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High resolution mapping of urban built environment: A perspective from construction materials

Zhou Huang & Yi Bao

Peking University

What is urban built environment stocks?

Urban built environment material stocks refer to **the quality of materials (such as cement, steel, sand, and gravel) used in infrastructure** like buildings and roads that support human activities such as living, working, and transportation.

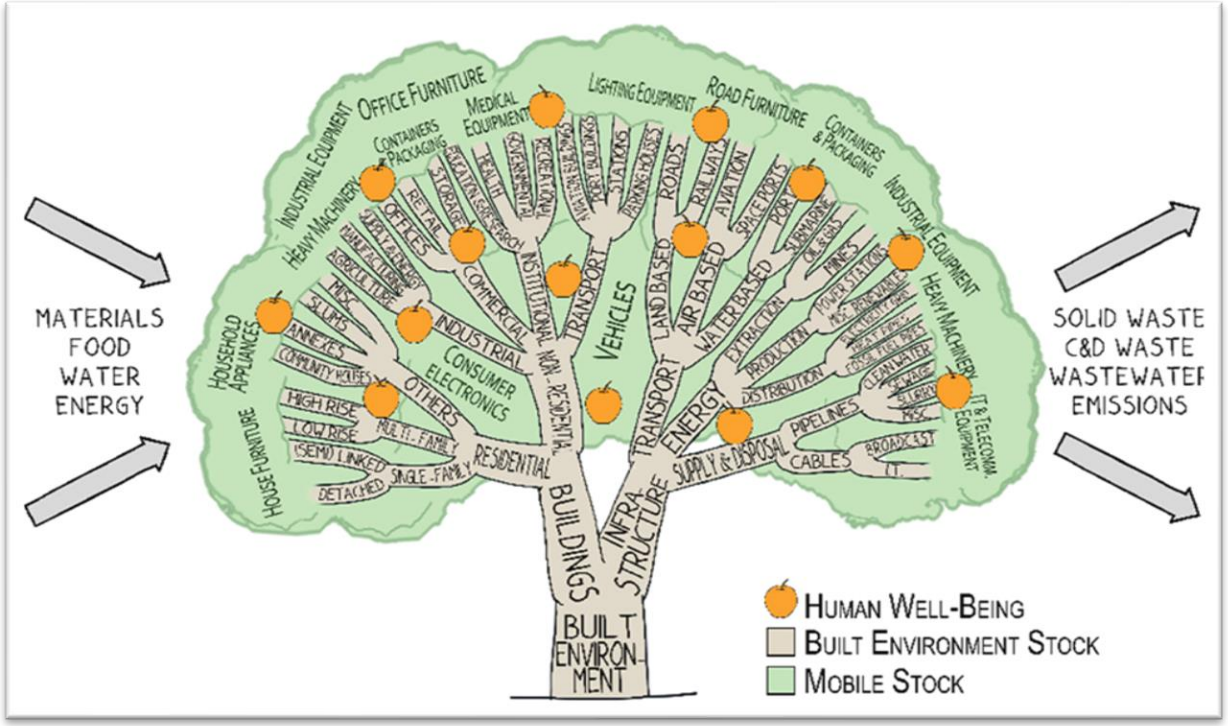


Figure 1: Schematic diagram of material stock in urban built environment[1]

[1] Lanau, M., Liu, G., Kral, U., Wiedenhofer, D., Keijzer, E., Yu, C., & Ehlert, C. (2019). Taking stock of built environment stock studies: Progress and prospects. Environmental science & technology, 53(15), 8499-8515.

Introduction & Background

Cities have promoted the development of human society

Urbanization has huge resource and environmental costs

Built environment is a major source of material accumulation

The mass of artificial materials doubles every 20 years, and the total global mass of buildings and infrastructure has exceeded **1 trillion tons**.

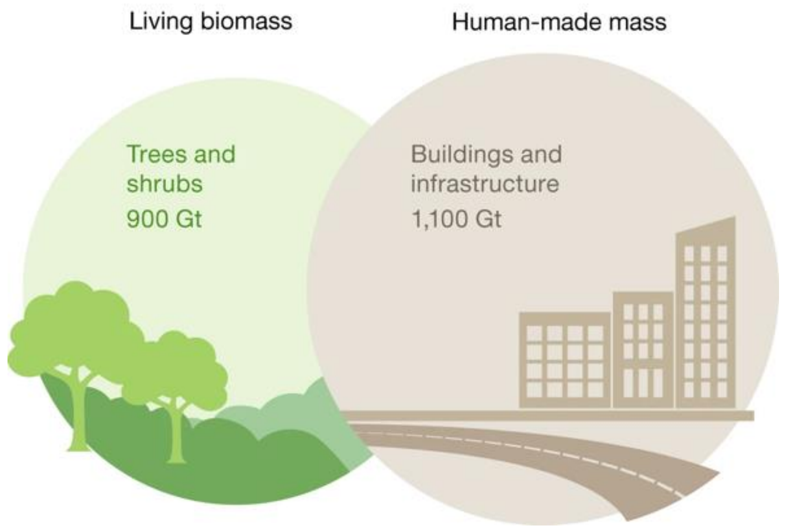


Figure 2: Comparison of artificial materials and biological materials[2]

[2] Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y. M., & Milo, R. (2020). Global human-made mass exceeds all living biomass. Nature, 588(7838), 442-444.

Introduction & Background

Research of Urban Built Environment Material Stocks

Research Field	Research Scale	Research Object	Research Focus
Social Sciences	Global Scale	Building	Economy, population
Environmental Science	National Scale	Road	Urban Mining
...	...	...	...
Geography	Regional Scale	Railway	Growth Pattern

Methods for material stock estimation

1. Top-down method

Material Flow Analysis

MFA is a systematic approach used to track and quantify the flow and transformation of materials within a specific region or system.

$$\sum Input = \sum Output + \Delta Stock$$

Dynamic Material Flow Analysis

Dynamic Material Flow Analysis (DMFA) **extends traditional MFA** by incorporating temporal dynamics, enabling the quantification and analysis of long-term, large-scale material stocks and flows, particularly suited for studying **global or national metal accumulation patterns** in iron, aluminum, copper, and other metals over decades.

$$dS(t) = \left(inflow(t) - outflow(t)\right) \cdot dt = net\ flow(t) \cdot dt$$

Methods for material stock estimation

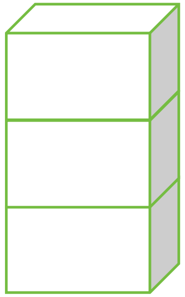
2. Bottom-up method

Bottom-up method

The Bottom-up approach, also known as the coefficient-based method, is a labor-intensive computational method for estimating material stocks

$$\mathrm{MS}_{m,i,j} = \sum_{m,i,j} \left(PS_{i,j} \times MCI_{m,i,j} \right)$$

$\mathrm{MS}_{m,i,j}$ represents Material stock, $MCI_{m,i,j}$ is Material composition indicator, $PS_{i,j}$ refer to physical size of the built environment



Physical Size
Floor area (m^2)

×

MCI
kg/m^2

+

ArcGIS

→

3. Nighttime Light based Regression method

NTL based Regression

This method leverages the association between human activities, as reflected by NTL, and the accumulation of material stocks in built environments

$$Y = \alpha X$$

Advanced fitting techniques, such as power function fitting, enhance the accuracy of stock estimations

$$\log(\text{stock}) = k + \beta \cdot \log(\text{light})$$

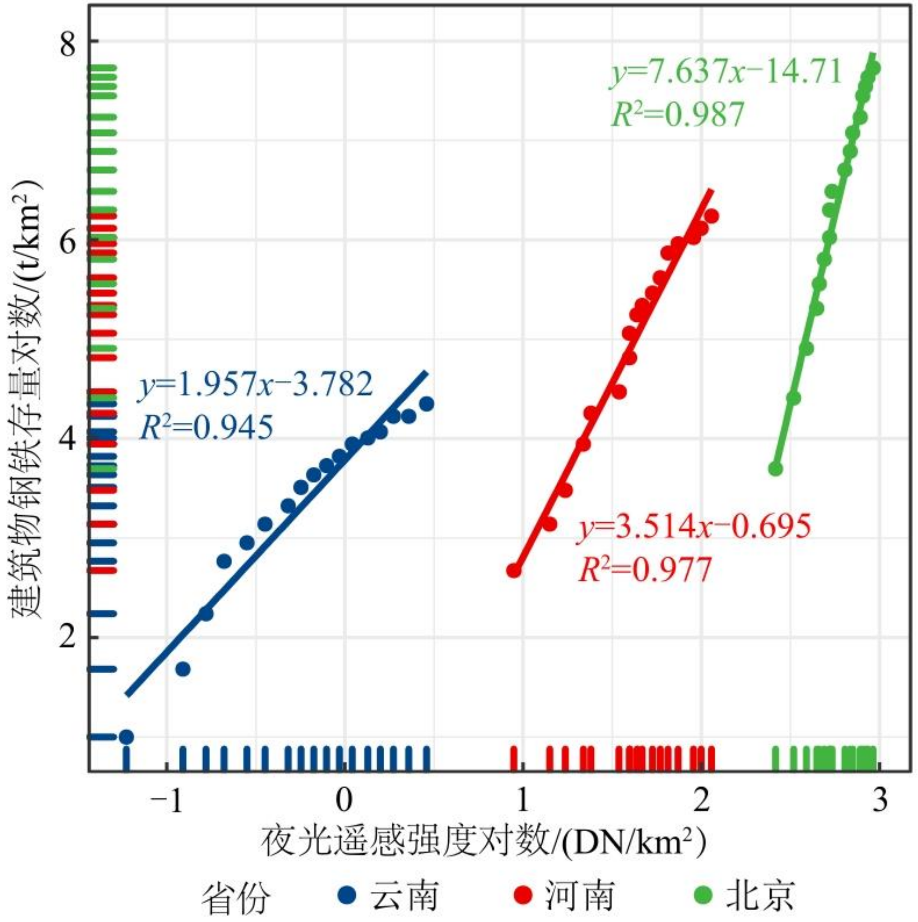


Figure 3: Relationship between NTL and steel stocks

Problems and solutions

Limitations of traditional methods

1. **Data Limits：** Too much reliance on statistics makes these methods hard to use in areas with little data.
2. **Spatio-temporal Constraints：** Most methods only work for certain time periods and areas, and are not good for long-term, large-area, high-resolution studies.
3. **Model Incompatibility:**
   Poor comparability between models and Restricted scalability and generalizability

Opportunities in the Era of Big Data

1. **New Data**: Remote sensing images offer rich information at low cost and with wide coverage. Spatial-temporal data, such as POIs and trajectory data, can support more accurate estimations.
2. **New Methods**: Machine learning methods, successful in fields like population and poverty studies, could greatly improve the accuracy and scope of material stock estimations.

High-Resolution Mapping of the Urban Built Environment Stocks in Beijing

Background and method

1. **Traditional bottom-up approaches:**
   - Labor-intensive, low efficiency
   - Limited scalability at urban level
2. **Geo big data approaches:**
   - Infers building information (age, type) in urban areas.
   - Expands applicability of bottom-up methods
   - Enables large scale, high resolution material stock estimation

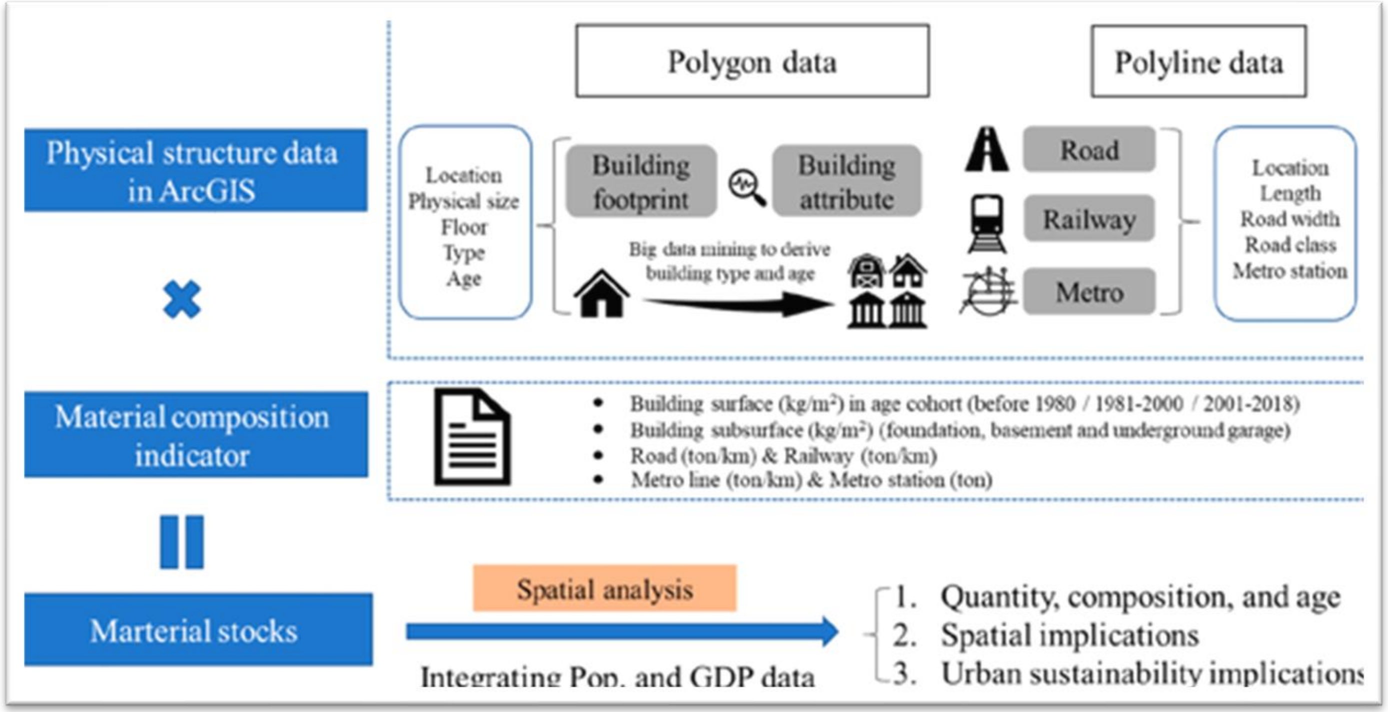


Figure 4: Work flow for high-resolution mapping of the built environment stocks in Beijing[4]

[4] Mao R, Bao Y, Huang Z, Liu Q, Liu G. High-resolution mapping of the urban built environment stocks in Beijing. Environmental science & technology. 2020 Apr 10;54(9):5345-55.

High-Resolution Mapping of the Urban Built Environment Stocks in Beijing

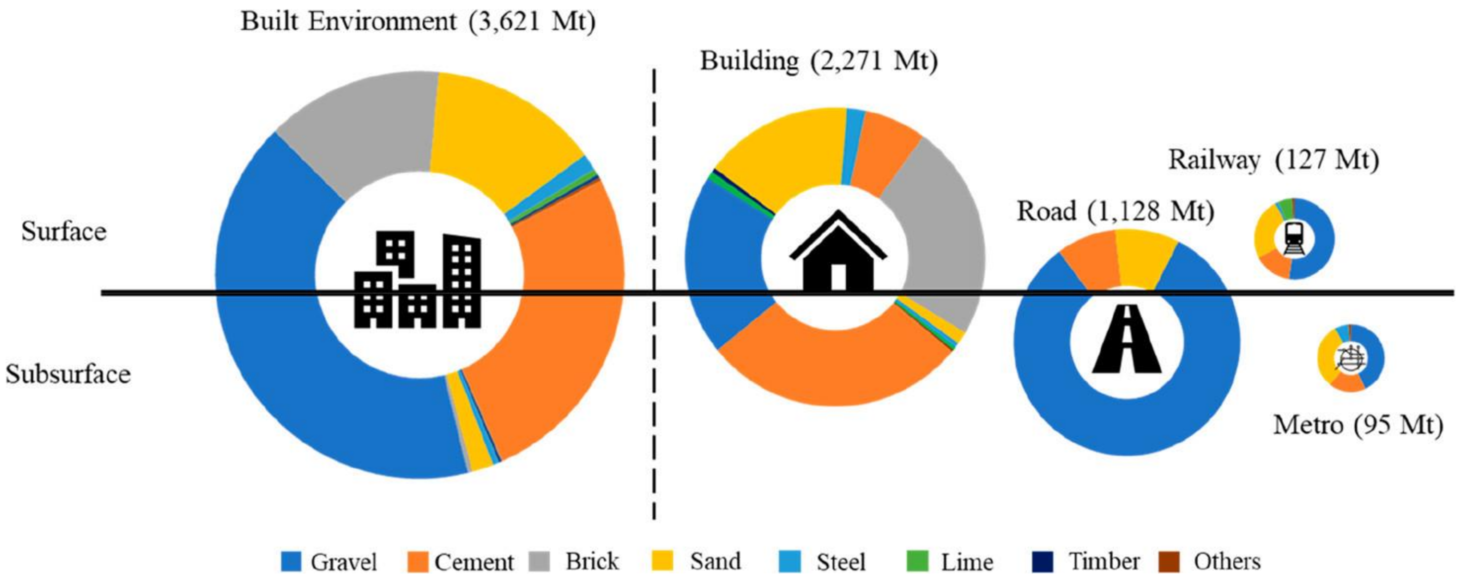


Figure 5: Quantity and composition of urban built environment stocks in 2018 in Beijing by typology and by material[4]

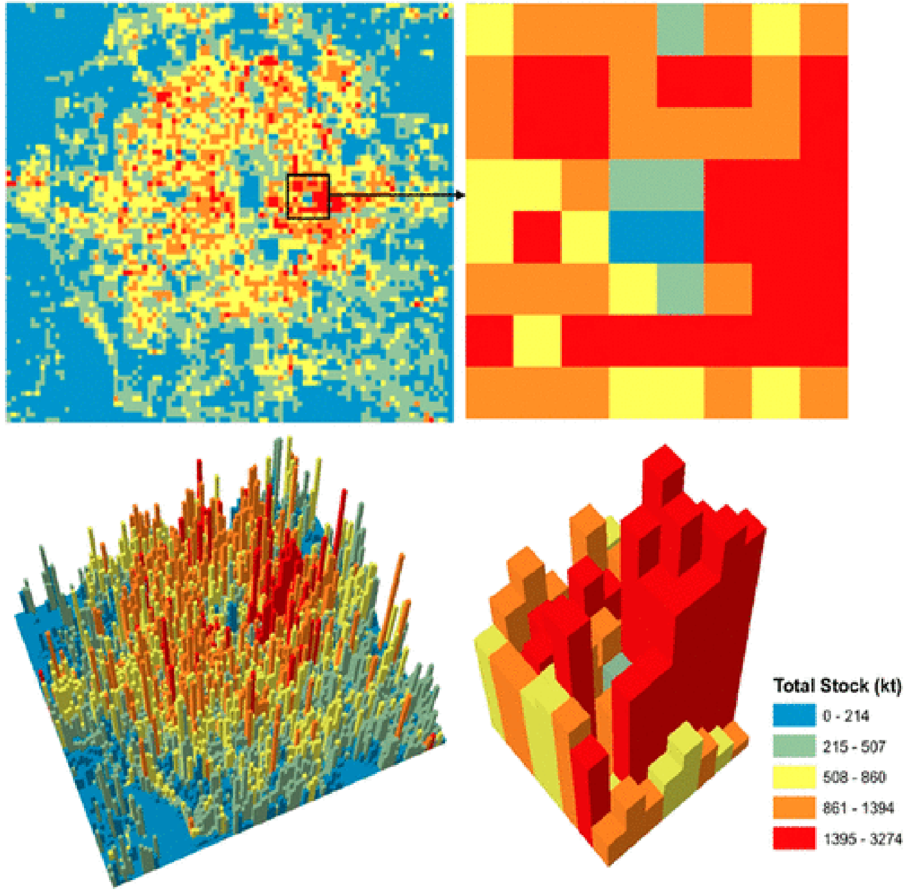
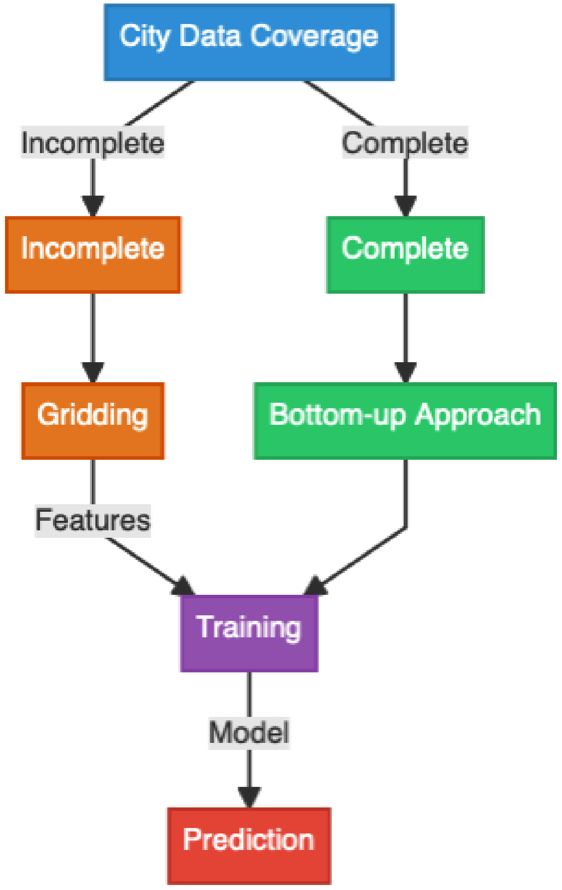


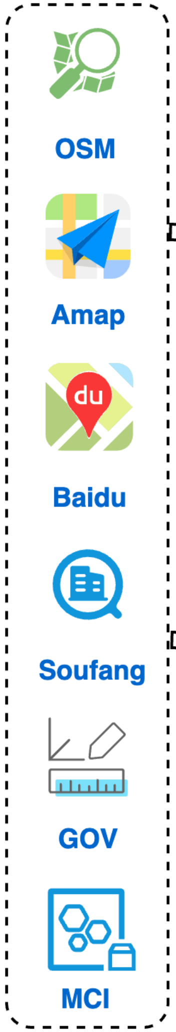
Figure 6: 500m grid distribution of environmental stock built in Beijing[4]

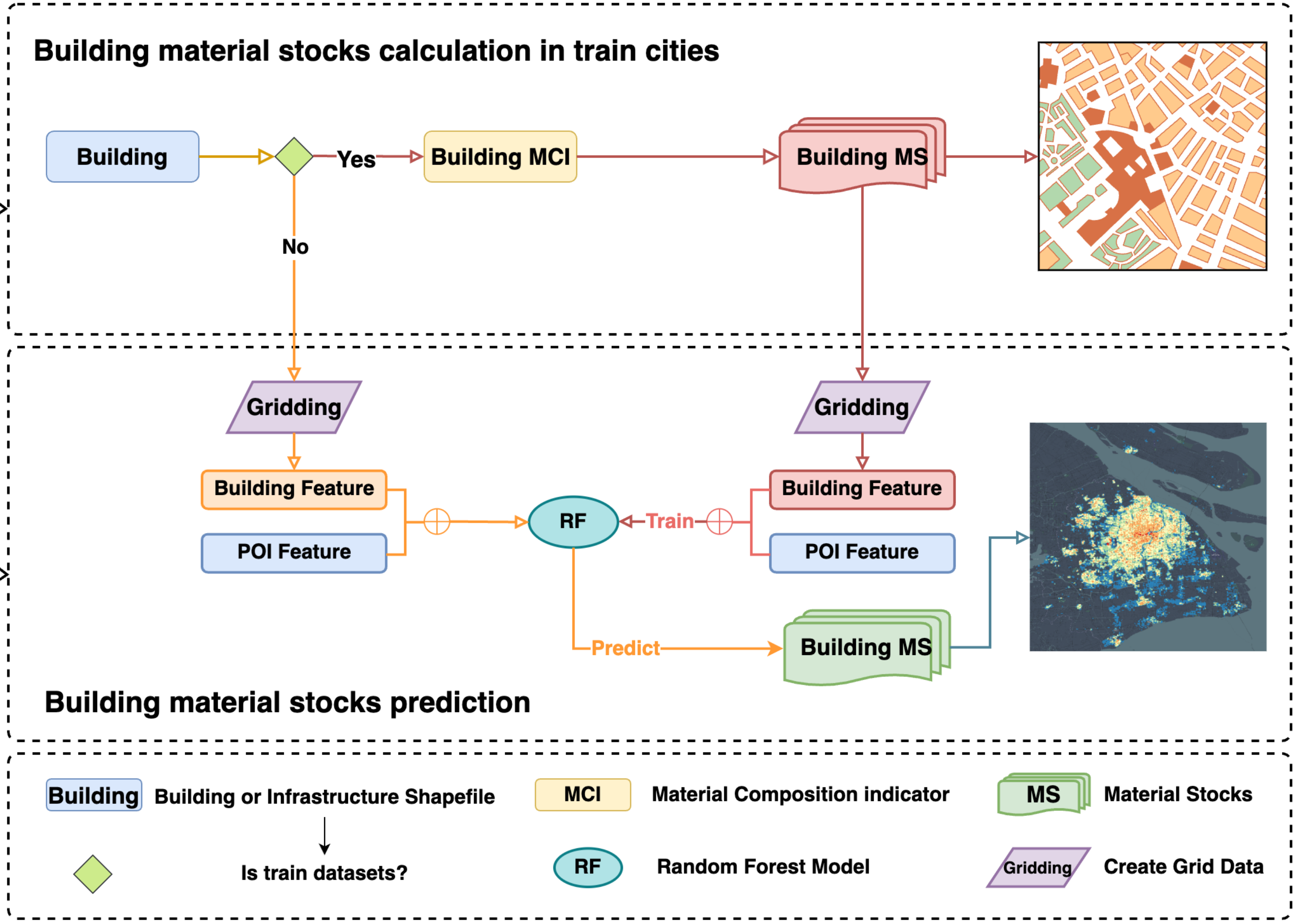
[4] Mao R, Bao Y, Huang Z, Liu Q, Liu G. High-resolution mapping of the urban built environment stocks in Beijing. Environmental science & technology. 2020 Apr 10;54(9):5345-55.

Material stocks estimation method based on geographical big data

End-to-end material stock estimation based on architectural vector features







[5] Bao, Y., Huang, Z., Mao, R., Liu, G., Wang, H., & Yin, G. (2023). High-resolution mapping of material stocks in the built environment across 50 Chinese cities. Resources, Conservation and Recycling, 199, 107232.

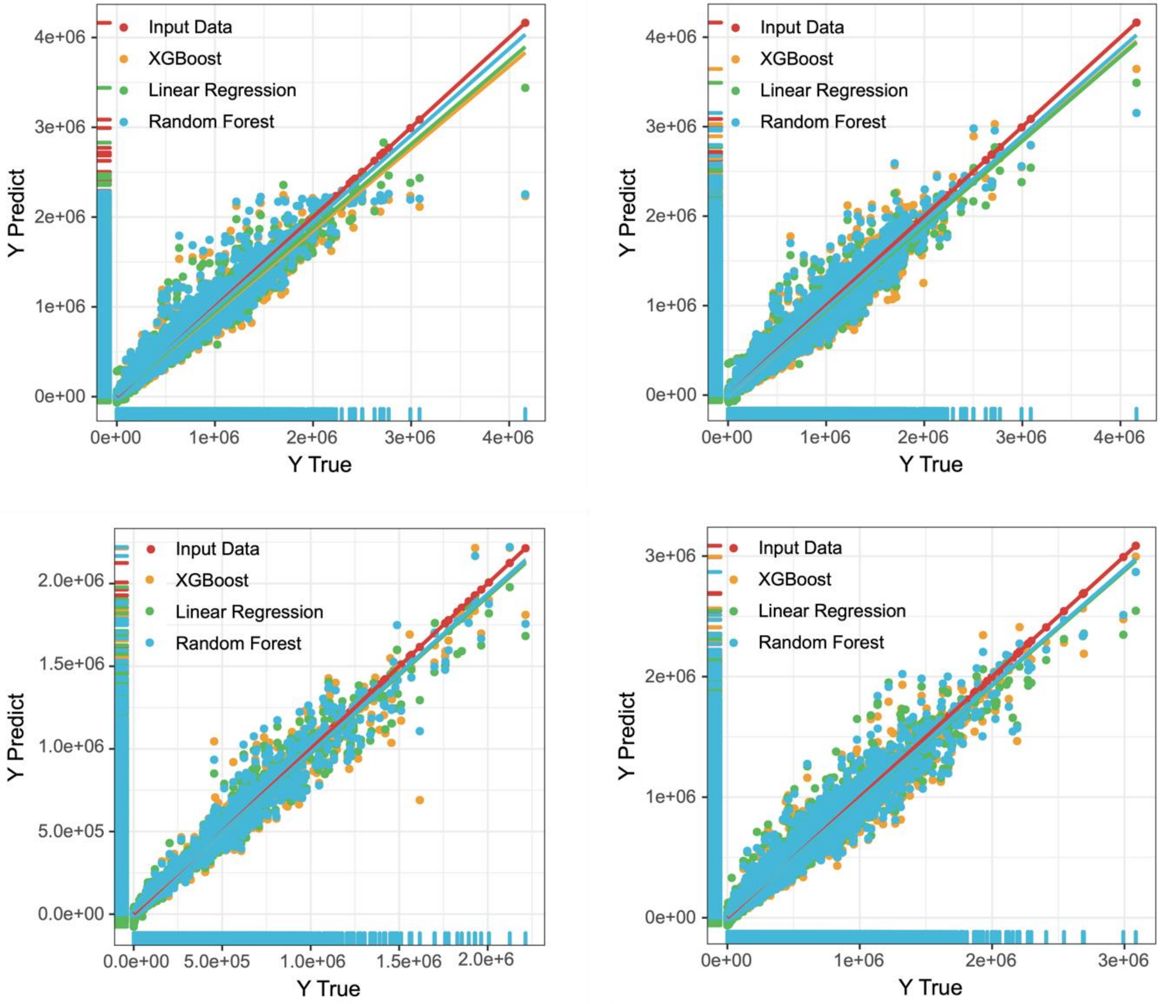
End-to-end material stock estimation based on architectural vector features

① One city for training, another for validation.

② Two cities for training, the third for validation.

③ 80% of grids within a city for training, 20% for validation.

④ 80% of mixed grids from all cities for training, 20% for validation.



		RMSE	MAE	MAPE
(1)	Linear	99444	58111	71.5891
	XGBoost	106513	58309	0.3318
	Random Forest	98869	50531	0.3027

		RMSE	MAE	MAPE
(2)	Linear	97653	60597	26.8986
	XGBoost	107919	62693	0.2538
	Random Forest	98900	55811	0.2251

		RMSE	MAE	MAPE
(3)	Linear	78679	50340	8.5788
	XGBoost	84170	48990	0.1514
	Random Forest	79213	47595	0.1524

		RMSE	MAE	MAPE
(4)	Linear	91230	53440	3006.78
	XGBoost	88685	49804	4.6270
	Random Forest	88408	49047	0.4682

[5] Bao, Y., Huang, Z., Mao, R., Liu, G., Wang, H., & Yin, G. (2023). High-resolution mapping of material stocks in the built environment across 50 Chinese cities. Resources, Conservation and Recycling, 199, 107232.

Building material stock estimation based on multi-source remotes sensing

Can an end-to-end model leverage readily available remote sensing data to compensate for lack of vector data coverage?

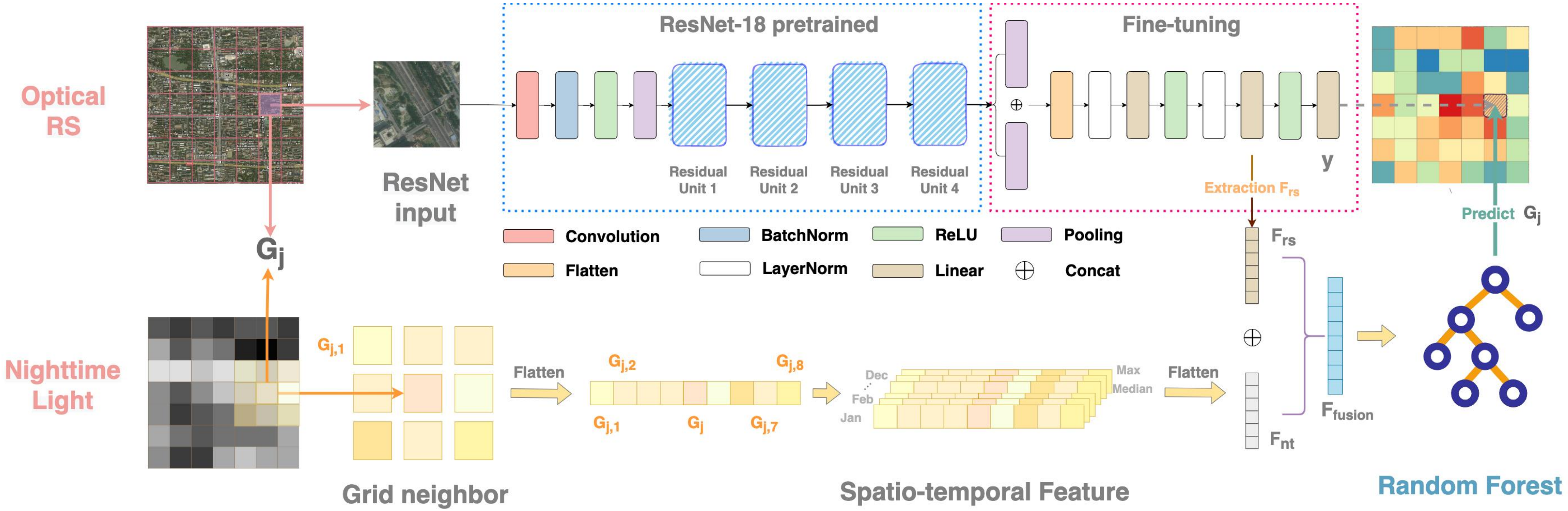


Figure 7: The framework of building-stock estimation through multi-source remote sensing and machine learning[6]

[5] Bao, Y., Huang, Z., Mao, R., Liu, G., Wang, H., & Yin, G. (2023). High-resolution mapping of material stocks in the built environment across 50 Chinese cities. Resources, Conservation and Recycling, 199, 107232.

Building material stock estimation based on multi-source remotes sensing

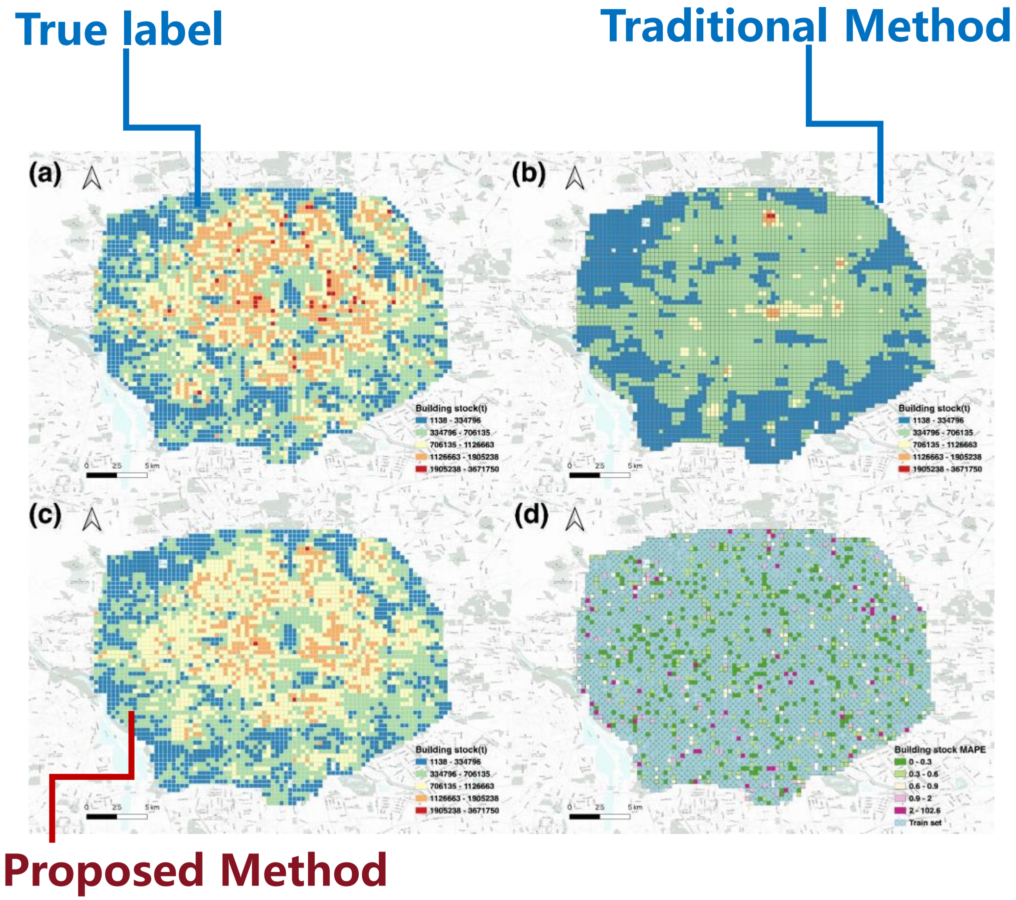


Figure 8: Prediction results at the grid scale

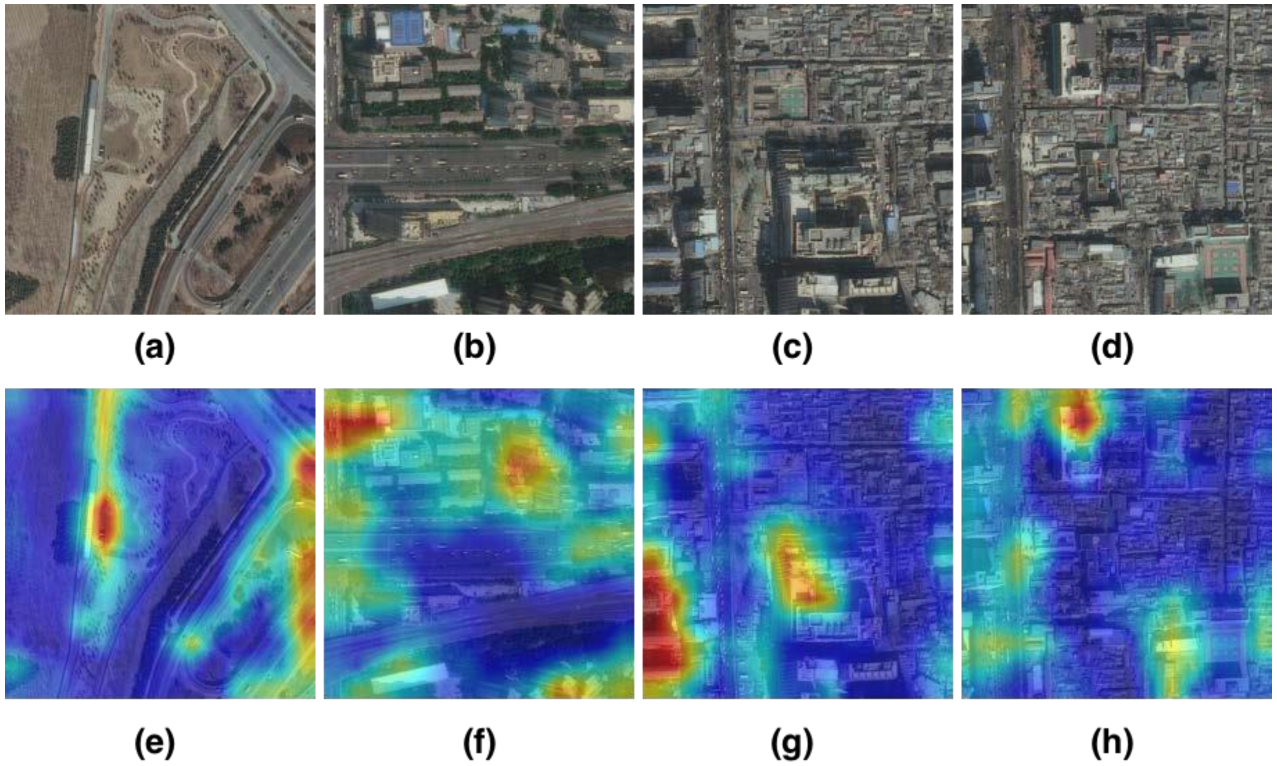
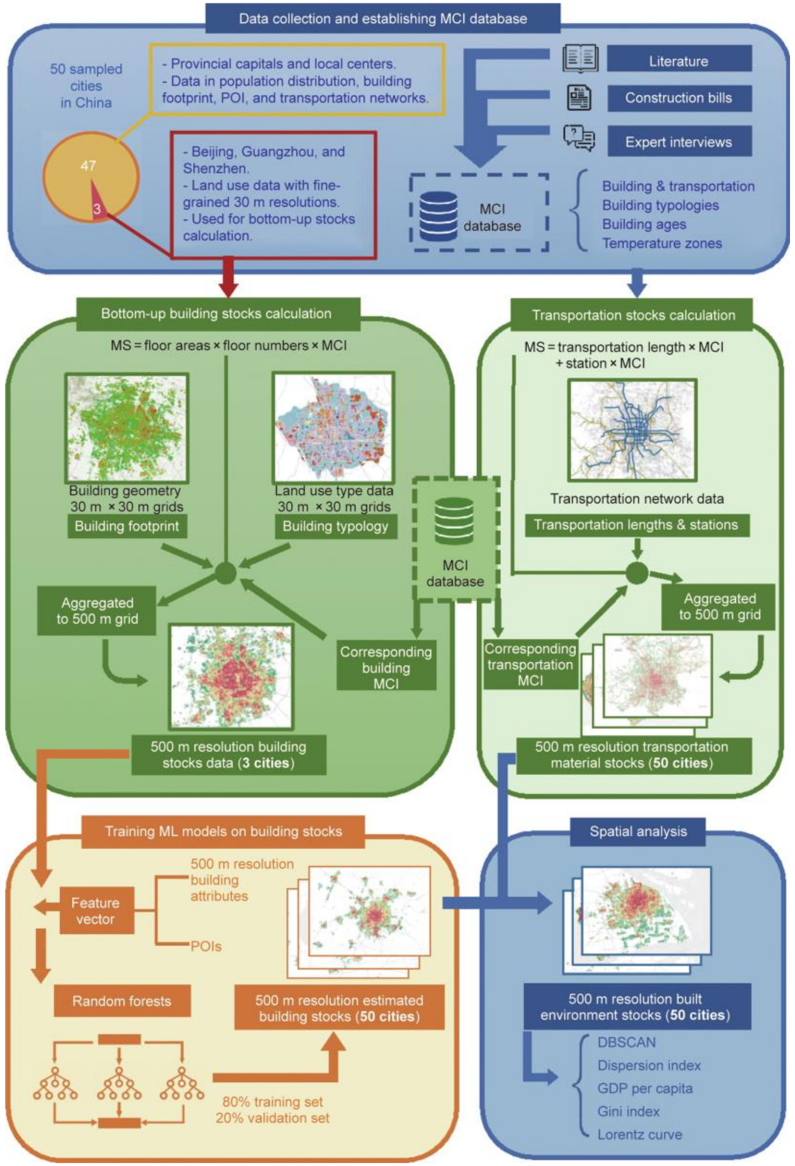


Figure 9: Feature Importance Visualization Based on Grad-CAM

[5] Bao, Y., Huang, Z., Mao, R., Liu, G., Wang, H., & Yin, G. (2023). High-resolution mapping of material stocks in the built environment across 50 Chinese cities. Resources, Conservation and Recycling, 199, 107232.

Built environment stock spatial distribution

Data Type	Data Description	Application	Source
Buildings	Physical characteristics of buildings	Building material stock calculation	Baidu Maps
Infrastructure	Characteristics of roads, railways, and subways	Infrastructure material stock calculation	OpenStreetMap, AutoNavi Maps
POI	17 POI categories	Features for predicting building material stock	AutoNavi Maps
Building Characteristics	Building types and ages in Beijing, Guangzhou, and Shenzhen	Calculating building material stock using bottom-up approach	Urban Planning Departments, SouFun, AutoNavi Maps



Training in Beijing, Guangzhou, and Shenzhen, with predictions for the other 47 cities.

[6], Z., Bao, Y., Mao, R., Wang, H., Yin, G., Wan, L., ... & Liu, G. (2024). Big geodata reveals spatial patterns of built environment stocks across and within cities in China. Engineering, 34, 143-153.

Built environment stock spatial distribution

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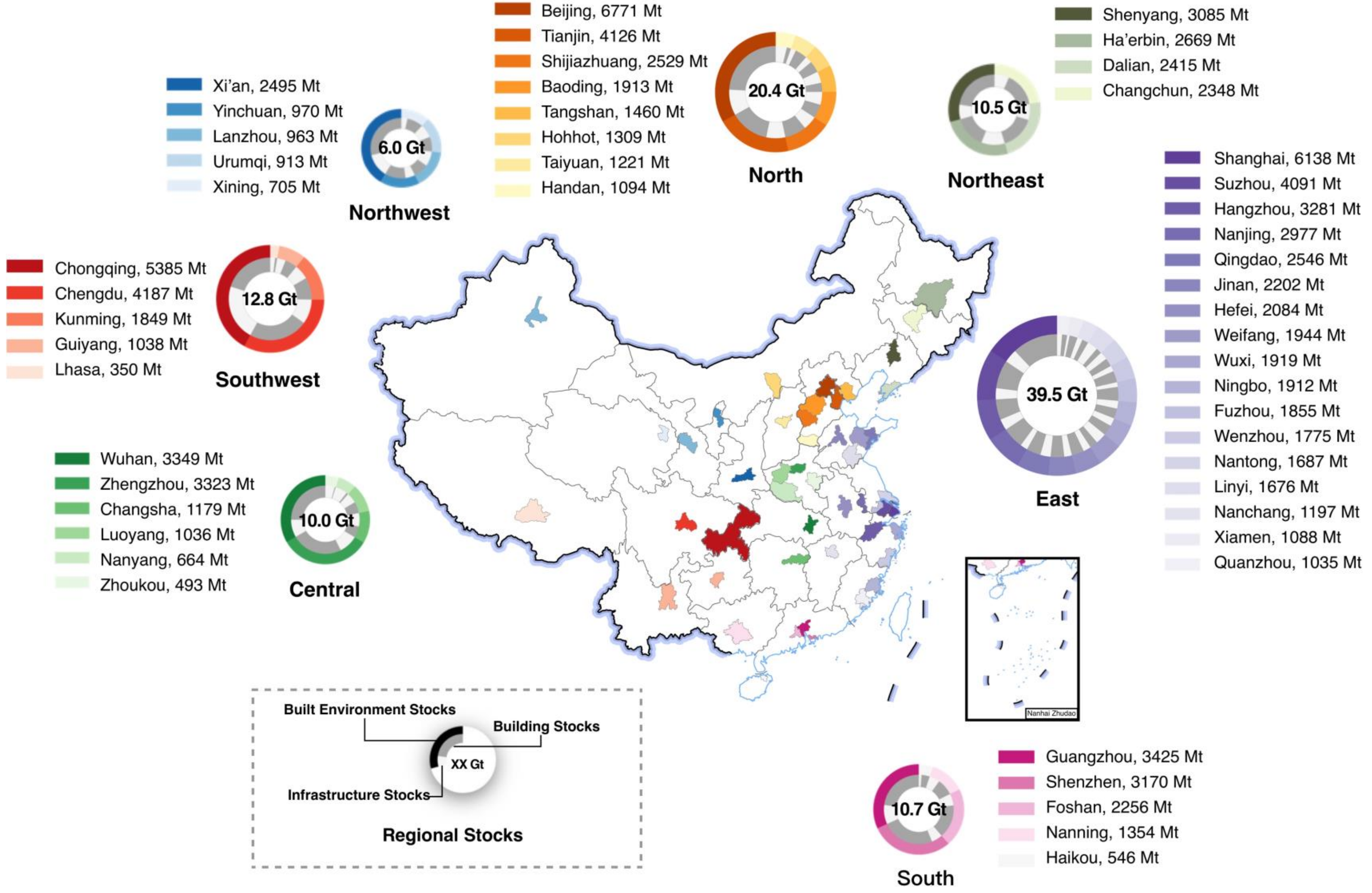


Figure 10: Urban built environment stocks of the 50 selected cities in China

[6], Z., Bao, Y., Mao, R., Wang, H., Yin, G., Wan, L., ... & Liu, G. (2024). Big geodata reveals spatial patterns of built environment stocks across and within cities in China. Engineering, 34, 143-153.

Built environment stock spatial distribution

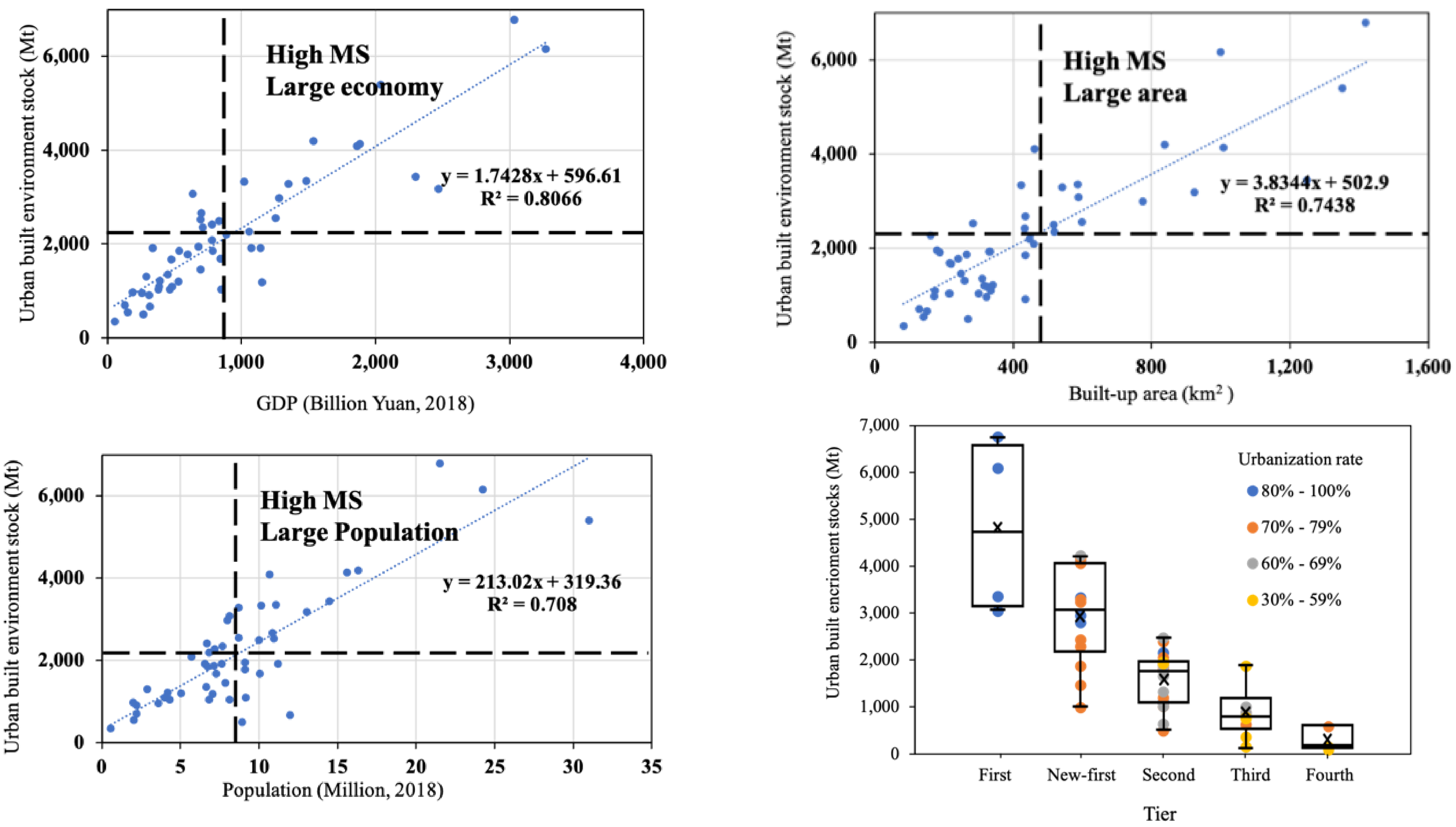


Figure 11: The relationship between the material stock of the built environment and indicators such as urban population, GDP, built-up area, and urban level.

Built environment stock spatial distribution

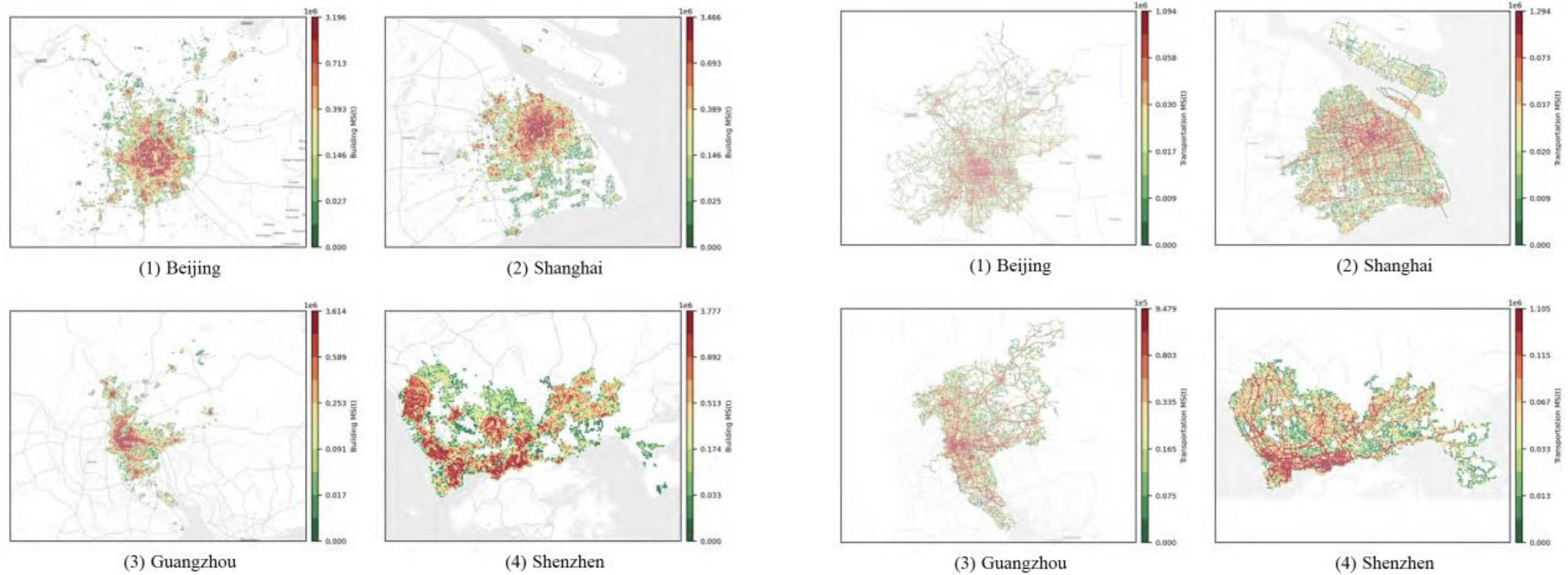


Figure 12: The spatial distribution of built environment stock in a 500m grid in the four cities of Beijing, Shanghai, Guangzhou, and Shenzhen.

Built environment stock spatial distribution

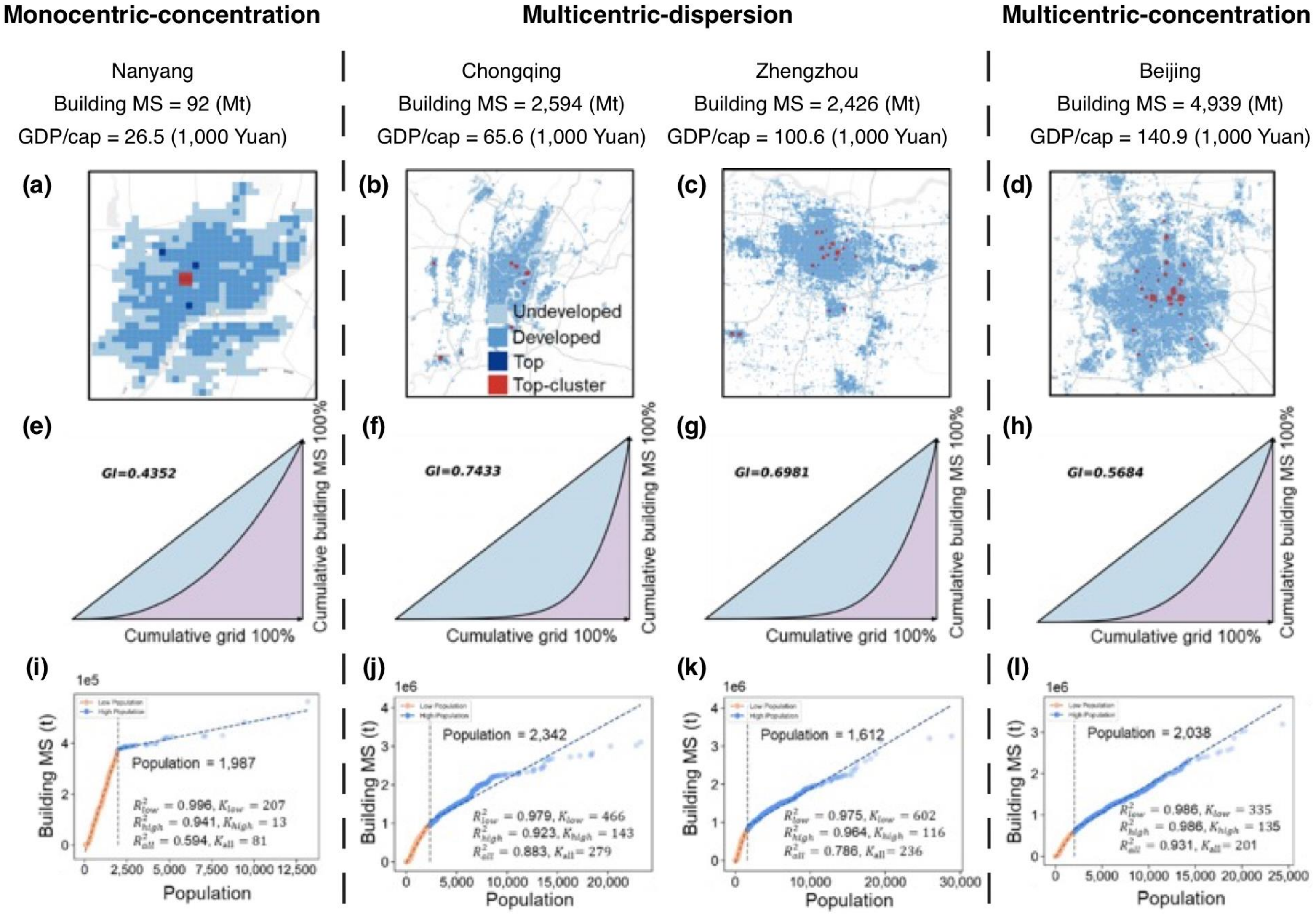
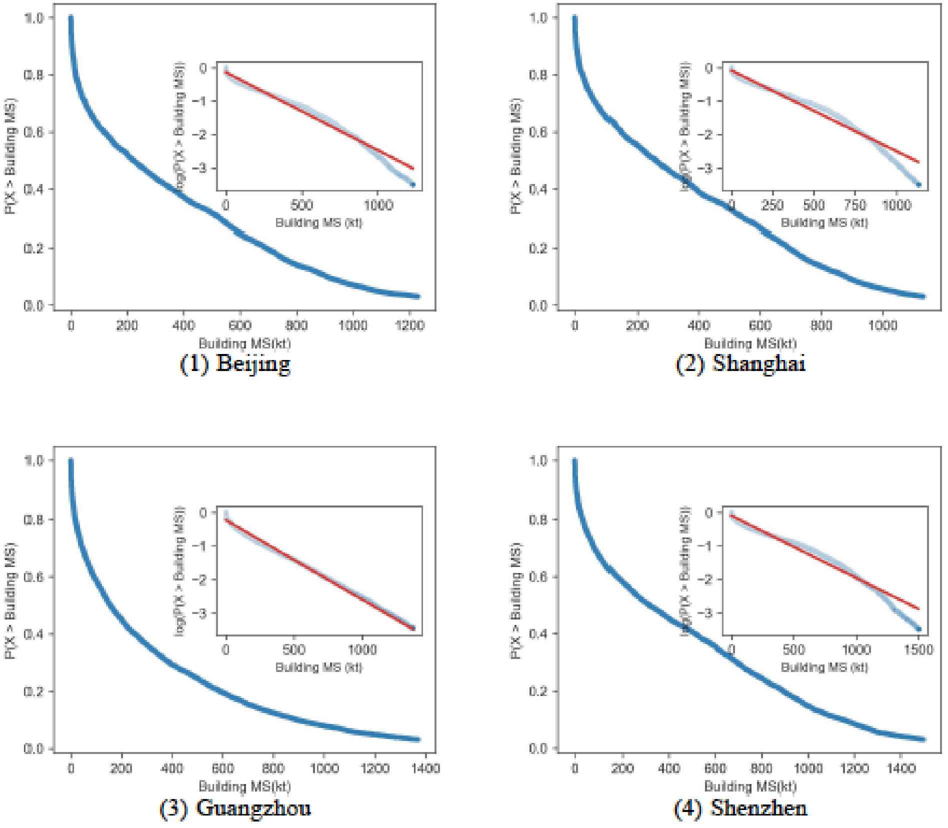


Figure 13: Urban built environment stocks of the 50 selected cities in China

Built environment stock spatial distribution

$$pdf(x;\mu,\theta) = \frac{1}{\theta} e^{-\frac{x-\mu}{\theta}}$$



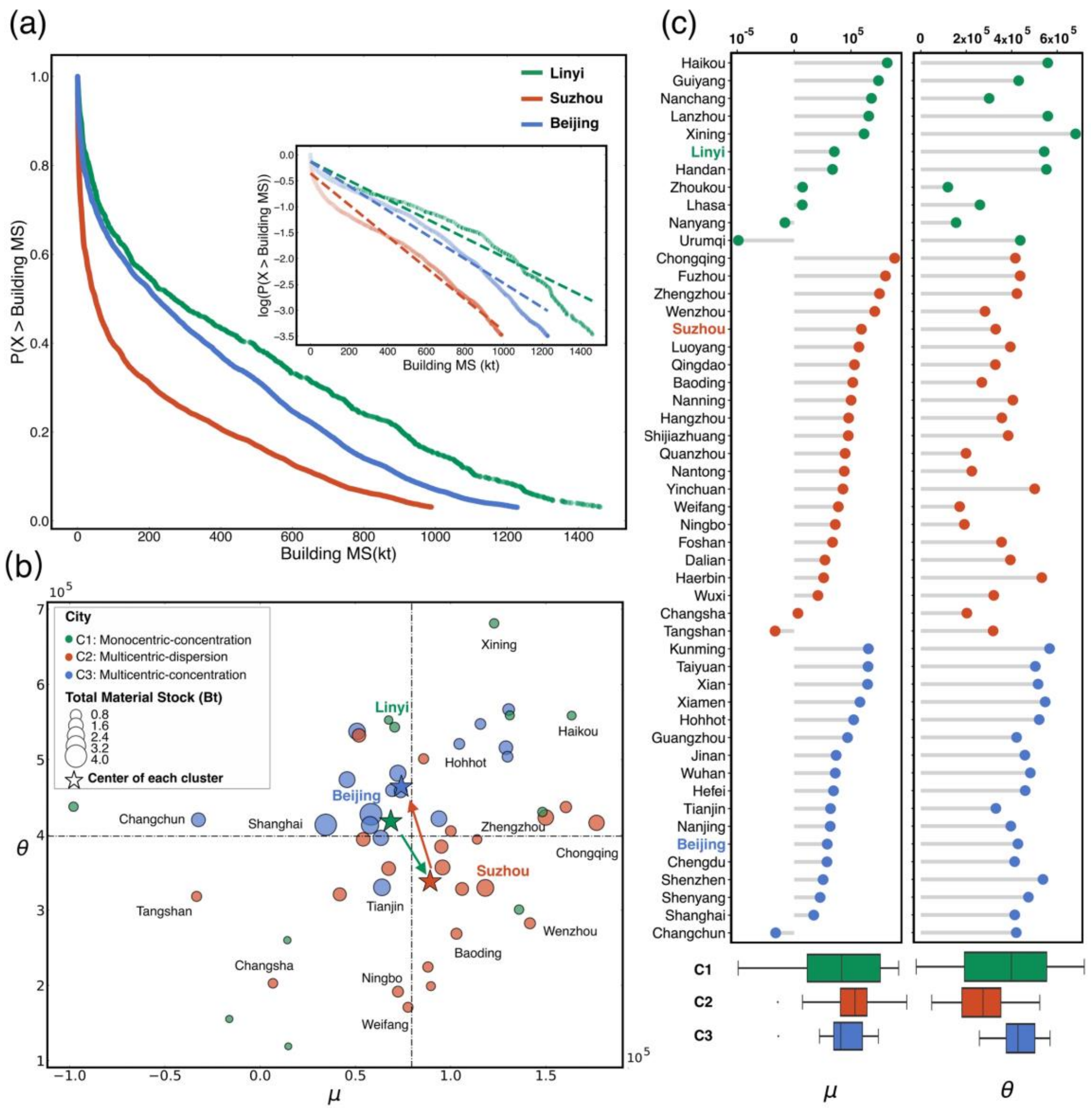
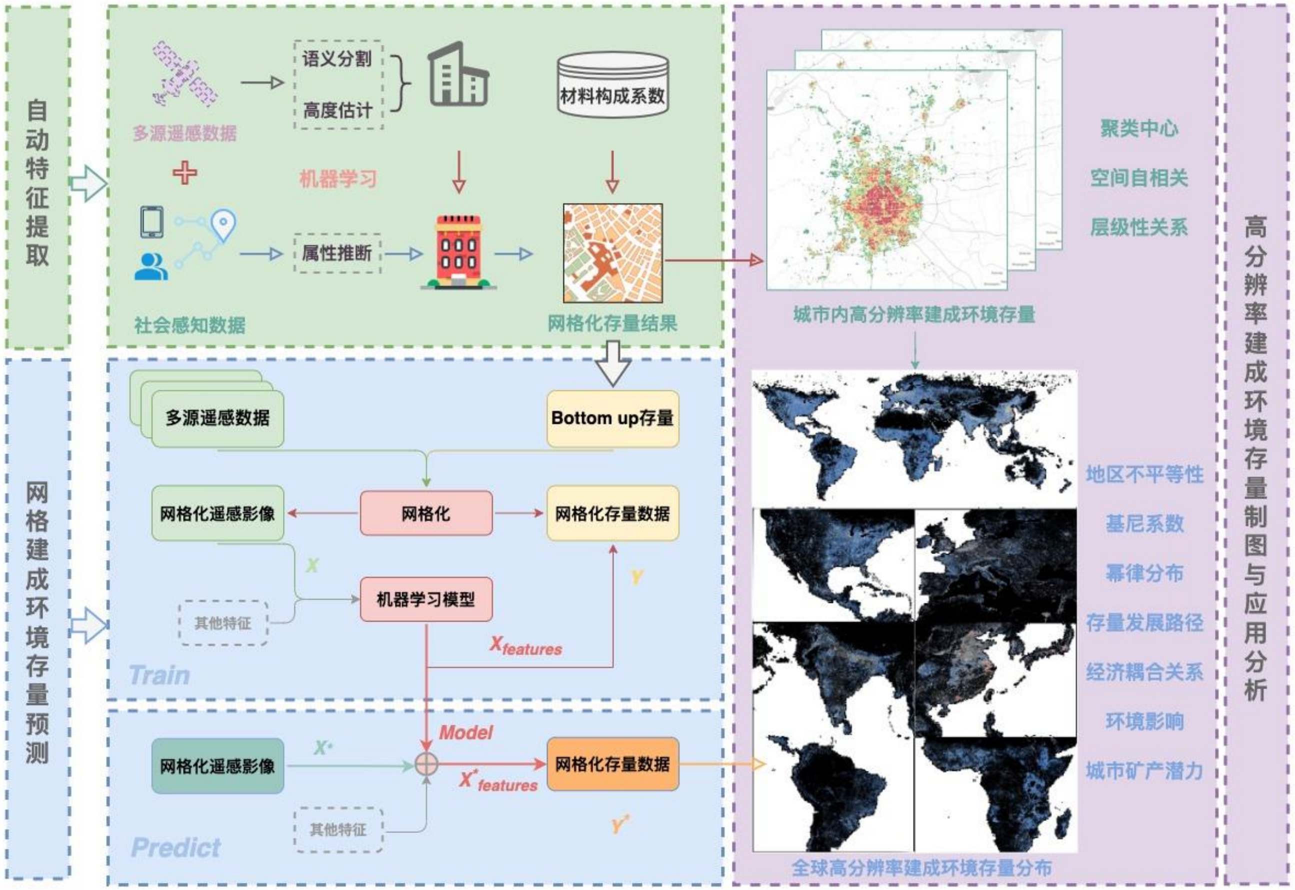


Figure 15: The dual-parameter exponential distribution model of material stock in urban buildings in China and urban development paths

A Computational and Analytical Framework for Built Environment Material Stock Based on Multi-source Geospatial Big Data



① Developed high-resolution model for predicting building material stock.

② Mapped material stock distribution in major Chinese cities

THANK YOU

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