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City laboratory: Embracing new data, new elements, and new pathways to invent new cities

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Introduction

Taking cities as objects for observation, understanding, conceptualisation, and practice has always been the continual focus of urban researchers, planners, and designers. It is also the central theme of the journal **Environment and Planning B (EPB)**. From the steam and electrical revolution to the information revolution, disruptive technologies have continuously reshaped cities and driven the innovation of methods and means in urban studies (Batty, 2022). In recent years, cutting-edge technologies such as information and communication technology (ICT), autonomous driving, artificial intelligence, and large language models have been proliferating amidst the Fourth Industrial Revolution. These disruptive technologies have not only redefined and reshaped urban spaces and daily life but also exerted a profound influence on the work and intellectual discourse of urban education, research, and practice professionals (Mitchell, 2000).

In this context, city laboratories have been gradually emerging in recent decades, exemplified by institutions such as the Santa Fe Institute, the Centre for Advanced Spatial Analysis, the Senseable City Lab, the QUT Design Lab, the Future Cities Laboratory, the Urban Informatics Lab, and Beijing City Lab. These laboratories are dedicated to developing technical, computational, and data-driven solutions to sustainability challenges, aiming to create more liveable and equitable cities. The primary objective of this commentary is to elucidate the concept and characteristics of the city laboratory, as well as its developmental opportunities in the era of the Fourth Industrial Revolution. This endeavour seeks to offer fresh insights and references for the advancement of

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urban studies and their applications. We also believe this could be one of the main streams for the upcoming decade of **EPB** as we are standing at its 50th anniversary.

Definition of city laboratory

The concept of the city laboratory is an integrated scientific research, design, and practice framework that considers cities as experimental settings for enhancing urban planning, design, policy-making, and city management. It involves applying scientific methods, design principles, and long-term observations to drive urban improvements. The core notions of city laboratories encompass the following three key aspects.

First, city laboratories consider urban environments as the primary focus of urban studies, encompassing the built environment (e.g. buildings, plazas, and infrastructures), the natural environment (e.g. noise, light, and air quality), and the social environment (e.g. demographics, travel patterns, and activities). This comprehensive perspective allows city laboratories to holistically understand urban dynamics and challenges, providing a solid foundation for their research and initiatives.

Second, city laboratories rely on data analytics and modelling. Various spatial data, such as high-resolution remote sensing images, street view pictures, activity trajectories, and user comments from social media platforms, provide rich opportunities for analysis and research within these laboratories. Utilising data analytical techniques, including geocomputation, spatial statistics, visualisation, modelling, machine learning, and deep learning, city laboratories can validate, update, and expand existing knowledge systems, thus laying the groundwork for the evolution of urban science.

Last, city laboratories aim to bolster urban planning, design, policy-making, and management to achieve sustainable and liveable cities. City laboratories not only assess policies and planning implementation by analysing current and historical data and identifying existing problems to support practice directly but also promote the update and iteration of practical theories, knowledge, norms, and guidelines with longer research cycles (Figure 1).

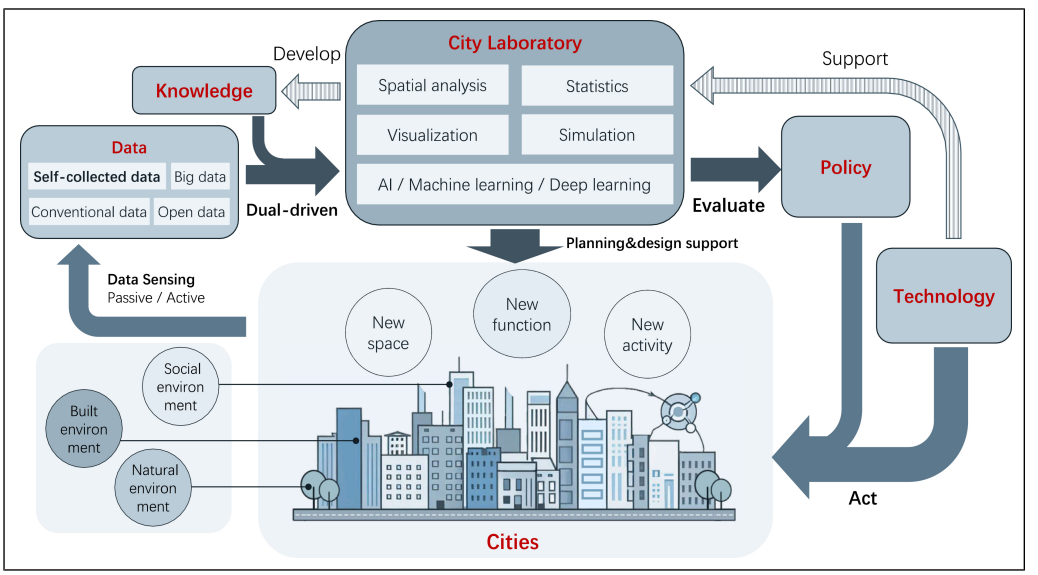

Figure 1. Conceptual framework of the city laboratory.

Emerging trends and opportunities for city laboratories

As technologies of the Fourth Industrial Revolution mature and their applications deepen, city laboratories are presented with new opportunities: (1) transitioning from passive to active modes of observing and understanding urban environments; (2) responding to contemporary city development trends and evolving demands; (3) conducting evidence-based research and applications through the utilisation of advanced digital innovations. This paper employs the concepts of 'new data', 'new elements', and 'new pathways' to illustrate shifts in the methodology of urban research, the ontology of cities, and the implementation of applications, respectively, to demonstrate the prospect of city laboratories in the near future.

New data: Observing cities using active urban sensing

The emergence of a new data environment characterised by big data and open data has created unprecedented opportunities for urban research, propelling it into data-intensive scientific discovery, also called the Fourth Paradigm (Hey et al., 2009). The availability of new data sources with high spatial and temporal resolutions enables city laboratories to gain insights into the built and natural environments from aerial perspectives (e.g. daytime and night-time satellite remote sensing) and ground perspectives (e.g. street view pictures). Social sensing data (e.g. travel trajectory and smart card data) also facilitates understanding the social environment through human mobility and activity perspectives (Long and Huang, 2019). However, existing 'new' data still faces limitations, including inadequate spatial resolution, timeliness, coverage, and specificity.

The active urban sensing framework, based on various sensors and Internet of Things (IoT) technologies, offers a solution to complement existing 'new' data (Li and Long, 2024). It employs fixed sensing, mobile sensing, and coupled sensing modes to actively collect data on the urban built environment, the natural environment, and the social environment. Fixed sensing provides continuous data monitoring and evaluation for high-frequency changing phenomena like the activities in the social environment, while mobile sensing offers greater data coverage for changes in the built environment that occur less frequently, particularly in areas with lower economic development and poor infrastructure. With advancing technologies, active urban sensing holds significant promise. Sensor options such as Wi-Fi probes, eye trackers, unmanned aerial vehicles, hunting cameras, wearable devices, and emerging autonomous vehicles and robots are increasingly available, versatile, and even ubiquitous. Additionally, advancements in data fusion processing and analytical methods, including data visualisation, natural language processing, computer vision, and deep learning models, enable urban researchers to capture intricate urban dynamics and measure the unmeasurable.

New elements: Understanding the reshaped cities

The advancement of new technologies not only introduces novel data and methodologies but also profoundly impacts cities at an ontological level. Emerging lifestyles and services, such as Airbnb, co-working, teleworking, bike-sharing, O2O (online to offline) services, on-demand food delivery, and autonomous driving, are reshaping individuals' behaviour and preferences for dwelling, working, transportation, recreation, and access to amenities (Li et al., 2024). As the influence of ICT and autonomous things deepens, research on urban life and spatial transformations has progressed from theoretical and case studies to more quantitative analyses. This evolution is marked by shifts in focus from regional to intra-urban scales and an expansion of research domains from knowledge-based innovative centres to shared residents, shared work, remote work, shared micro-mobility, and

O2O services. Despite these advancements, research in this domain remains nascent, warranting further exploration of theoretical frameworks and practical applications.

We advocate for increased attention to the ongoing changes in urban environments. These transformations initially manifest at the individual behavioural level but eventually influence the functional utilisation of urban spaces and even contribute to the gradual evolution of urban form/structure (Batty, 2018). Some key considerations include the following: How do emerging technologies impact people's behaviours and preferences? What factors determine the pace and extent of these technological impacts? How do these emerging behaviours reshape urban spaces? And what are the potential positive and negative externalities associated with these changes? Researchers should consistently monitor the evolving dynamics of urban life and urban space, thus formulating, developing, and updating urban spatial theories. Meanwhile, researchers should also engage in thorough discussions and deductions regarding potential equity issues, conflicts, and risks to explore solutions.

New pathways: Empowering cities with digital innovations

As a fundamental approach to creative design, spatial intervention has long been a cornerstone of teaching and practice in urban design, architecture, interior design, and product design. Building upon this foundation, place-making encourages individuals' participation in the design, construction, and utilisation of space, enhancing their perception and interaction with the environment. With the development of ICT, from digital cities to smart cities and even future cities, more digital solutions are proposed to deal with the issues in transportation, spatial usage, and environmental controls. However, current digital design and smart city practices prioritise the application of digital tools in the planning and design process, such as planning support systems (PSSs) and platform management capabilities, such as building information models (BIMs) and city information models (CIMs). This underscores the use of software applications and soft technology solutions rather than integrating digital elements more closely with the built environment.

With the development of various digital innovation technologies, an increasing number of design labs, firms, and institutions are exploring new design elements coupled with spatial intervention and place-making. These explorations include enhancing the playability of spaces by adding human–machine interactive facilities, monitoring and managing the use of urban spaces by installing sensors, actuators, and digital management platforms, and strengthening the themes and atmosphere of spaces through audiovisual, lighting, and mixed reality technologies. Integrating hardware and software is expected to empower cities by innovating human-space interactions, enhancing space utilisation efficiency, achieving low carbon, and promoting inclusivity and resilience. However, selecting and applying these digital innovation facilities require careful evaluation and optimisation through active and passive feedback from users and managers, which is essential for better integrating spatial intervention and digital innovation, and for enhancing place-making.

Conclusions and prospects

In the Fourth Industrial Revolution era, city laboratories are facing new potential to leverage active urban sensing, observe new lifestyles and spatial representation, and enhance urban practice through digital innovation technologies. However, it is essential to emphasise that a city's socioeconomic status, emergent events, and policy regulations also significantly influence cities. Our focus can extend to cities at various development stages (e.g. growth, renewal, or shrinkage), for diverse demographic groups (e.g. elderly, children, and women), experiencing emergencies (e.g. pandemics and natural disasters), and striving for sustainability (e.g. low-carbon and health). While we cannot predict the future of cities, we can leverage the opportunities derived from the aforementioned

technological and analytical advances to actively identify, model, formulate, and develop new urban rules, principles, and solutions to support the invention of new cities. This aligns with the scope of the **EPB** and provides reference and inspiration for researchers in related fields for explorations in the next decade.

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