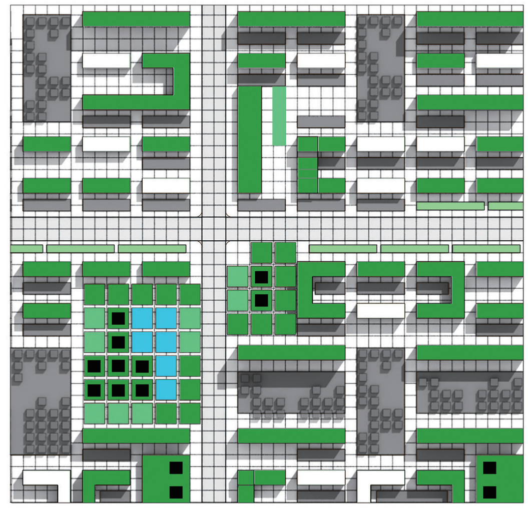
4. 将6项基础设计情景应用于工作平台的示意图

4. Schematic diagrams of the six basic design scenarios applied to the platform



情景1
线性发展情景（参照系）
Scenario 1
Linear development scenario as reference

情景2
绿色发展情景
Scenario 2
Green-oriented scenario



情景3
城市农业优先发展情景
Scenario 3
Urban agriculture-oriented scenario

情景4
可再生能源优先发展情景
Scenario 4
Renewable energy-oriented scenario

情景5
慢交通优先发展情景
Scenario 5
Slow traffic-oriented scenario

情景6
高技术优先发展情景
Scenario 6
High-tech-oriented scenario

图例
Legend

城市农业空间
Urban agriculture

绿色植物种植空间
Space for plants

可再生能源空间
Renewable energy development

水处理设施空间
Area with water treatment facilities

G-1 垂直农业空间
Vertical farming

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出了很高的要求[23]。很多学术研究目前仍停留在通过模型模拟自圆其说的层面，并未与设计实践建立直接联系。为了解决上述问题，本文提出的设计决策框架在建立伊始就必须符合以下特征：1）使用界面易于理解和操作；2）能够全面整合各相关领域的专业知识；3）能够对

the framework not only to analyze city's current situation but also to predict urban future[23] that many simulation methods and models have not gone beyond the theoretical self-justification to help designers. To solve this problem, the framework proposed in this paper should respond to five requirements: 1) it is easy to understand and operates with a user-friendly interface; 2) it fully integrates expertise in relevant fields; 3) it is able to evaluate design alternatives

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5. 以2016年北京国贸地区1.5km×1.5km区域为原型的工作平台分析图（含建筑三维信息）

5. Analysis diagram of working platform based on the 1.5 km × 1.5 km area of China World Trade Center area, Beijing, in 2016 (3D building information is included)

设计选项进行快速评价；4）具有生动的可视化效果；5）能够便捷地安装新工具或新模块。

为了验证上述决策框架的可行性，本文以交通堵塞严重、人口密度高的北京国贸地区可步行区域为例，依次进行了城市现状分析、设计情景设定、设计选项清单生成，以及设计评价。受篇幅所限，框架的具体应用过程不再详述。最终，框架为国贸地区提出以下城市设计导则：

1）大量铺设太阳能板，充分利用屋顶空间。情景比较分析显示，可再生能源优先发展情景对城市环境的改善效果明显；

2）控制私家车使用率，鼓励发展公共交通系统。慢交通优先发展情景可明显改善高密度和超高密度区域的环境状况；

3）垂直绿化或屋顶绿化对区域整体环境影响甚微，在设计实践中可以不予考虑；

4）尽量利用地下空间进行有机废物和废水处理，可有效降低城市有机废物和水资源的交换速率，对城市资源流动情况有较大改善；

5）该地区城市密度已超出城市环境所能承载的最大值。鉴于几乎

quickly; 4) with good visualization performance; and 5) it is open for updating tools and modules conveniently.

In order to prove the feasibility of the framework, a pilot study was conducted in the walkable part of China World Trade Center area in Beijing which suffers from serious traffic congestion and high population density. Through urban status analysis, design scenario setting, design alternative formation, and design scenario evaluation (the specific process would not be introduced owing to length limitation of the paper), guidelines for urban design practices of this area are proposed as following:

1) Make full use of the roof space mainly by installing solar panels. Compared with other scenarios, the renewable energy-oriented one could improve the area’s environment significantly;

2) Control the use of private cars and encourage the development of public transportation systems, as the slow traffic development scenario has shown a significant improvement of the environment in high- and extreme-high-density urban areas;

3) Vertical greening or roof greening contributes little to improving the environment, and it is not recommended in design practice;

4) Use the underground space as much as possible for treatment of organic waste and wastewater, which can

Implementation category	Density	Abbr.	Streets	Roads	Vacant land	Gardens	Infrastructure	Open space	Rooftop	Underground	Parking space	Facades & walls	Other
Greenhouse farming	Low	GF_L	+		+++	++	++	++	+++		+		
	Medium	GF_M	+		+++	++	+	+	++		+		
	High	GF_H			+++	++	+	+	+				
Traditional farming	Low	TF_L	+	+	+++	++		++	+++		+++		
	Medium	TF_M		+	++	++		++	++		++	+	
	High	TF_H	+	+	+	++		++	+		+		
Aquaculture system	Low	AS_L			+++	++	+		+++	+			
	Medium	AS_M			+++		+		++	++			
	High	AS_H			+++		+		+	+++			
Hydroponic system	Low	HS_L	+		+++					+			+
	Medium	HS_M	+		+++	++	++			++			+
	High	HS_H	+		+++	++	++			+++			+
Aquaponic system	Low	AS_L		+	+++					+			+
	Medium	AS_M			+++					++			+
	High	AS_H		+	+++					+++			+
Vertical farming system	Low	VF_L	+	++	+++			+			+		
	Medium	VF_M	+	++	+++			+		++	+		
	High	VF_H	+	++	+++			+		++	+		
Wall farming system	Low	WF_L										+++	
	Medium	WF_M										+++	
	High	WF_H										+++	
The living machine	Low	LM_L			+++	+	++	+		+			+
	Medium	LM_M			++	+	++	+		++			+
	High	LM_H			+	+	++	+		+++			+
Membrane bio-reactor	Low	MBR_L						++		+			+
	Medium	MBR_M						++		++			+
	High	MBR_H						++		+++			+

Implementation category	Density	Abbr.	Streets	Roads	Vacant land	Gardens	Infrastructure	Open space	Rooftop	Underground	Parking space	Facades & walls	Other
Anaerobic digestion	Low	AD_L			+++			++		+			+
	Medium	AD_M			++			++		++			+
	High	AD_H			++			++		+++			+
Rainwater collector	Low	RC_L	++	+	+++	++	++	+	++		+		
	Medium	RC_M	++	+	+++	++	++	+	++		+		
	High	RC_H	++	+	+++	++	++	+	++		+		
Waste incineration	Low	WI_L			+++			++		+			+
	Medium	WI_M			+++			++		++			+
	High	WI_H			+++			++		+++			+
Gasification	Low	GAS_L			+++			++		+			+
	Medium	GAS_M			+++			++		++			+
	High	GAS_H			+++			++		+++			+
Wind turbine	Low	WT_L	+	+++				+++	++				
	Medium	WT_M	+	++				+++	++				
	High	WT_H	+	+				+++	++				
Biogas boiler	Low	BB_L	++			++		+++			+		
	Medium	BB_M				++		+++			+		
	High	BB_H				++		+++			+		
Photovoltaic panel	Low	PV_L	++	++	+++	+++	++	+++	+++		++	+	++
	Medium	PV_M		++	+++	++	++	++	+++		++	++	++
	High	PV_H		++	+++	+	+	++	+++		+	+++	++
Cooling and heating system	Low	CH_L			++			++		+++			
	Medium	CH_M			++			++		+++			
	High	CH_H			++			++		+++			
Planting green (grass)	Low	PGG_L	+	++	+++	+++	++	+++	+++		+++	++	++
	Medium	PGG_M	+	++	+++	+++	++	+++	+++		+++	++	++
	High	PGG_H	+	++	+++	+++	++	+++	+++		+++	++	++
Planting green (trees)	Low	PGT_L	+	++	+++	+		++			+		+
	Medium	PGT_M	+	++	+++	+		++			+		+
	High	PGT_H	+	++	+++	+		++			+		+

图例 Legend: 无适应性 No feasibility; + 低适应性 Low feasibility; ++ 中适应性 Medium feasibility; +++ 高适应性 High feasibility

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6. 北京国贸地区以减慢城市资源流动为目标的策略及技术应用可适应性结果

6. Feasibility of strategies and technologies applied to slow down the urban resource flows of China World Trade Center area in Beijing

所有设计策略对超高密度区域的能源消耗和水消耗都改善甚微，若只从环境保护效益角度考虑，应尽量减少城市中类似的超高密度区域。

5 结论与讨论

城市是一个非常复杂的系统，需要多尺度、多专业的模拟工具去量化、分析和模拟设计干预可能对其环境产生的影响。本文以城市新

effectively slow down the exchange rate of them, greatly improving the urban resource flows;

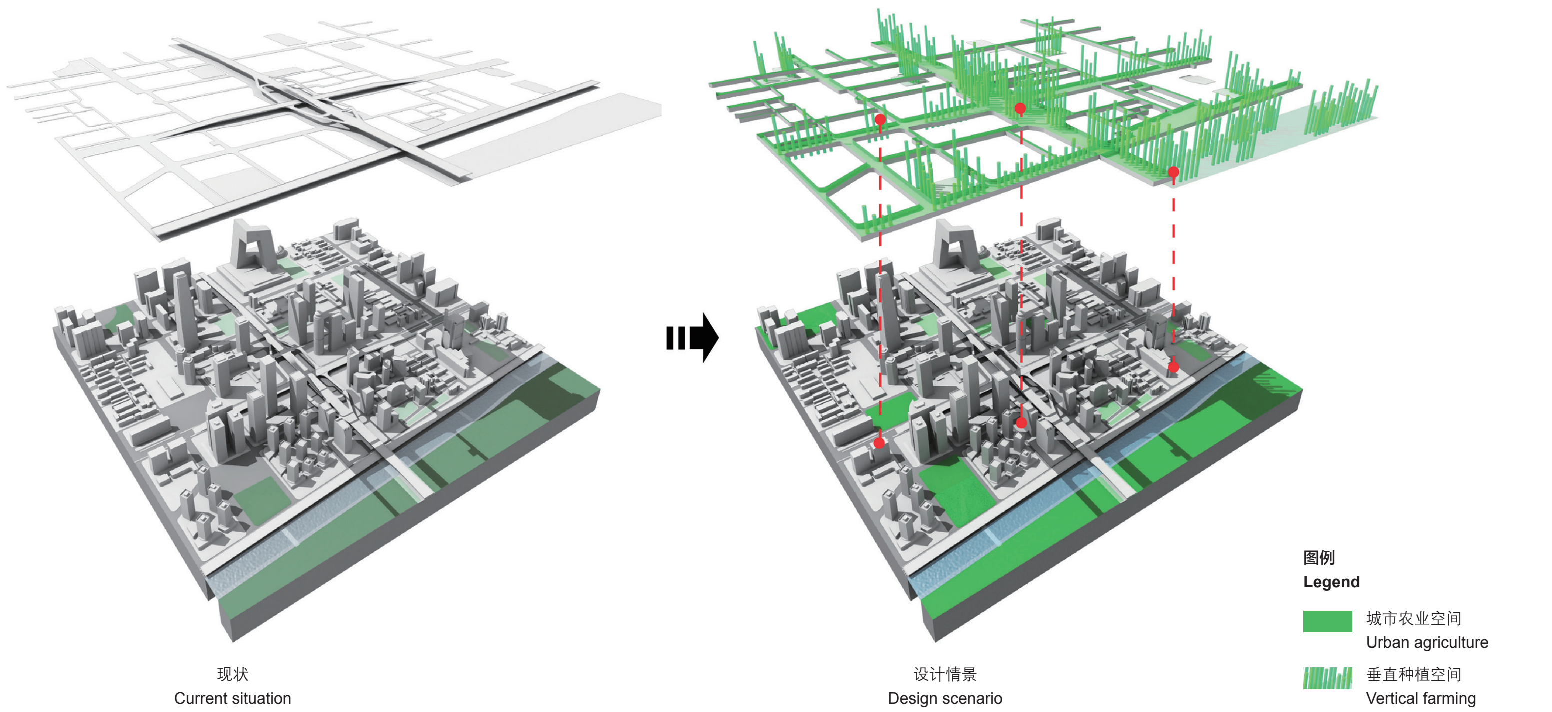
5) The urban density of this area has exceeded its bearing capacity. Since almost all design interventions have little effect on energy and water consumption in such areas, super-high-density development should be avoided merely from the perspective of environmental bearing.

5 Conclusion and Discussion

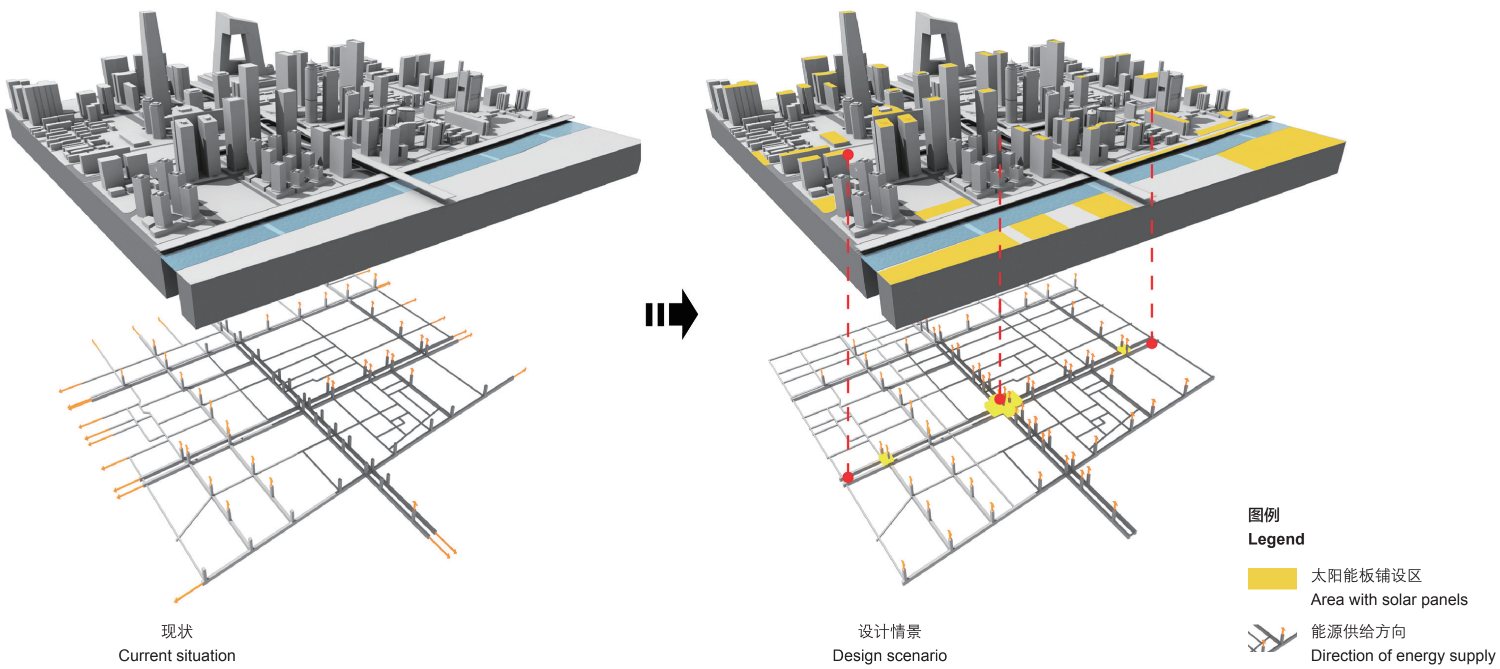
The city is a very complex system that requires multi-scale and trans-disciplinary simulation tools to quantify, analyze, and

7. 城市农业发展优先情景下的北京国贸地区城市空间利用示意图
8. 可再生能源发展优先情景下的北京国贸地区城市空间利用示意图

7. The schematic diagram of urban space utilization in China World Trade Center area, Beijing in the urban agriculture-oriented scenario
8. The schematic diagram of urban space utilization in China World Trade Center area, Beijing in the renewable energy-oriented scenario



7



8

陈代谢为视角，以将城市资源流动慢下来为目标，创建了一个整合性城市设计决策支持框架。作为一个定量分析工具，该框架面临的最大挑战之一是如何确保所需数据的可获得性及其统计方法的准确性。因此，框架并未为每个指标设置固定权重值，而是通过数据之间的单向

predict the impacts design interventions may bring to it. The goal to establish the integral decision-supportive framework in this paper is to slow down the city's resource exchange from the perspective of Urban Metabolism. As a quantitative analysis tool, one of the greatest challenge of this framework is to ensure the availability of data and the accuracy of statistical

比较简化模型，以在一定程度上回避数据不全的问题。框架的最终输出结果并不意味着某一种设计方案或设计策略即是最优选项，而是帮助设计决策者建立对该设计方案的直观认识，并更深刻理解其将对城市环境造成何种影响。

最后需要指出的是，城市设计不仅影响城市环境，也会对居民的幸福度和社会心理等造成影响。因此，城市设计也涉及社会学和经济学方面的内容，而这些内容尚无法通过该设计决策支持框架进行量化分析。本文仅从城市资源管理的角度出发，以改善城市环境为目标。因此，不宜使用该框架去评价城市设计方法的正确与否，这也有违作者的初衷。**LAF**

methods. Therefore, a one-way comparison between different data types would be adopted instead of setting the weight value of the single indicators to simplify the use of model and partially avoid data deficiency. Instead of showing the optimal design strategy, the final output of the framework provides decision makers an intuitive understanding of a specific design proposal and the impacts the design intervention would bring to the urban environment.

Finally, it should be pointed out that urban design influences not only on the urban environment, but also on the resident's happiness and social psychological status. Therefore, urban design involves Sociology and Economics, yet which cannot be quantified through the decision-supportive framework. This paper only aims at improving the urban environment from the perspective of urban resource management, so it is inappropriate to use this framework to judge whether an urban design method is "right" — this is not the author's original intention. **LAF**

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