URBAN SOLUTIONS AND SUSTAINABILITY R&D CONGRESS 2023
BUILDING SUSTAINABLE, RESILIENT, AND LIVEABLE CITIES OF TOMORROW
4TH – 5TH OCTOBER 2023

UrbanSense: Empowering Communities through Active Sensing for Sustainable Urban Development

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1 Introduction

1.1 The significance of monitoring the urban environments and their dynamics

Crucial for sustainable urban development, particularly in the context of the **Sustainable Development Goals** (SDGs)

However, **appropriate and accurate monitoring** is a challenging task due to wide variations and scales of urban issues.

1 Introduction

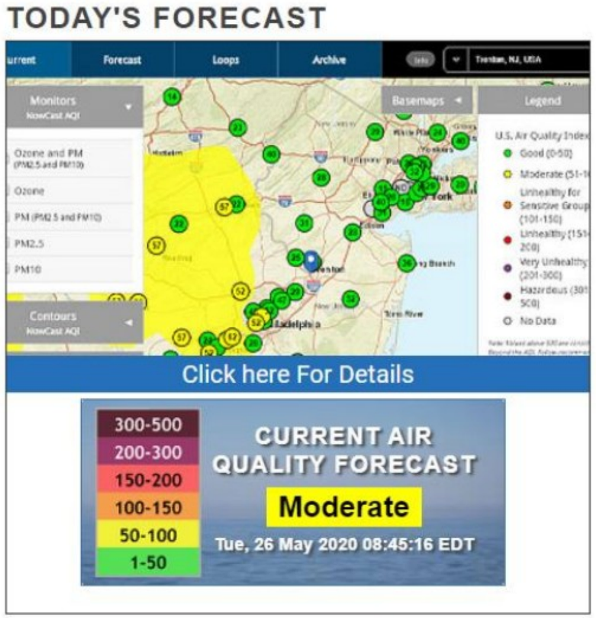
1.2 Traditional monitoring methods

Census data: outdated and infrequent

Meteorological and environmental monitoring stations: low spatial resolution

Urban remote sensing: limited capability to extract socio-economic attributes and human dynamics

Census data



Monitoring stations

Urban remote sensing

Source:https://www.nj.gov/dep/airmon/pdf/2019-nj-aq-report.pdf

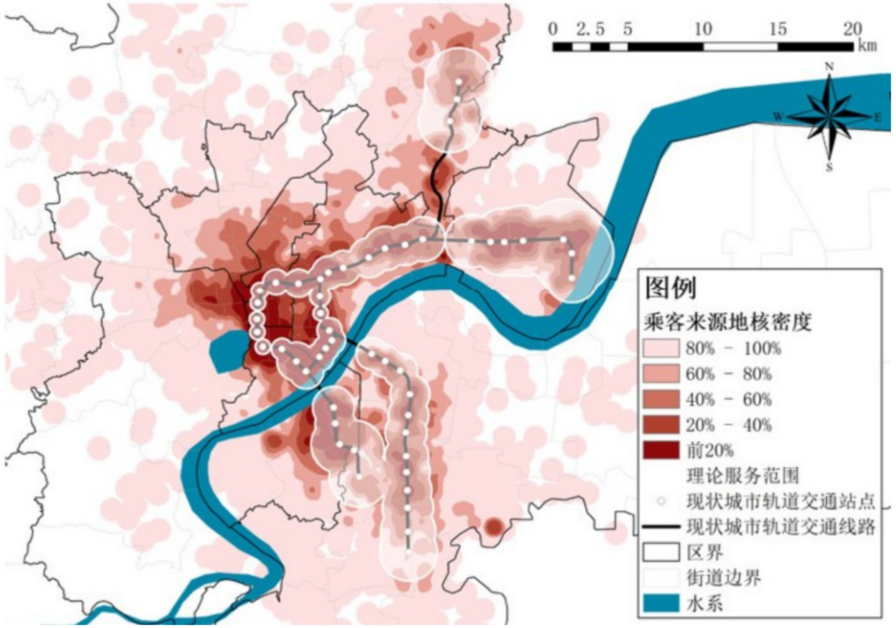
1 Introduction

1.3 Passive sensing methods

With advancements in **information and communication technology (ICT)** and sensor technology

Data types: **big data of social dynamics** and **big image data**

However, limitations still exist in terms of **spatial coverage, data frequency, and data types**.



Social dynamics Big Data - mobile signaling data

Big image Data - Street View pictures

Source: (Left) Liu Sihan, Lin Shijia, ZHANG Zhujun, NIU Xinyi. Temporal Decision Support Model for Urban Rail Transit Line Network Construction Based on Mobile Phone Signaling Data [J]. Journal of Human Settlement and Environment in Western China. 2021,36(05):113-120
(Right) Zhang Shujie, Li Wenzhu, Long Ying, et al. Evaluation of the improvement of urban street walking facilities based on street view images for many years: a case study of 45 Chinese cities [J]. Urban Development Research,2022,29(06):53-64+73.

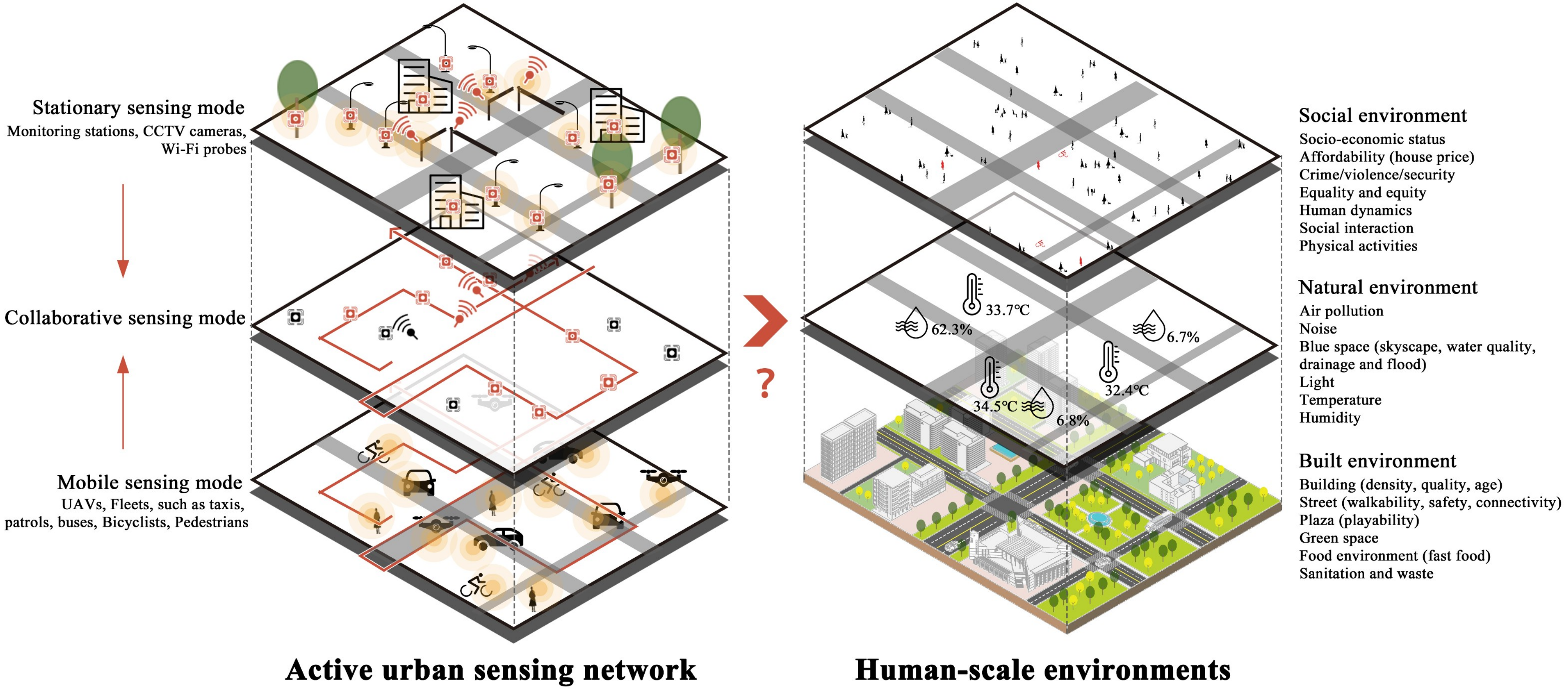
1 Introduction

1.4 Active sensing framework (UrbanSense)

Proposes an active urban sensing approach

Flexibly adapted to specific needs; practical and cost-effective

Categorized into **three paradigms**: Stationary Sensing, Mobile Sensing, and Collaborative Sensing



2.1 Evidence-based analysis of indicators

Compilation of **typical monitoring indicators** for subsequent categorization of specific monitoring requirements.

	Variable	Source	Sensing mode
Built envir.	Road width, length	Yang, Fang, and Li (2013)	Mobile
	Civil infrastructure monitoring	Ni, Xia, Lin, Chen, and Ko (2012)	Mobile
	Sanitation/Cleanness of dumpsters	Ramírez et al. (2020), Mujumdar, Rajamani, Subramaniam, and Porat (2013)	Mobile
	Road-side parking statistics	Mathur et al. (2010)	Mobile
	Road anomaly	Li et al. (2019)	Mobile
	Green exposure	Z. Zhang, Amegbor, Sigsgaard, and Sabel (2022)	Mobile
	Sky, tree view factors	Grimmond, Potter, Zutter, and Souch (2001)	Mobile
	Bridge conditions, vibrations	Corbally and Malekjafarian (2022)	Mobile
	Streetlight infrastructure	Guan, Li, Cao, and Yu (2016)	Mobile
Natural envir.	Air pollution	Anjomshoaa et al. (2018), Eisenman et al. (2010),Clark et al. (2020)	Mobile, Stationary
	Greenhouse gases	Tao et al. (2015)	Mobile
	Noise	Y. Zhang, Zhao, Li, Long, and Liang (2023), Clark et al. (2020)	Mobile,Collaborative
	Thermal comfort	Xie et al. (2022)	Mobile
	Urban heat islands	Lam, Ong, Wong, Sin, and Lo (2021)	Stationary
Social envir.	Crime/Violence/ security	Lindegaard and Bernasco (2018)	Stationary
	Pedestrian activities	Salazar-Miranda et al. (2023)	Mobile
	Public space vitality	Hou, Zhang, and Long (2023), Niu et al. (2022)	Stationary

Table 1. Evidence-based analysis of environmental targets

2 Methods

2.2 Categorization process for the indicators from existing studies

Indicators were classified according to four key attributes:

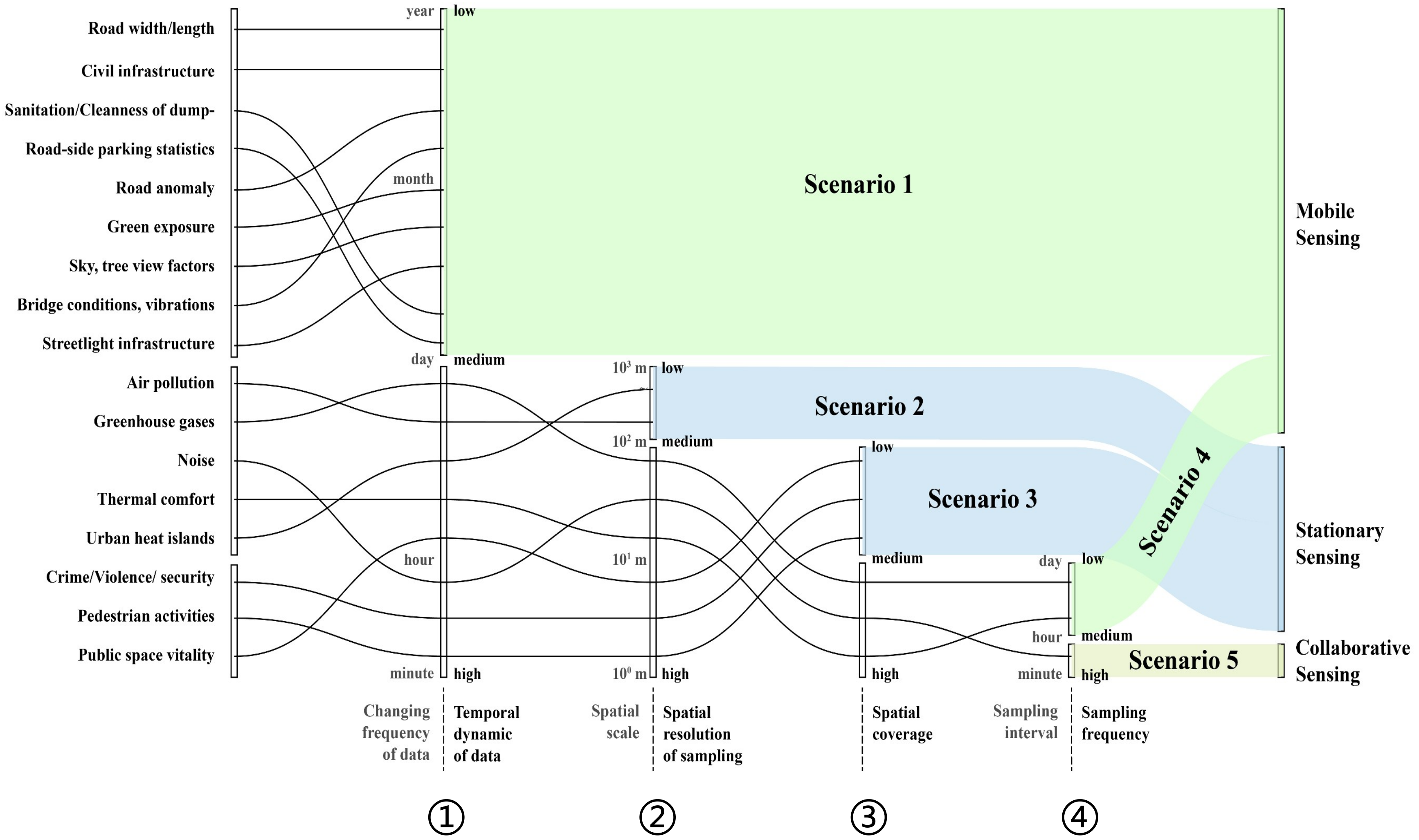
"Temporal dynamic of data"

"Spatial resolution of sampling"

"Spatial coverage of sampling"

"Sampling frequency"

Categorized into **five distinct scenarios**, each corresponding to the same sensing model



2 Methods

2.3 Settings of UrbanSense

(1) Stationary Sensing mode

Site selection:

(1) land cover type, (2) area division based on data characteristics , (3) site topography and spatial occlusion, (4) privacy and ethical concerns, (5) equipment safety, and (6) installation difficulty.

Combines all the criteria using a **weighted linear combination (WLC)** approach.

$$SSI_i = \sum_{j=1}^{n} W_j x_{ij}$$

where SSI_i is the site suitability index for unit , n is the number of criteria, W_j is the relative importance weight of criteria j, and x_{ij} is the standardized score of unit for criteria .

Device installation

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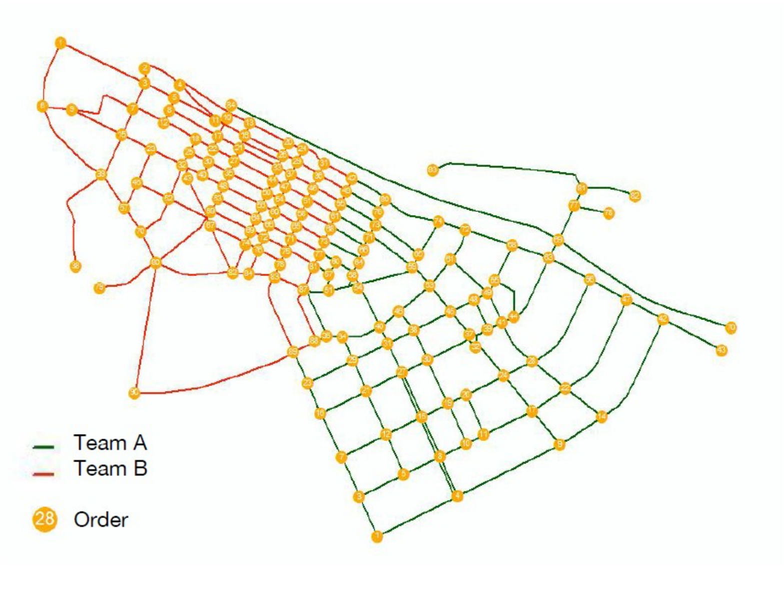
2.3 Settings of UrbanSense

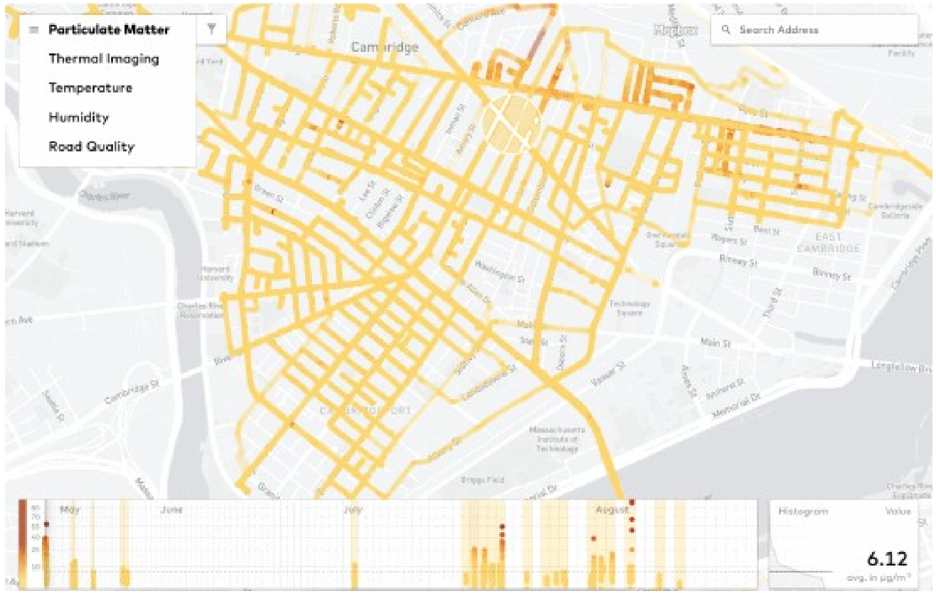
(2) Mobile Sensing mode

Two types of agents:

1. Dedicated agents with **customized routes and sampling frequency**
2. **Periodically moving** agents (public service carrier like garbage truck) that cover the entire area on **preset routes**



Route planned by the Chinese postal route algorithm



Space deployment mode of public service carrier (garbage truck)

Source: (Right) Anjomshoaa A, Duarte F, Rennings D, et al. City scanner: Building and scheduling a mobile sensing platform for smart city services[J]. IEEE Internet of things Journal, 2018, 5(6): 4567-4579.

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2.3 Settings of UrbanSense

(3) Collaborative Sensing mode

Two approaches to combine the data collected by **stationary and mobile sensing**:

1. Stationary sensing data as a temporal baseline, with the relative spatial differences obtained through mobile sensing;
2. Mobile sensing data along with temporal interpolation as a temporal baseline, superimposing the relative deviations between the two methods

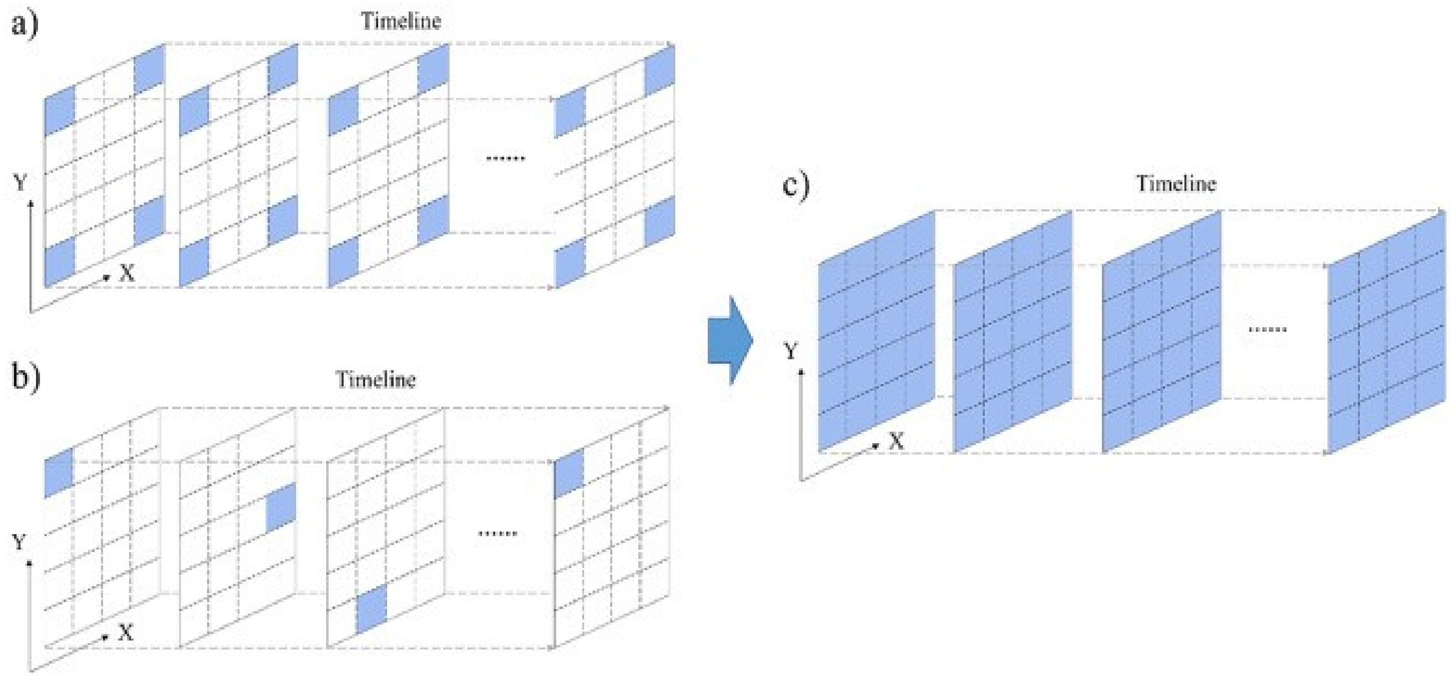

Illustration of collaborative sensing

Source: Geng Y, Yuan M, Tang H, et al. Robot-based mobile sensing system for high-resolution indoor temperature monitoring[J]. Automation in Construction, 2022, 142: 104477.

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Scenario 1: Built environment monitoring with Mobile Sensing in Xining

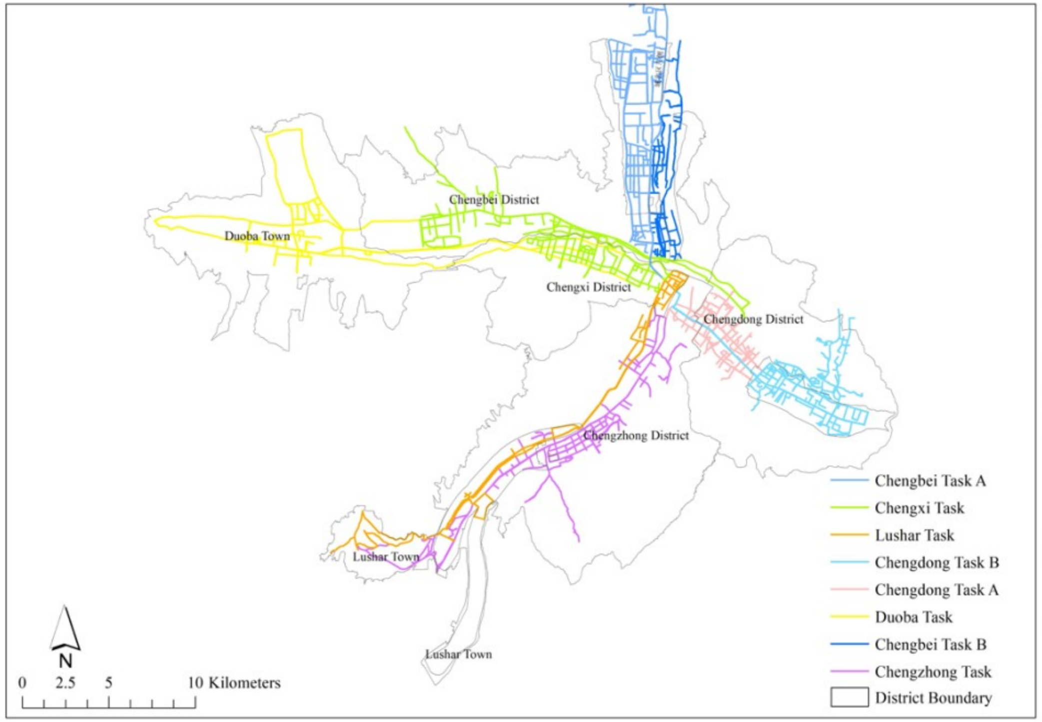
Low data fluctuation frequency

Scenario choose: Architectural elements usually change on a monthly or yearly basis with a low frequency, which fits into **Scenario 1**.

Time Period: 2022 and 2023

Experiment area: 1446km primary and secondary trunk road in Xining

Mobile sensing process: 3 cars equipped with sensors collected obtained 64,264 georeferenced images with a 25-meter spacing.



Task division for mobile sensing: simultaneous data collection and equipment installation on three taxis

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Scenario 1: Built environment monitoring with Mobile Sensing in Xining

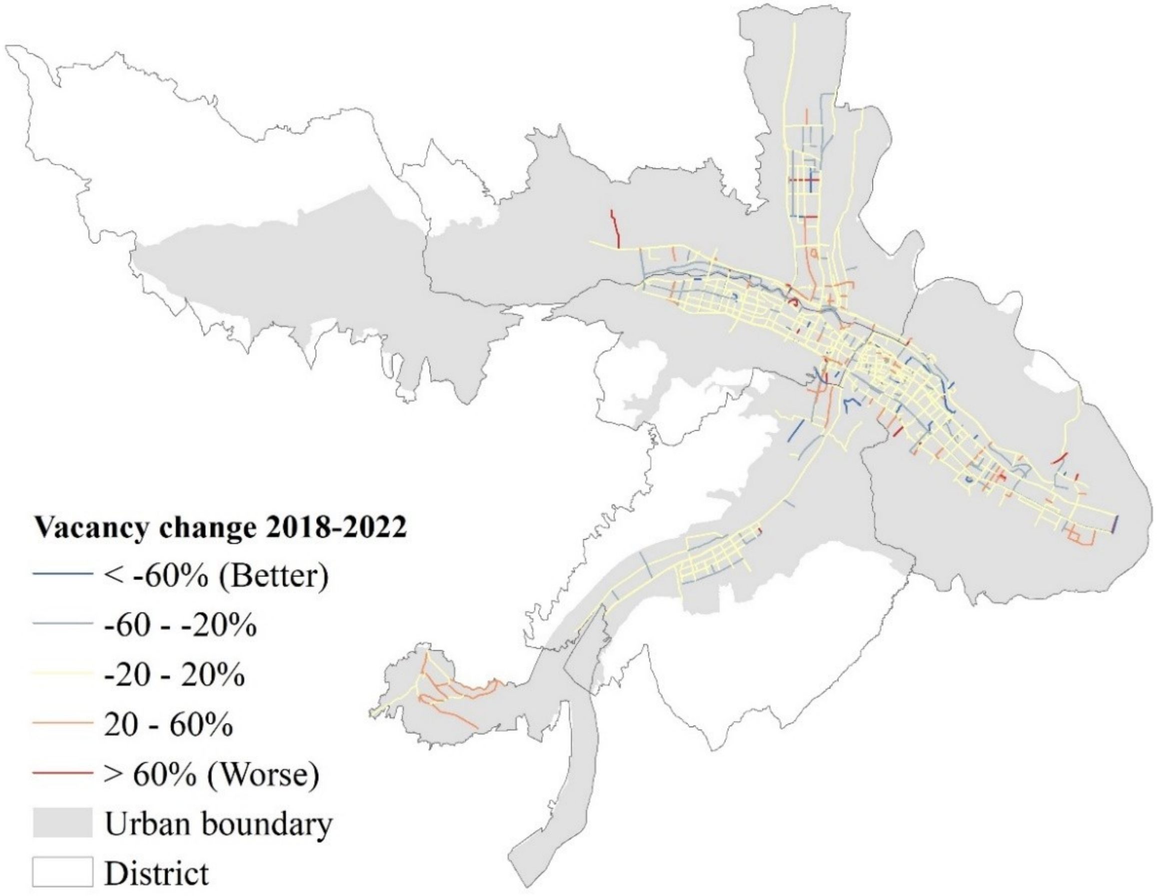
Low data fluctuation frequency

Analysis approach: the Faster R-CNN model, the Tesseract algorithm and the FuzzyWuzzy algorithm was used to establish a model for estimating storefront vacancy rates.

Result:

93,069 stores were identified in the city in March 2022, of which 25,488 were vacant.

The storefront vacancy rate increased significantly after the pandemic, from 21.8% in 2018 to 30.0% in 2022.



Spatial distribution of street-level storefront vacancy and changes over the years

Scenario 2: City-wide environmental noise monitoring with Stationary Sensing in Accra

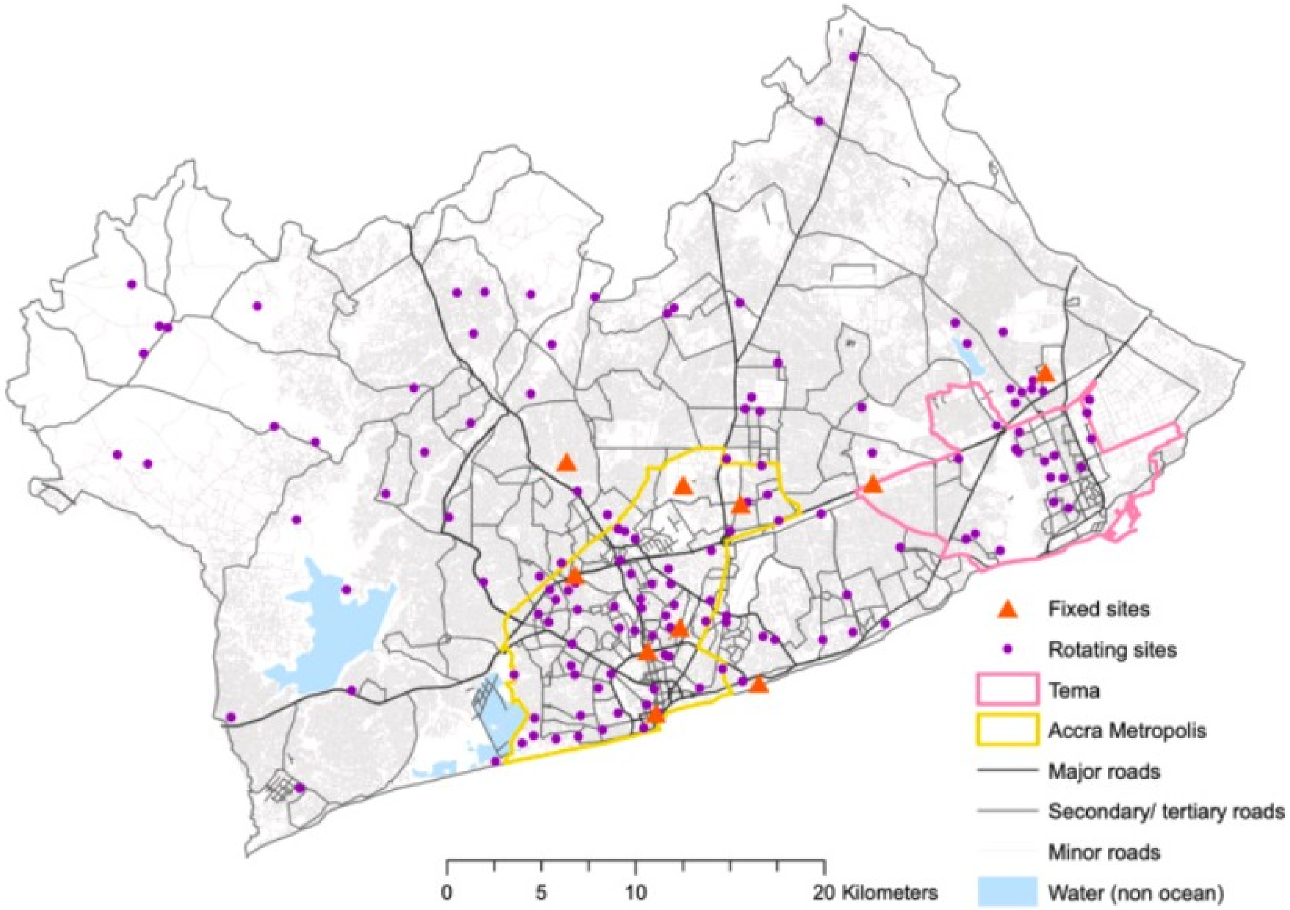
High data fluctuation frequency → **low sampling spatial resolution**

Scenario choose: Noise exhibits a high frequency of change, but for monitoring purposes, high spatial resolution is not required for urban-scale mapping. Aligns with **Scenario 2**.

Time period: Between April 2019 and June 2020

Experiment area: within the Greater Accra Metropolitan Area (GAMA)

Stationary sensing process: utilized sound level meters (SLMs) positioned near the roadside at 146 locations consisted of 136 rotating (7-day) measurement sites and 10 fixed (~1-year).



Locations of (rotating) stationary sensing sites in Accra, Ghana

Source: Sierra N Clark et al. Spatial modelling and inequalities of environmental noise in Accra, Ghana. Environmental research vol. 214, 2022, p.113932.

Scenario 2: City-wide environmental noise monitoring with Stationary Sensing in Accra

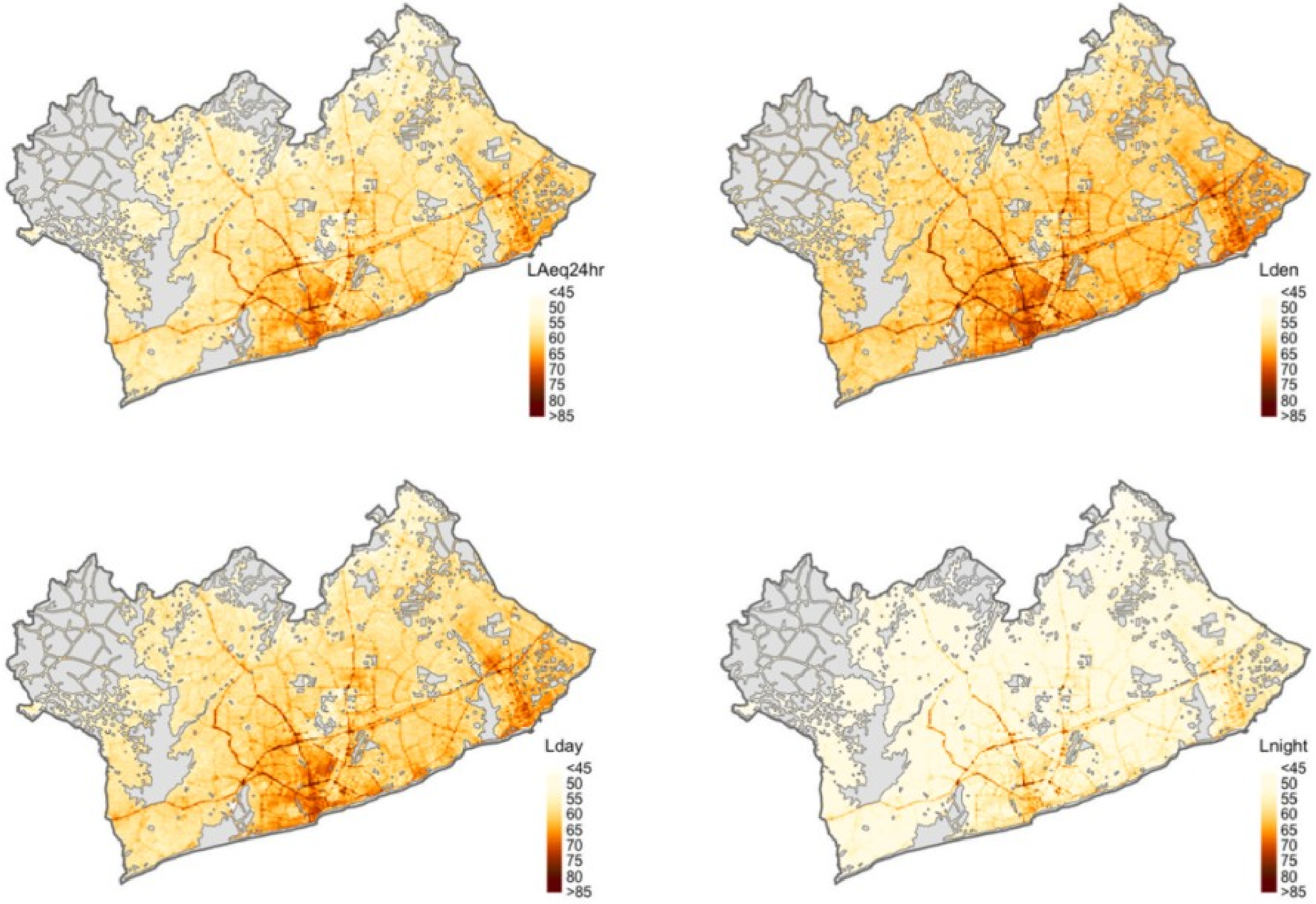
High data fluctuation frequency → **low sampling spatial resolution**

Analysis approach: A land use regression model was utilized, incorporating factors such as road network density, distance to airports, land cover, and population density.

Results:

Daytime noise levels were consistently higher by 7-8 decibels compared to nighttime levels.

A positive correlation was found between noise levels and factors such as road classification and traffic flow.



Predicted noise level in 50m x 50m grids in the Greater Accra Metropolitan Area

Source: Sierra N Clark et al. Spatial modelling and inequalities of environmental noise in Accra, Ghana. Environmental research vol. 214, 2022, p.113932.

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Scenario 3: Staying behavior monitoring with Stationary Sensing in Beijing

High data fluctuation frequency → high sampling spatial resolution → low sampling spatial coverage

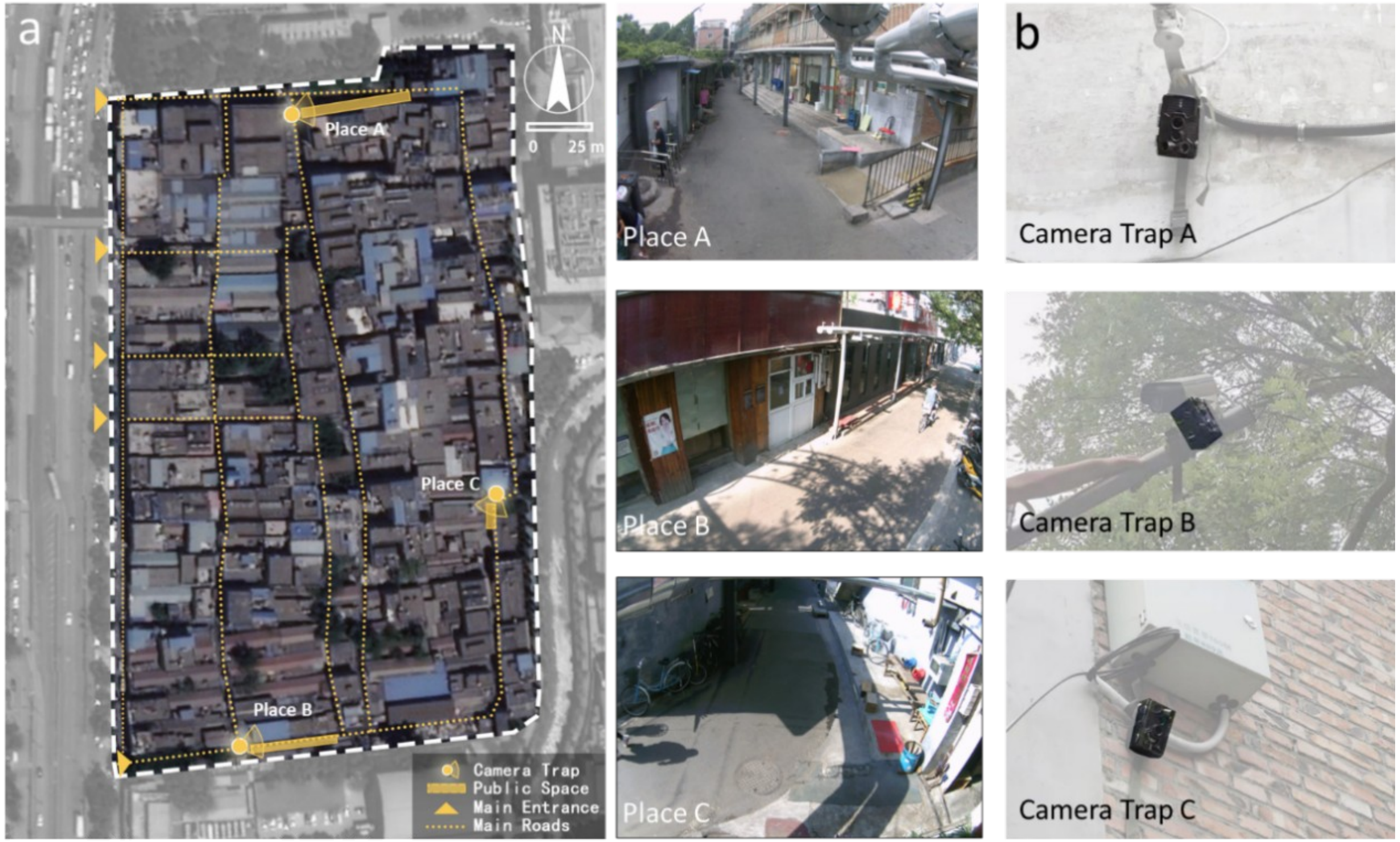
Scenario choose: Resident activities exhibit high spatiotemporal dynamics, and for small-scale spaces, stationary sensing can be employed, in line with **Scenario 3**.

Time Period: 33 days

Experiment area: A community of 0.25 square kilometers near Tsinghua campus

Stationary sensing process:

Selected 3 public space where residents frequently stay, deployed hunting camera, timelapse images for 15s.



The spatial patterns of the accumulated pedestrians and staying activities

Scenario 3: Staying behavior monitoring with Stationary Sensing in Beijing

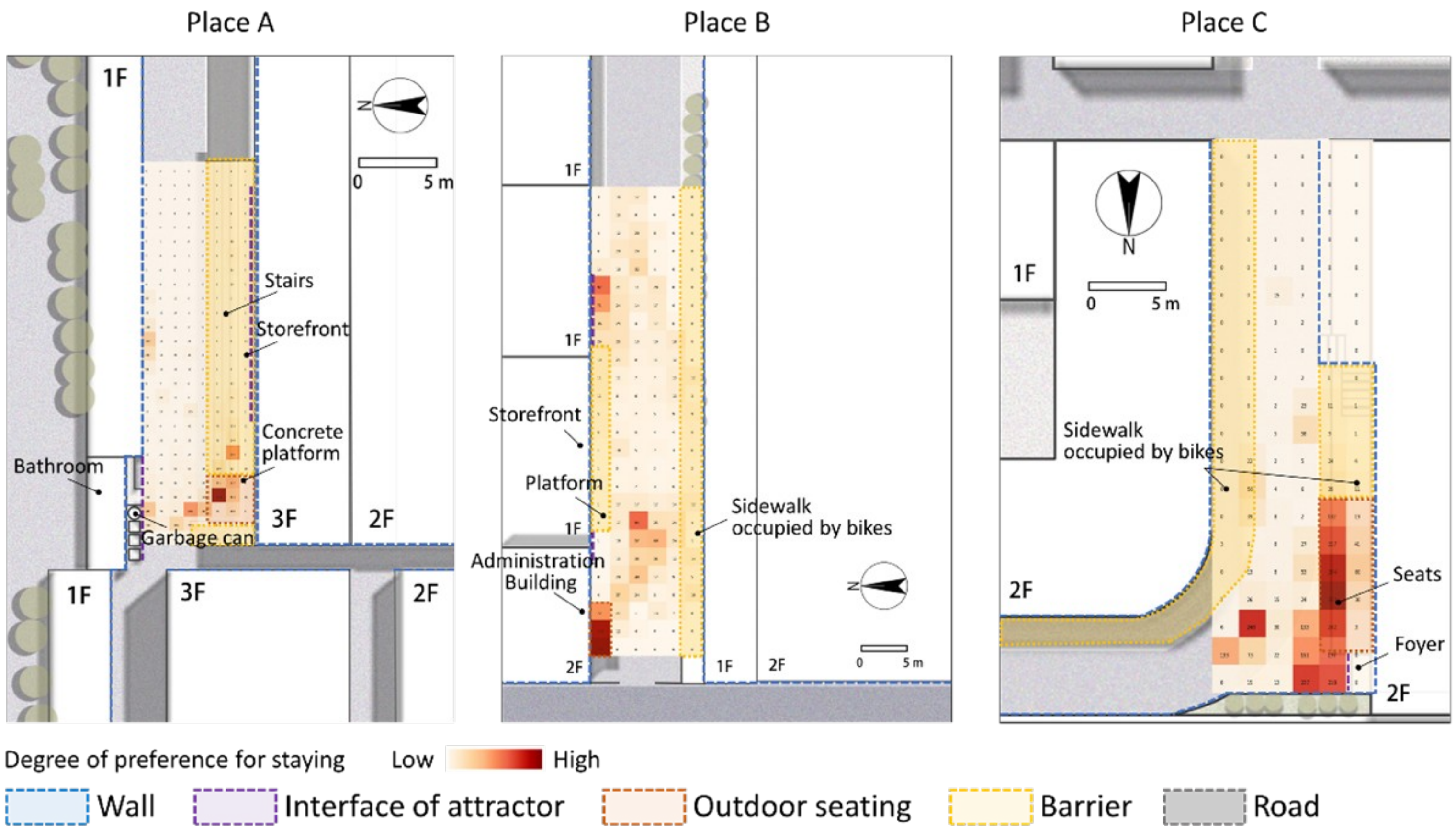
High data fluctuation frequency → high sampling spatial resolution → **low sampling spatial coverage**

Results:

Compared with other spaces, the end areas or street corners were more likely to be chosen to stay.

Stairs or suitable height differences between different areas were more likely to attract people.

People preferred to stay closer to the facade of the building.



The spatial patterns of the accumulated pedestrians and staying activities

Scenario 4: Neighborhood air quality monitoring with Mobile Sensing in residential communities in Heihe

High data fluctuation frequency → high sampling spatial resolution → high sampling spatial coverage → low sampling frequency

Scenario choose: air pollutant concentrations vary frequently, but monitoring is only carried out in the morning when indicator values are relatively stable and a high spatial coverage of monitoring is needed. Therefore, in line with **Scenario 4**.

Time period: September 23 to 29, 2021

Experiment area: 17.3 km^2 area in Heihe

Stationary sensing process: Cars with sensors collect data from urban roads as the external data of the communities. Bicycles collect data from the interior of 104 residential communities.

Scheduling of mobile agents external (a) and internal (b) to the communities in Heihe City

Scenario 5: Noise monitoring for individual exposure assessment with Collaborative Sensing on Tsinghua campus

High data fluctuation frequency → high sampling spatial resolution → high sampling spatial coverage → **high sampling frequency**

Scenario choose: noise has high frequency of changing, and high-spatiotemporal-resolution monitoring requires high frequency of acquisition, high spatial granularity and coverage of the data, which is in line with **Scenario 5**.

Time period: 12am to 20pm on March 2, 2023

Experiment area: a 3-hectare area on campus

Collaborative sensing process: Experimenters maintained 1.5m/s riding speed, along preset traversal path, passing through the stationary sensing points, taking 15min for one lap.

Collaborative sensing on a university campus.

Scenario 5: Noise monitoring for individual exposure assessment with Collaborative Sensing on Tsinghua campus

High data fluctuation frequency → high sampling spatial resolution → high sampling spatial coverage → **high sampling frequency**

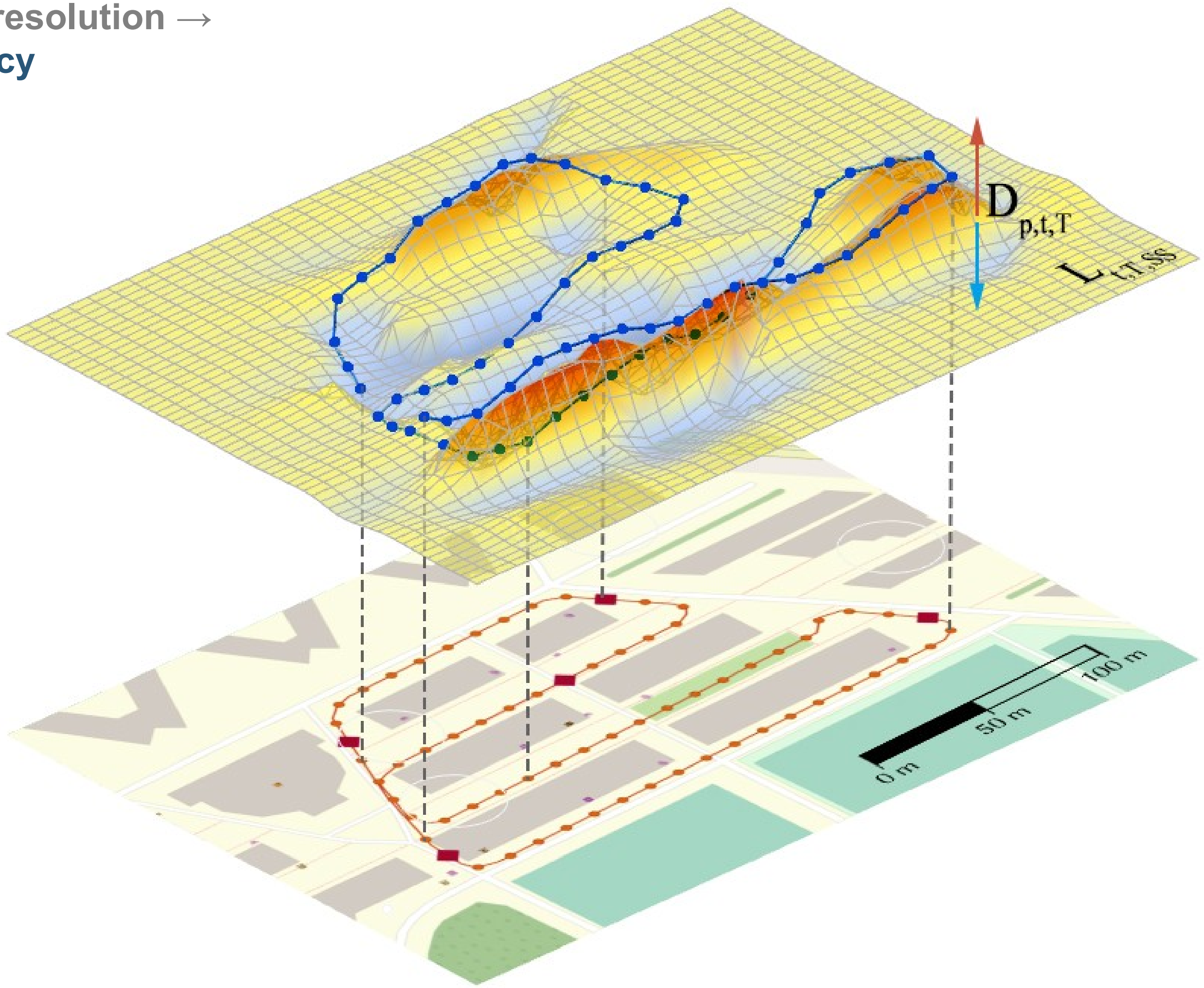
Analysis approach:

The stationary sensing data were averaged as a baseline value for noise, while the mobile sensing data were used to calculate the relative spatial variation in noise levels.

The two were superimposed to obtain predicted noise levels for all locations within the site.

Results:

The predictions based on collaborative sensing significantly outperform those based on one sensing mode only.



Spatial-temporal noise map

4 Conclusions

An active urban sensing framework is proposed to provide guidance for automatic urban data collection.

1. Sort out the literature form an evidence-based checklist of monitoring indicators.

2. Form a decision tree for paradigm selection.

3. Case studies of the five scenarios are illustrated.

Active urban sensing framework will play an important role for data improvement in less developed areas with missing data, or areas with untimely data updates or insufficient coverage, to support the achievement of SDGs.

Thanks for your attention

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