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Introduction to Automated Building Height Extraction from Remotely Sensed Data & Analysis of Building Height Distribution In Typical Chinese Cities

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Outline

- Background
- Different methods for building height extraction
- Building height distribution in typical Chinese cities

Background

- Building height information is central to numerous research areas, including： urban planning, natural disaster management, modelling and understanding the urban climate. (Grimmond and Souch,1994; Yan et al., 2015)
- As traditional manual methodologies for collecting 2D and 3D building information are often both time consuming and costly, automated methods are required for efficient large area mapping. (Zeng, 2014)
- Remote sensing provides a powerful tool that can detect and update building information in an efficient, low-cost, and rapid-response manner.

Different methods for building height extraction

- **Shawow analysis**. (Massalabi et al., 2004; Dare, 2005;Bai and He, 2011)
- **The LIDAR point cloud data processing method**. (Rottensteiner and Briese, 2002; Rottensteiner, 2003)
- **Building–ground elevation difference model (EDM) from Digital Surface Model (DSM).** (Zeng et al,. 2014)
- **EDM: buildings on slope**
- **The moving window.** (Kent, 2019)
- **The object-based fusion approach.** (Xu et al., 2017)
- **The simulation model** called BPANN–CBRSortCA. (He et al., 2017)

Shadow analysis

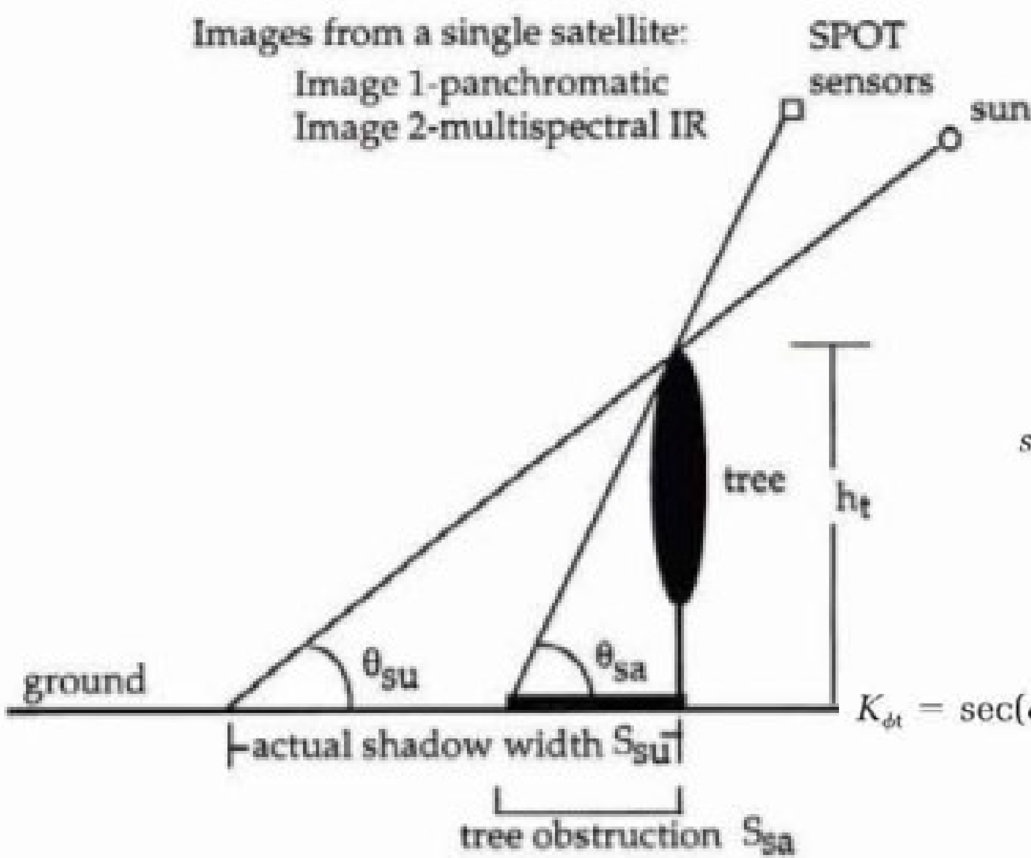


Figure 3. End view of the sun-satellite-tree configuration as seen during imaging.

$$s_{su} = h_t/\tan(\theta_{su}).$$

$$s_{sa} = h_t/\tan(\theta_{sa}).$$

$$s_{sun} = s_{su} \cdot \cos(\phi_{sun}).$$

$$s_{san} = s_{sa} \cdot \cos(\phi_{san})$$

$$s = s_{sun} - s_{san}$$
$$= h_t \{[\cos(\theta_{sun})/\tan(\theta_{su})] - [\cos(\phi_{san})/\tan(\theta_{sa})]\}$$

$$h_t = s \cdot K_{\phi t}$$

$$K_{\phi t} = \sec(\phi_{scan})/\{[\cos(\phi_{sun})/\tan(\theta_{su})] - [\cos(\phi_{san})/\tan(\theta_{sa})]\}.$$

(Shettigara and Sumerling, 1998)

The LIDAR point cloud data processing method

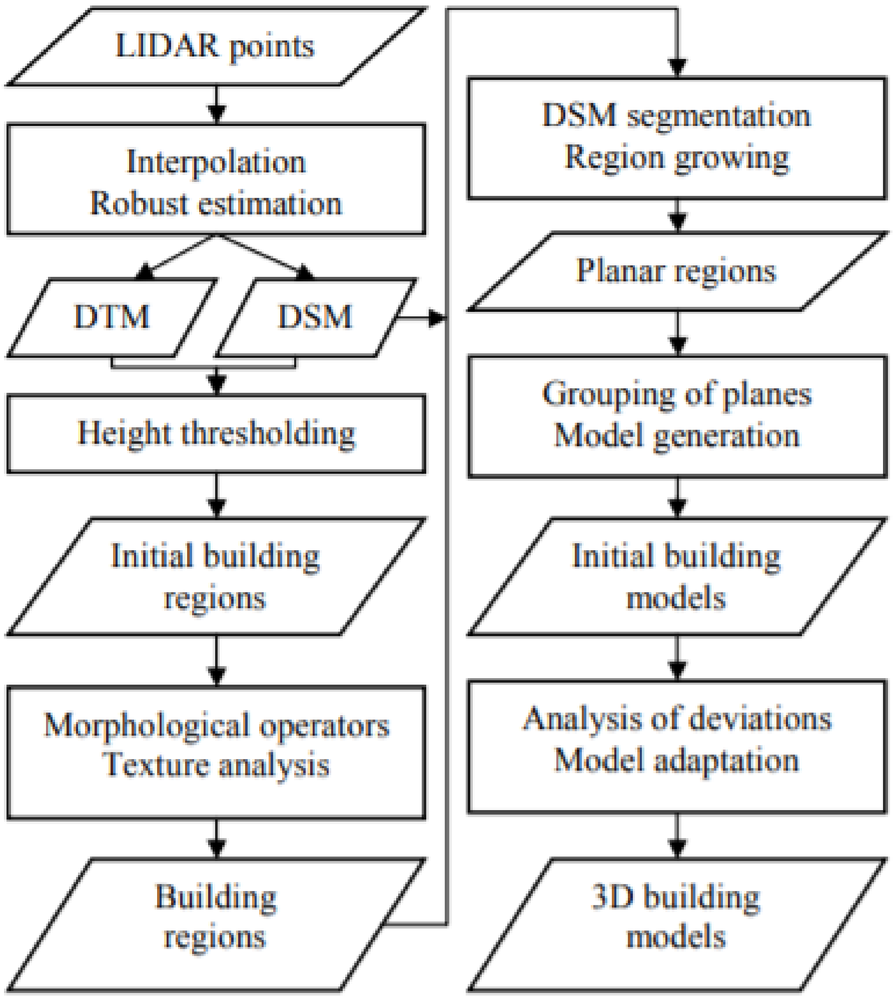
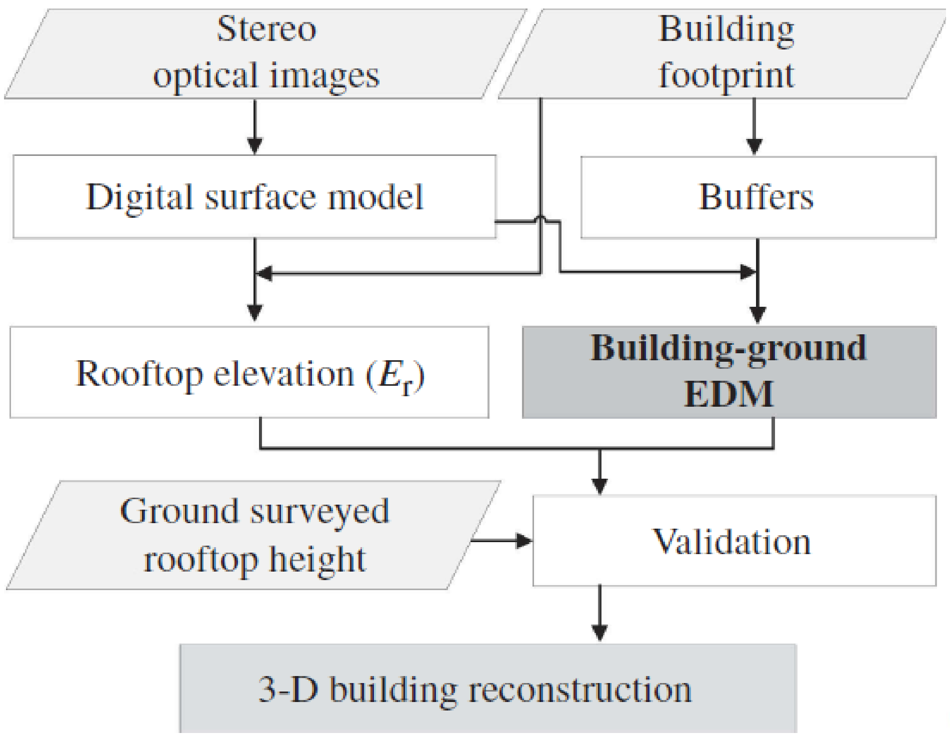
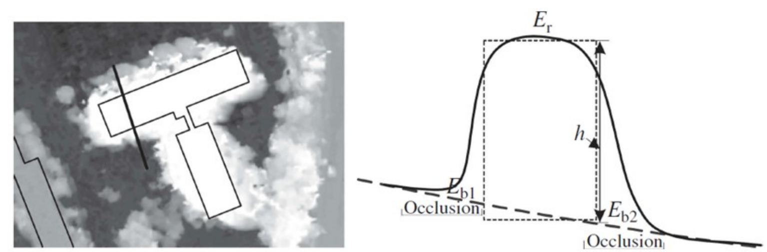


Figure 1. Work flow for building extraction from LIDAR data.

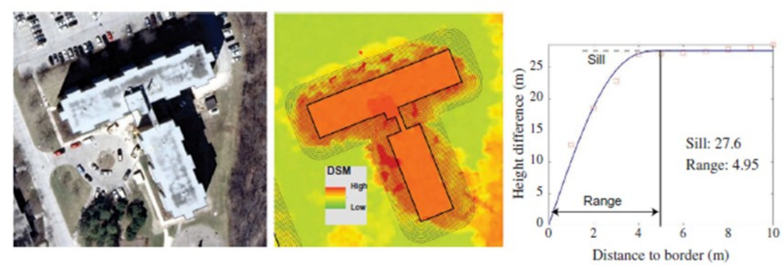
(Rottensteiner and Briese, 2002; Rottensteiner, 2003)

EDM from DSM





$$h(i) = E_r(i) - \min[\{E_b(j)\}], j = 1, 2, \ldots, m, i = 1, 2, \ldots, n$$



$$dE(d) = |\min(0) - \min(d)|, d \text{ from } 0 \text{ to } D$$

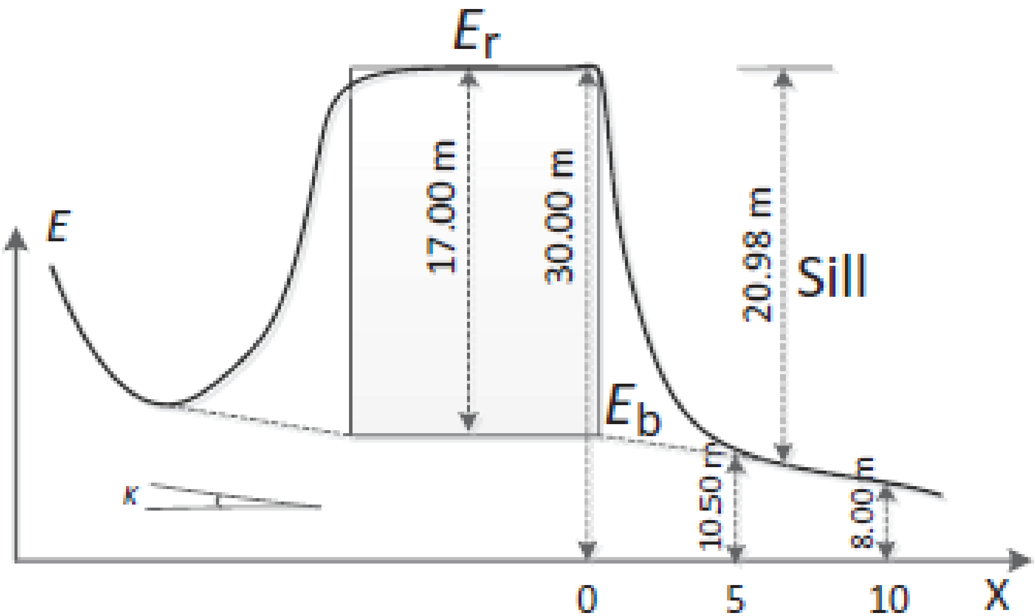
$$dE(d) = c_0\left[\frac{15}{8}\frac{d}{a_0} - \frac{5}{4}\left(\frac{d}{a_0}\right)^3 + \frac{3}{8}\left(\frac{d}{a_0}\right)^5\right]$$

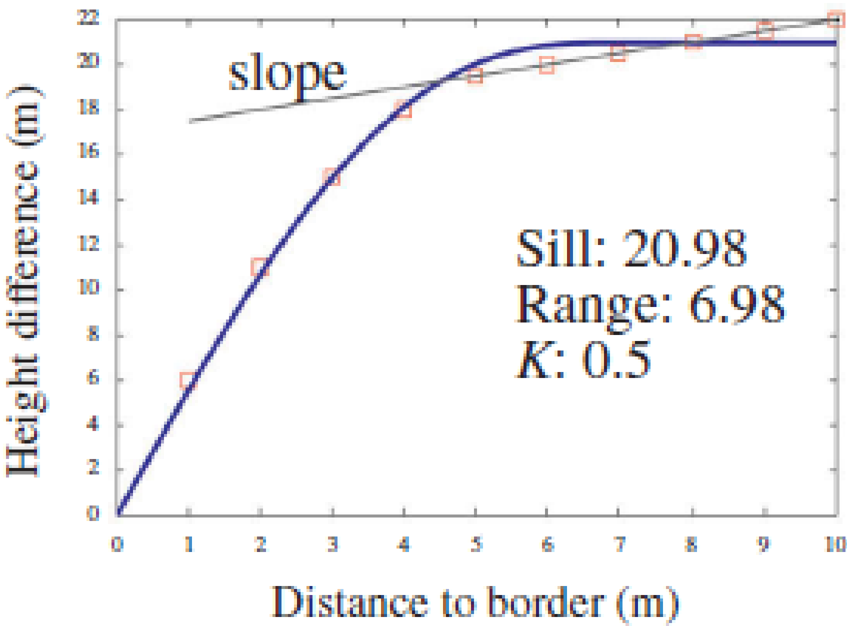
***S*:Still**
***R*:Range**

$$E_b = \min(0) - S$$

(Zeng et al., 2014)

EDM: buildings on slope





$$k = \frac{\Delta(\mathrm{d}E(d))}{\Delta d}, \quad \text{where } R < d < D$$

$$E_b = \min(0) - S + k \times R \approx \min(0) - \mathrm{d}E(\mathrm{d}^*) + \mathrm{k} \times \mathrm{d}^*$$

(Zeng et al., 2014)

EDM from DSM

- Individual building performance analysis

Table 3. The most accurate and most inaccurate building roof samples in UWO.

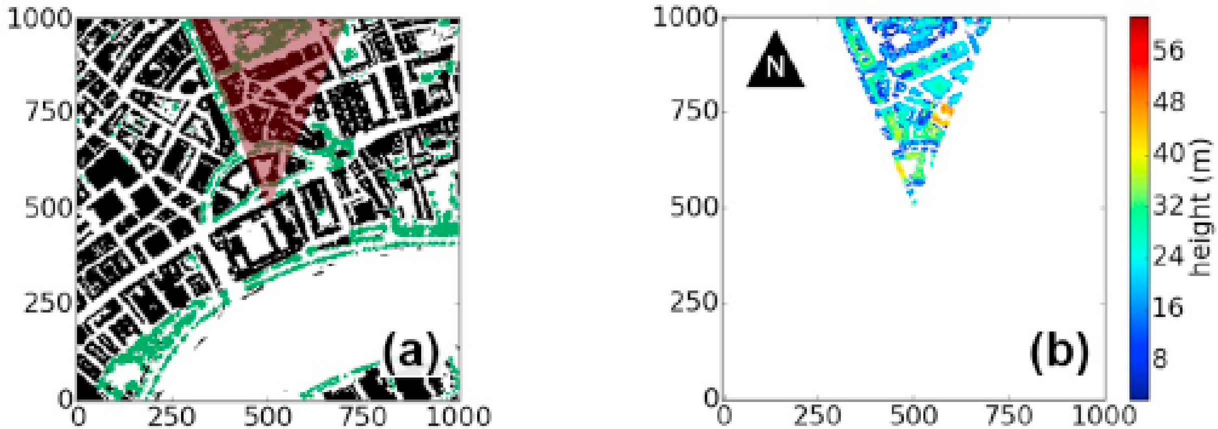
PointID	Survey H (m)	E_r (m)	E_b (m)	H (m)	Residual (m)
A1	11.4	269.37	257.89	11.47	0.07
A2	13.2	266.32	253.02	13.30	0.10
A3	8.2	248.76	240.68	8.08	−0.12
A4	7.8	253.24	245.24	8.00	0.20
A5	10.9	267.41	256.31	11.10	0.20
B5	17.9	268.39	253.83	14.55	−3.35
B4	10.5	266.00	252.04	13.96	3.46
B3	10.4	266.74	252.63	14.11	3.71
B2	30.1	272.48	238.59	33.89	3.79
B1	17.6	256.27	245.86	10.41	−7.19

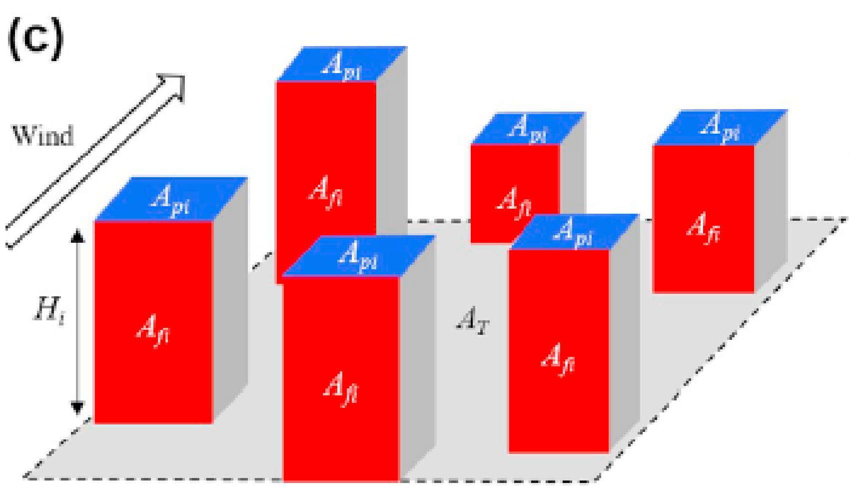
Table 4. The most accurate and most inaccurate building roof samples in Downtown.

PointID	Survey H (m)	E_r (m)	E_b (m)	H (m)	Residual (m)
A1	6.9	258.11	251.21	6.89	−0.01
A2	8.1	258.49	250.38	8.11	0.01
A3	14.0	263.63	249.54	14.10	0.10
A4	15.0	263.40	248.52	14.88	−0.12
A5	15.8	264.87	249.24	15.62	−0.18
B5	10.1	256.07	249.72	6.35	−3.75
B4	22.8	268.97	250.32	18.65	−4.15
B3	9.2	262.35	248.56	13.79	4.59
B2	31.6	274.16	247.95	26.21	−5.39
B1	14.4	268.38	248.37	20.01	5.61

The moving window

- A moving window is used to extract ground heights from the global digital elevation models (GDEM);
- Implications for aerodynamic roughness and for wind-speed estimation.



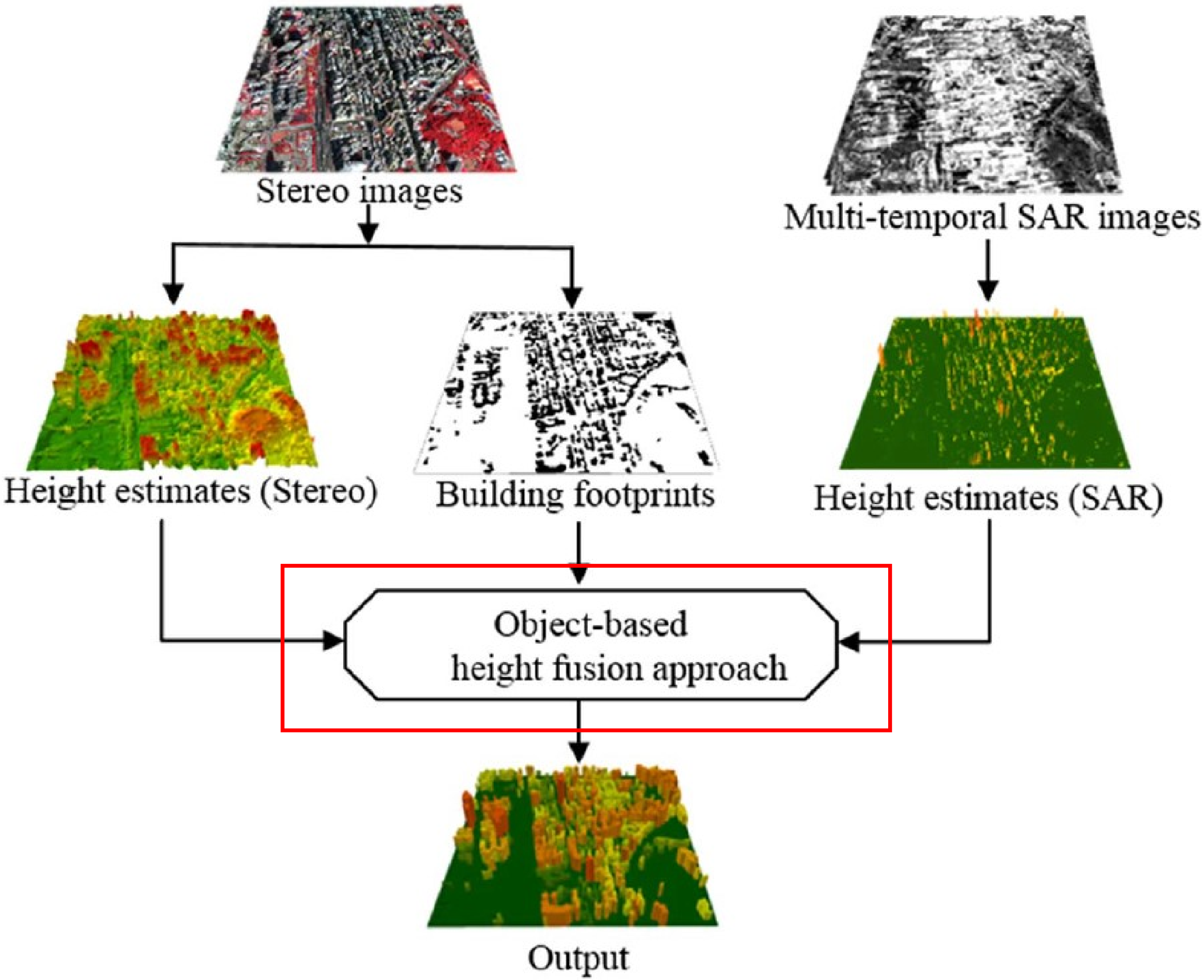


Parameter [units]	Formula
average height (H_{av}) [m]	$\frac{\sum_{i=1}^{n} H_i}{n}$
maximum height (H_{max}) [m]	$max(H_i)$
standard deviation of heights (σ_H) [m]	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(H_i - H_{av})^2}$
plan area index (λ_p)	$\frac{\sum_{i=1}^{n} A_{pi}}{A_T}$
frontal area index (λ_f)	$\frac{\sum_{i=1}^{n} A_{fi}}{A_T}$
zero-plane displacement (z_d) [m]	Kanda et al. (2013), their Eq. 10 and 12
roughness length (z_0) [m]	

(Kent et al., 2019)

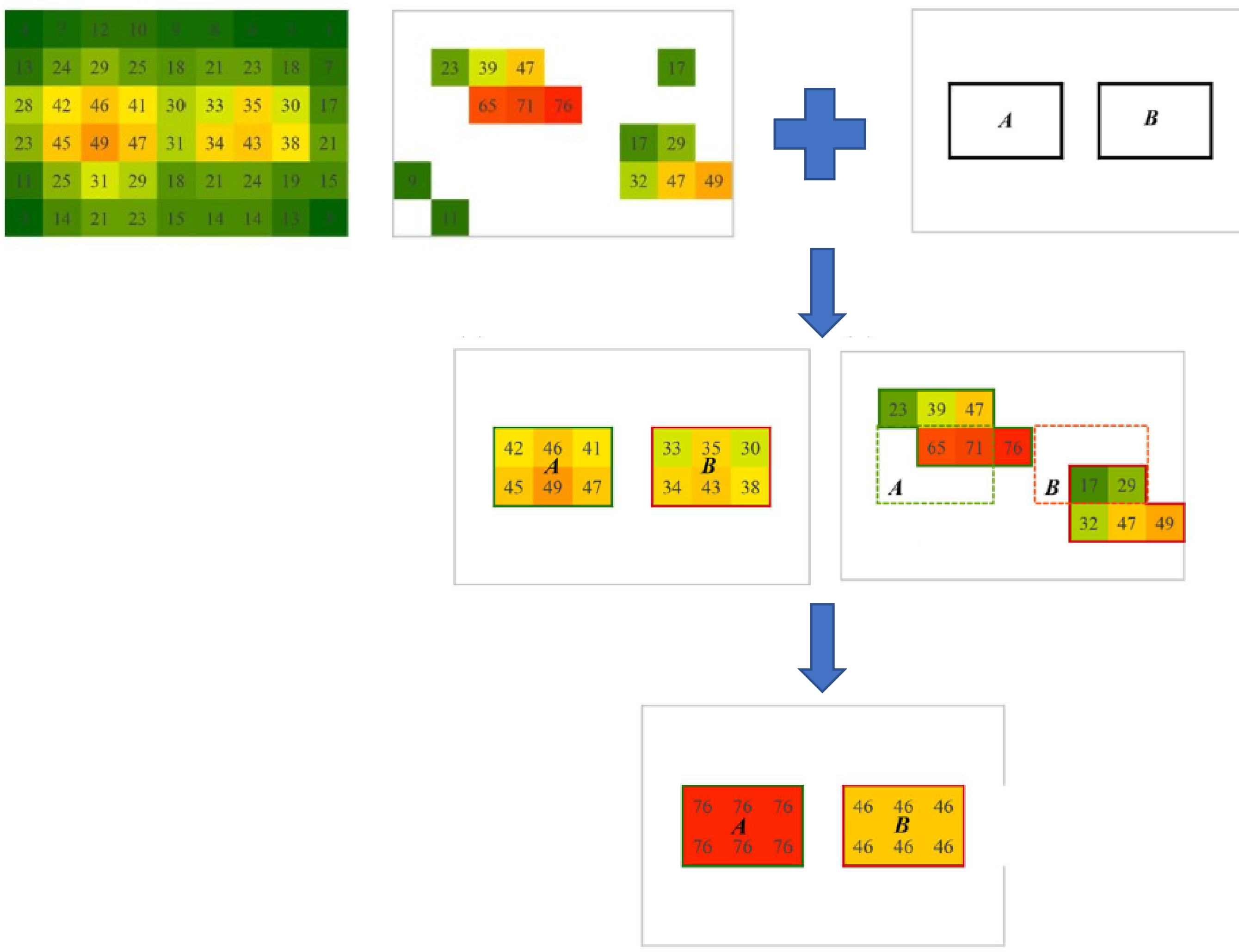
The object-based fusion approach

- Urban morphology detection and computation for urban climate research



(Xu et al., 2017)

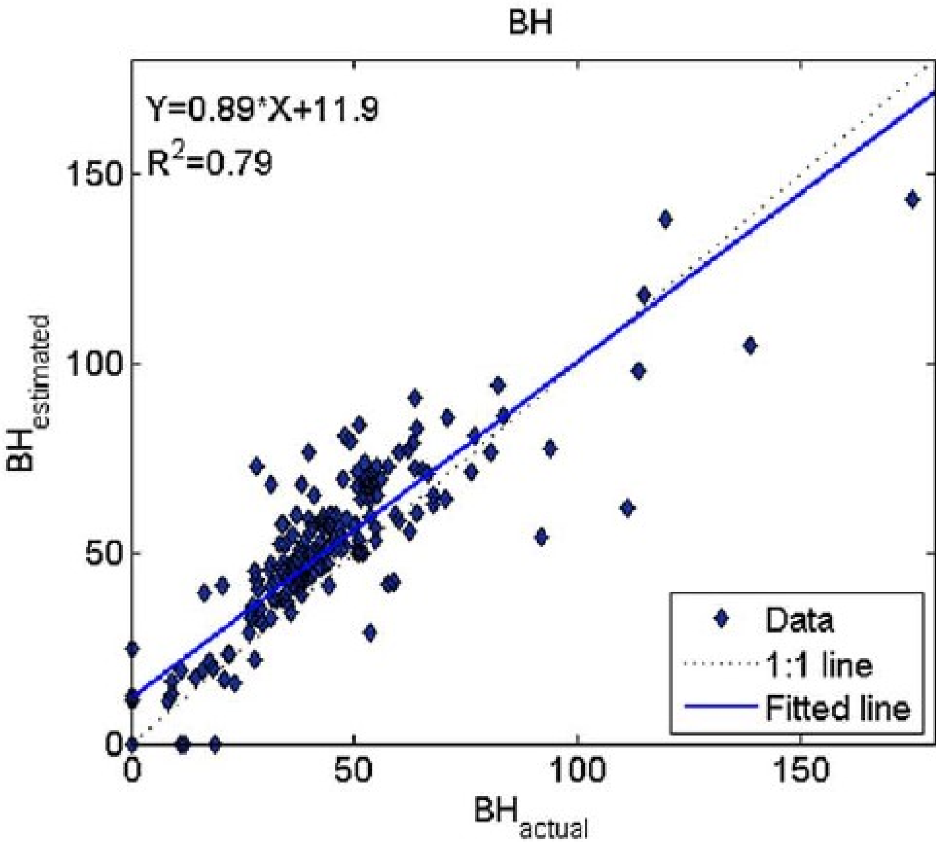
The object-based fusion approach

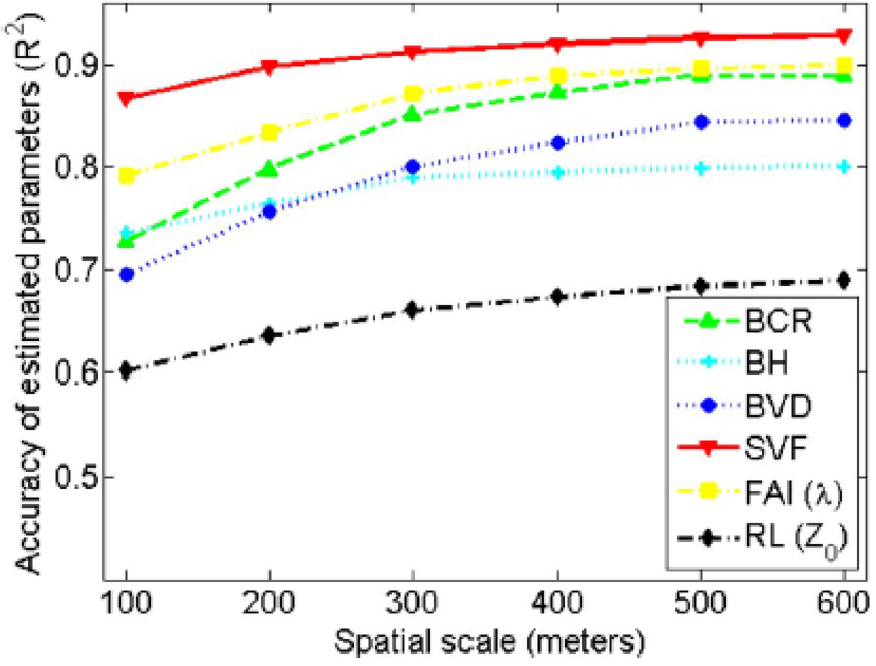


fused heights of buildings

The object-based fusion approach

Results：





(Xu et al., 2017)

The simulation model called BPANN–CBRSortCA

- Back propagation artificial neural network (BPANN) and case-based reasoning technology with sort cellular automaton (CBRSortCA)

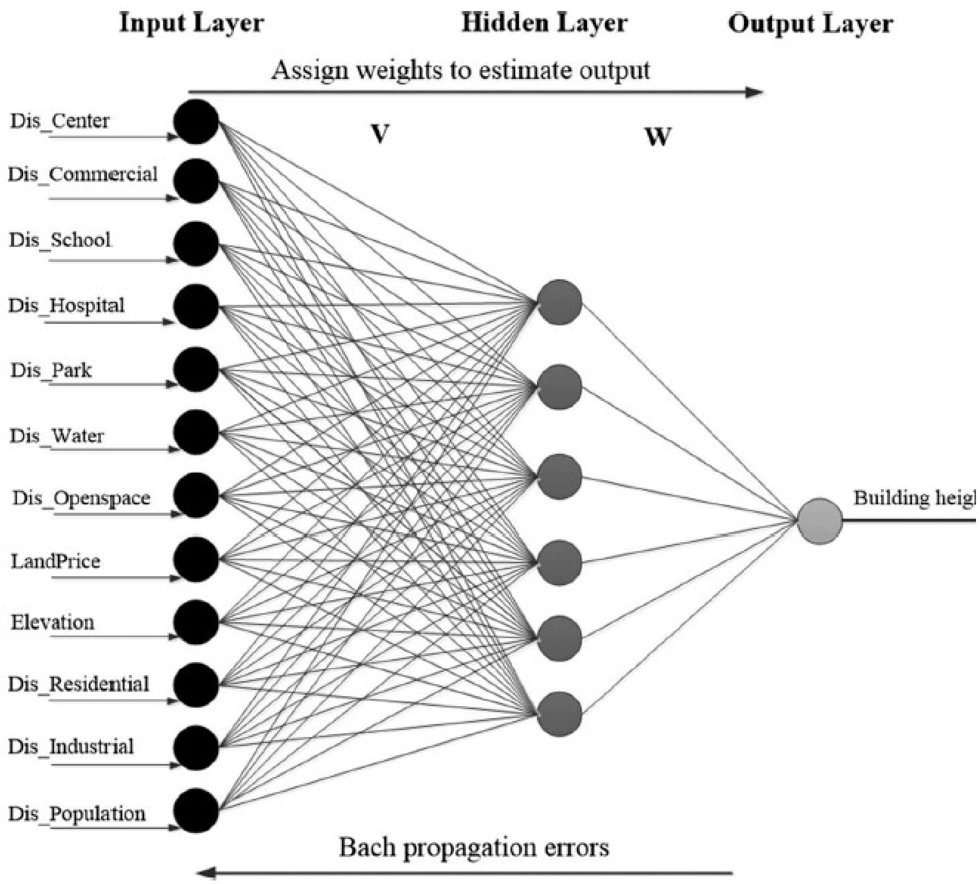


Figure 4. Neural network structure.

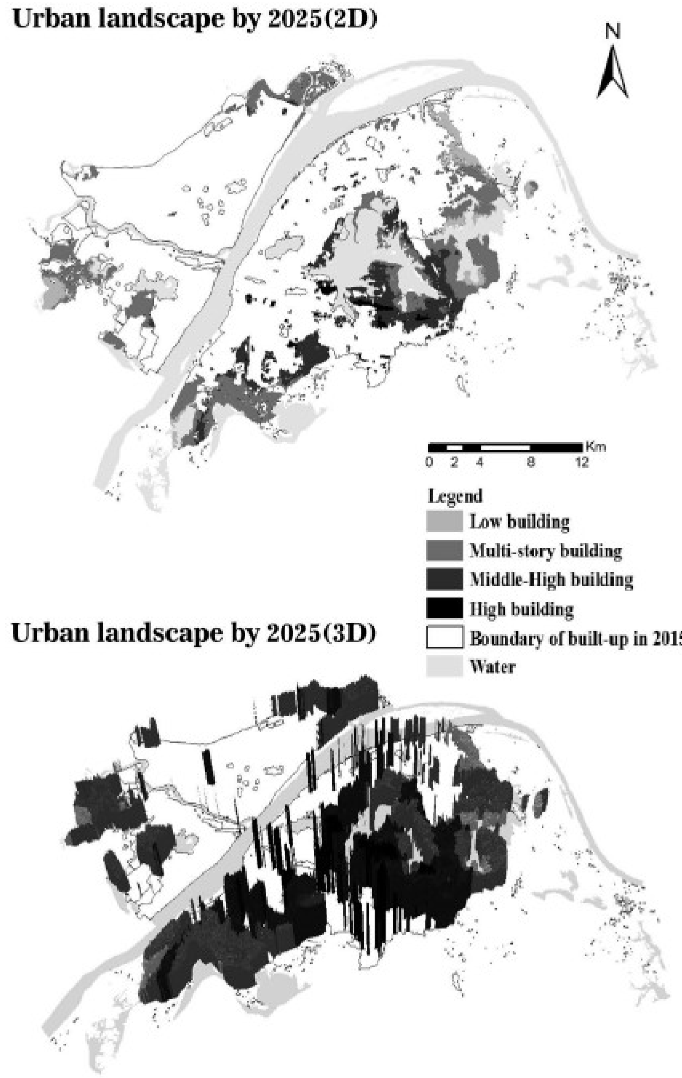


Figure 7. Forecast urban landscape of building height.

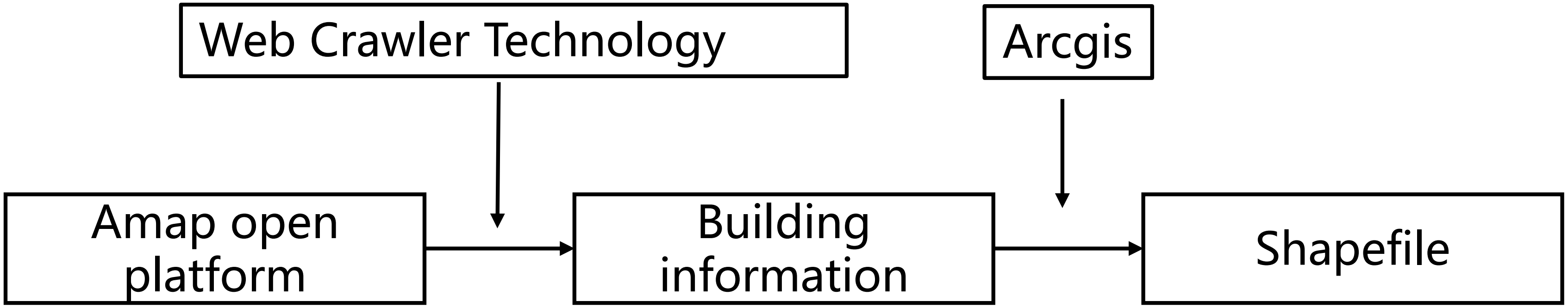
(He et al., 2017)

Analysis of Building Height Distribution In Typical Chinese Cities

Data information

- Building height data
  - Format: SHP
  - Unit: Floor
  - Amount : 44 cites
  - Generation method:

Original data (Nanjing) displayed in Arcgis10.6



Data information

- The actual height of the tallest building in each city

City	Tallest height (m)	City	Tallest height (m)	City	Tallest height (m)	City	Tallest height (m)
香港	484	惠州	288	武汉	336	苏州	450
澳门	261	福州	280	石家庄	245	沈阳	360.6
重庆	355	西安	350	济南	339	广州	530
昆明	316	南宁	402.65	常州	333	长春	226
深圳	592.5	宁波	256.8	厦门	229.8	北京	528
合肥	301	大连	383.45	南京	450	兰州	313
长沙	452	泉州	208	徐州	266	呼和浩特	176
杭州	280	上海	632	南昌	303	保定	258.9
成都	248	郑州	285	金华	215	扬州	300
贵阳	335	青岛	254.4	天津	597	鄂尔多斯	200
珠海	337	嘉兴	236	银川	136	三亚	165

(http://bbs.tianya.cn/post-hn-117091-1.shtml)

Data information

- Population density data for each city

City	Population density (people/km^2)	City	Population density (people/km^2)	City	Population density (people/km^2)	City	Population density (people/km^2)
香港	6763	惠州	272	武汉	1293.13	苏州	652
澳门	20777.5	福州	504.4	石家庄	757.2	沈阳	639
重庆	999.05	西安	743.26	济南	728.3	广州	1007.4
昆明	13800	南宁	296.99	常州	842.11	长春	389
深圳	5398	宁波	815	厦门	2265	北京	1312.7
合肥	658.31	大连	428.31	南京	918.32	兰州	286.53
长沙	665	泉州	771	徐州	821.71	呼和浩特	180.84
杭州	524	上海	3810	南昌	644.33	保定	526.8
成都	1134	郑州	1149.12	金华	416.7	扬州	683
贵阳	538	青岛	832.7	天津	1308.7	鄂尔多斯	24
珠海	920	嘉兴	850.57	银川	147.57	三亚	320.2

(http://www.stats.gov.cn/tjsj/ndsj/2018/indexch.htm)

Analysis method

- Classification of the buildings in terms of building height

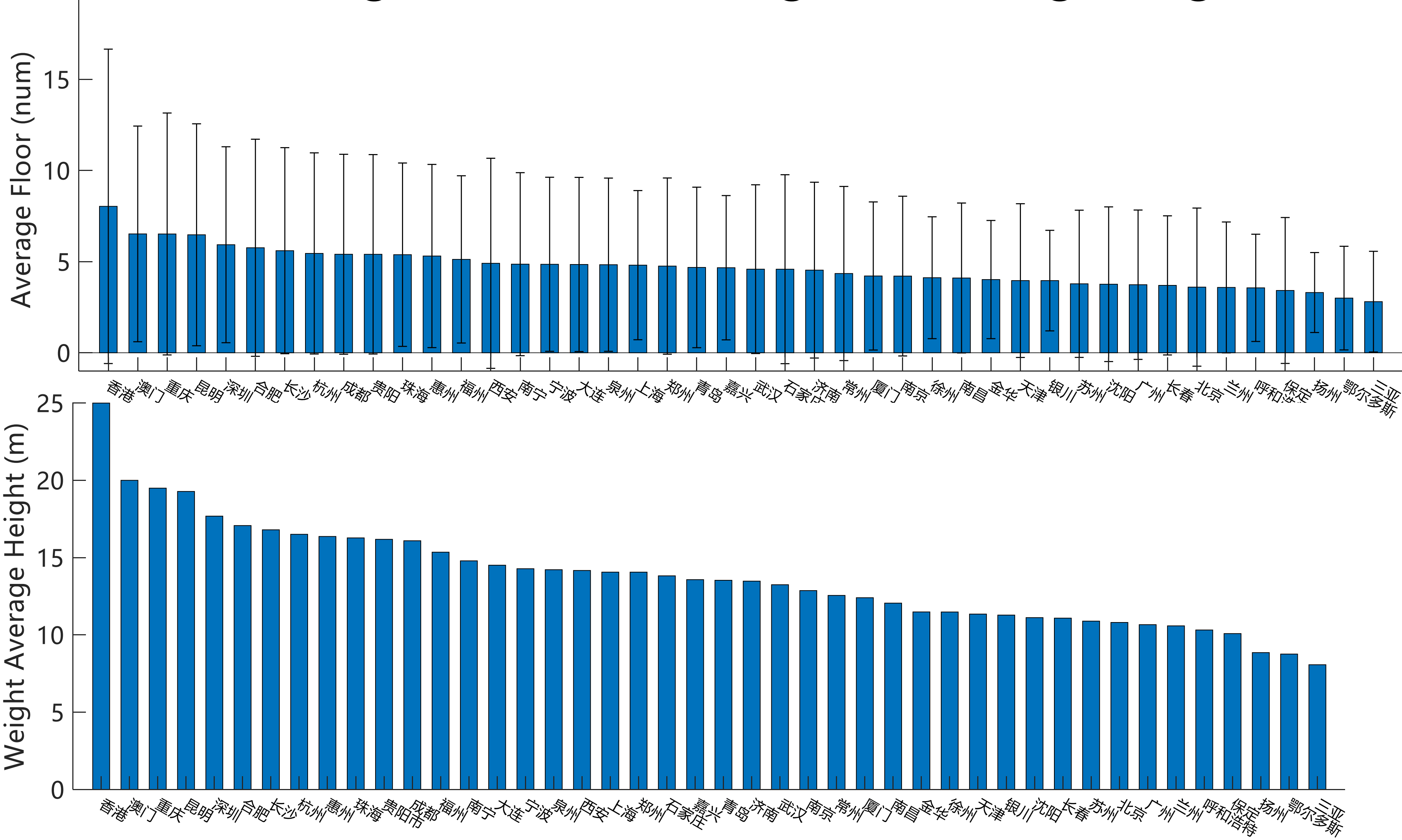
Classification	Floor	Height
Low-rise building	1-3	≤9
Multi-story building	4-6	9-21
Middle-rise building	7-9	21-30
Small high-rise building	10-16	30-50
High-rise building	17-40	50-100
Ultra-high-rise building	>40	>100

[China National Standards. Code for Design of Civil. Building (GB50352-2005); China Architecture & Building Press: Beijing, China, 2005.]

- Calculation of the weighted average height;
- Calculation of the floor distribution frequency and probability;
- Analysis of the building height spatial distribution.

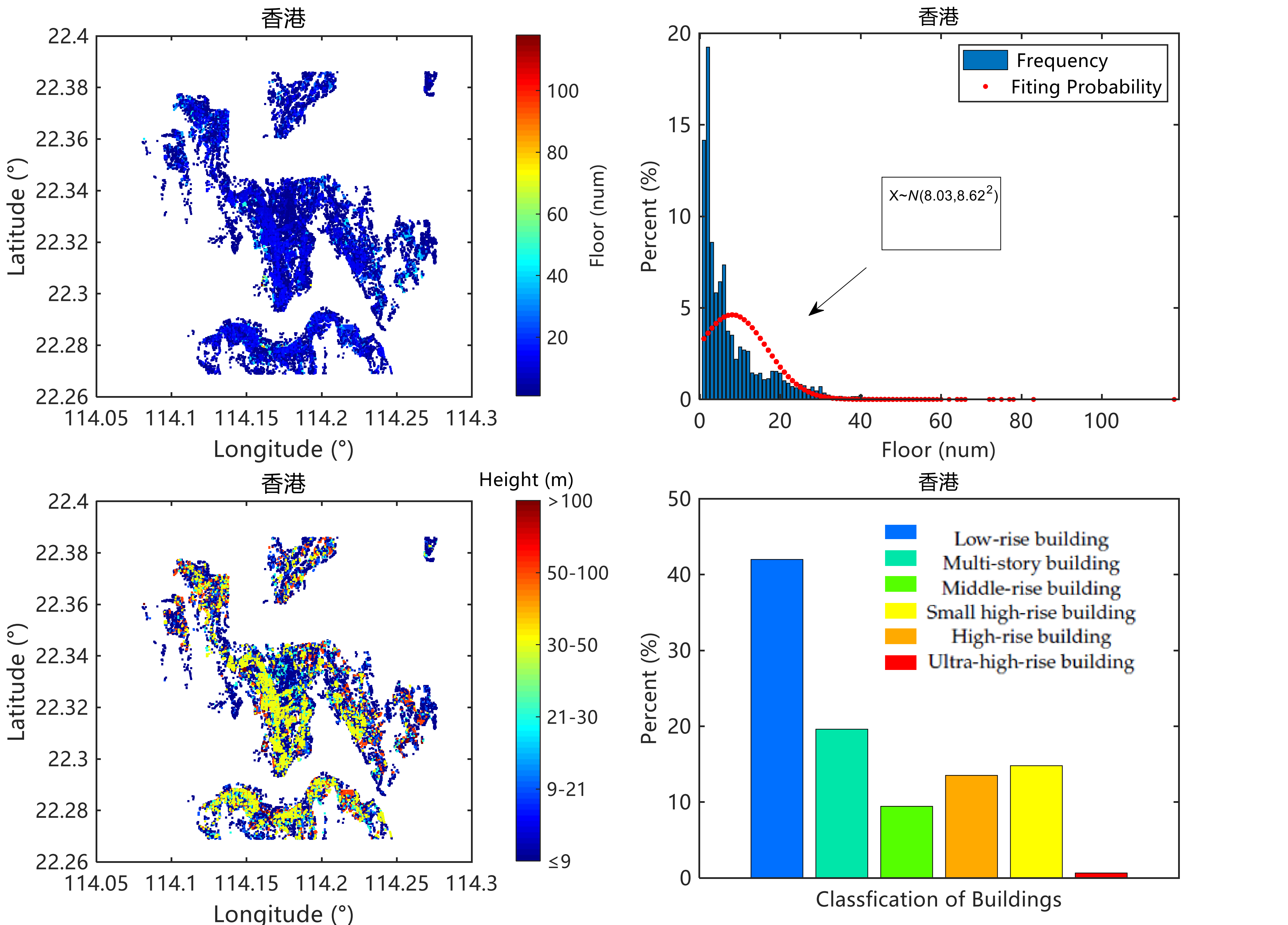
Results

□The Average Floor & the weighted average height



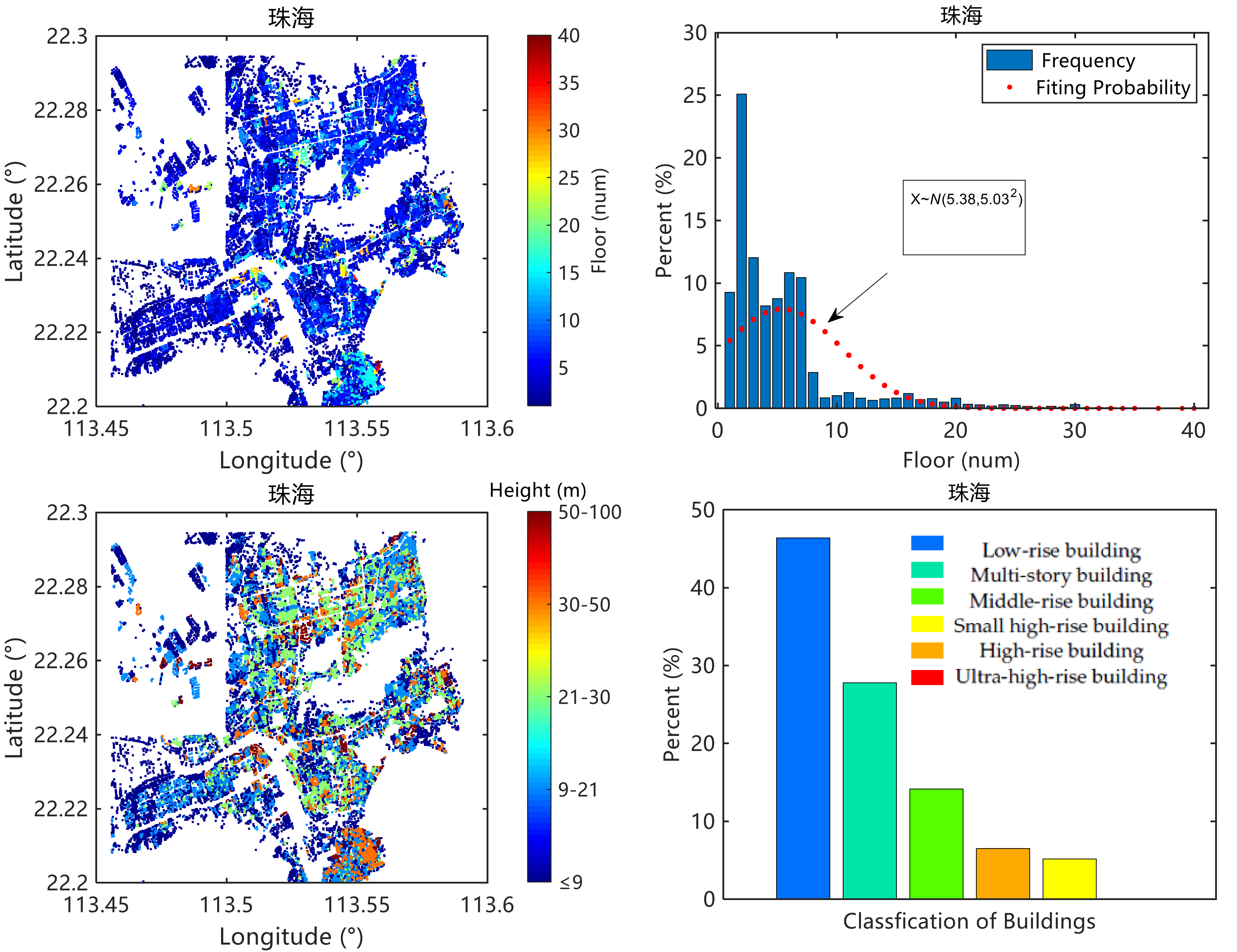
City	香港	澳门	重庆	昆明	深圳	合肥	长沙	杭州	成都	贵阳市	珠海
The Rank of Average Floor	1	2	3	4	5	6	7	8	9	10	11
The Rank of Weighted Average Height	1	2	3	4	5	6	7	8	12	11	10
Rank change	0	0	0	0	0	0	0	0	-3	-1	1
City	惠州	福州	西安	南宁	宁波	大连	泉州	上海	郑州	青岛	嘉兴
The Rank of Average Floor	12	13	14	15	16	17	18	19	20	21	22
The Rank of Weighted Average Height	9	13	18	14	16	15	17	19	20	23	22
Rank change	3	0	-4	1	0	2	1	0	0	-2	0
City	武汉	石家庄	济南	常州	厦门	南京	徐州	南昌	金华	天津	银川
The Rank of Average Floor	23	24	25	26	27	28	29	30	31	32	33
The Rank of Weighted Average Height	25	21	24	27	28	26	31	29	30	32	33
Rank change	-2	3	1	-1	-1	2	-2	1	1	0	0
City	苏州	沈阳	广州	长春	北京	兰州	呼和浩特	保定	扬州	鄂尔多斯	三亚
The Rank of Average Floor	34	35	36	37	38	39	40	41	42	43	44
The Rank of Weighted Average Height	36	37	38	35	37	39	40	41	42	43	44
Rank change	-2	-2	-2	2	1	0	0	0	0	0	0

◻Hong Kong



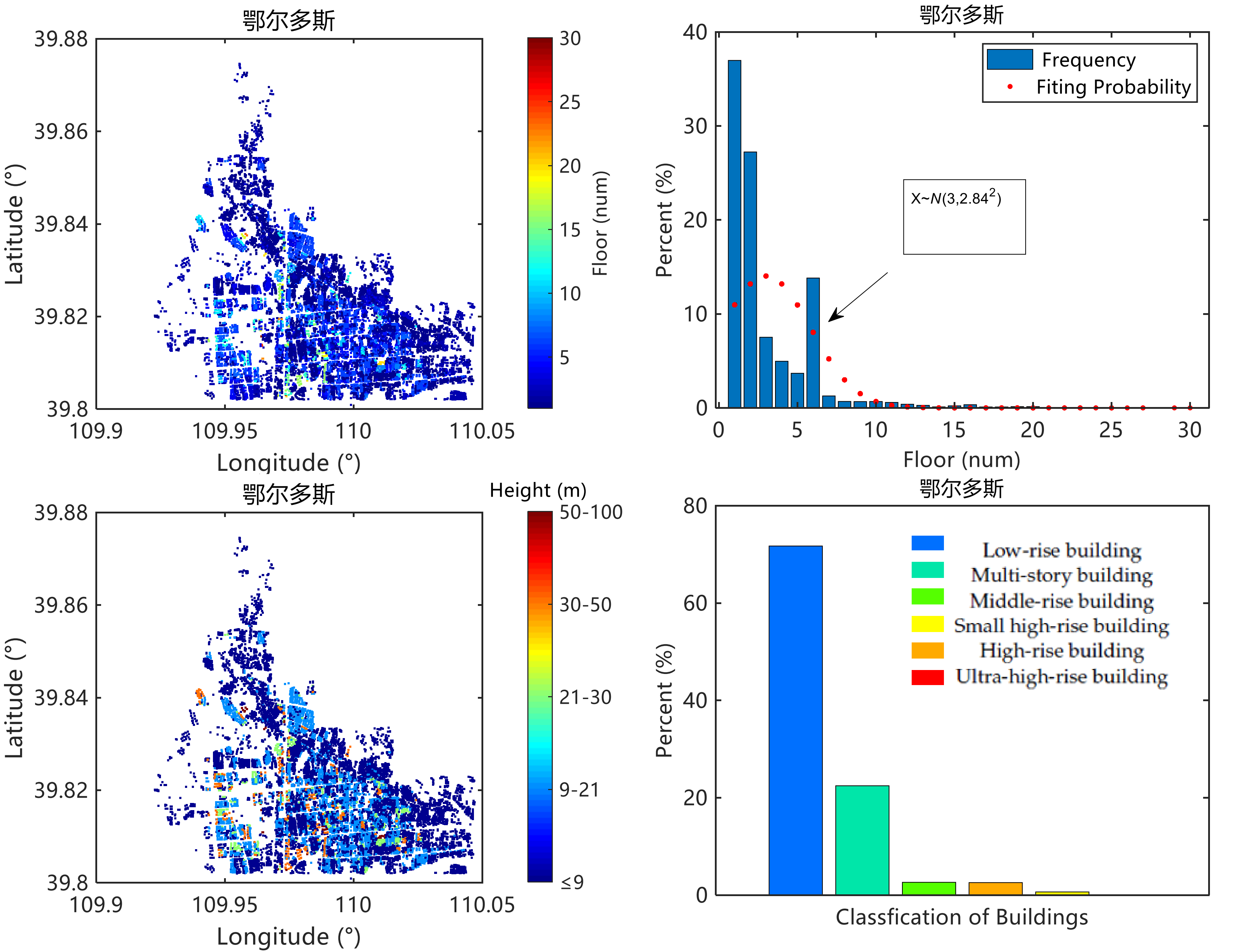
香港
22.4
22.38
22.36
22.34
22.32
22.3
22.28
22.26
Latitude (°)
114.05
114.1
114.15
114.2
114.25
114.3
Longitude (°)
100
80
60
40
20
Floor (num)
香港
20
15
10
5
0
Percent (%)
Frequency
Fiting Probability
X~N(8.03,8.62^2)
0
20
40
60
80
100
Floor (num)
香港
Latitude (°)
Longitude (°)
Height (m)
>100
50-100
30-50
21-30
9-21
≤9
香港
50
40
30
20
10
0
Percent (%)
Low-rise building
Multi-story building
Middle-rise building
Small high-rise building
High-rise building
Ultra-high-rise building
Classfication of Buildings

☐Zhuhai

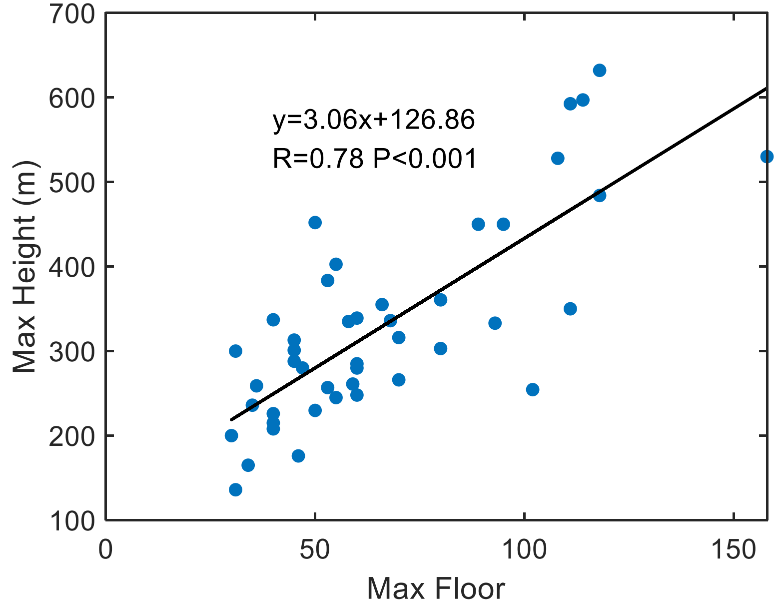


珠海
Latitude (°)
Longitude (°)
Floor (num)
珠海
Frequency
Fiting Probability
X~N(5.38,5.03²)
Percent (%)
Floor (num)
珠海
Height (m)
50-100
30-50
21-30
9-21
≤9
Latitude (°)
Longitude (°)
珠海
Low-rise building
Multi-story building
Middle-rise building
Small high-rise building
High-rise building
Ultra-high-rise building
Percent (%)
Classfication of Buildings

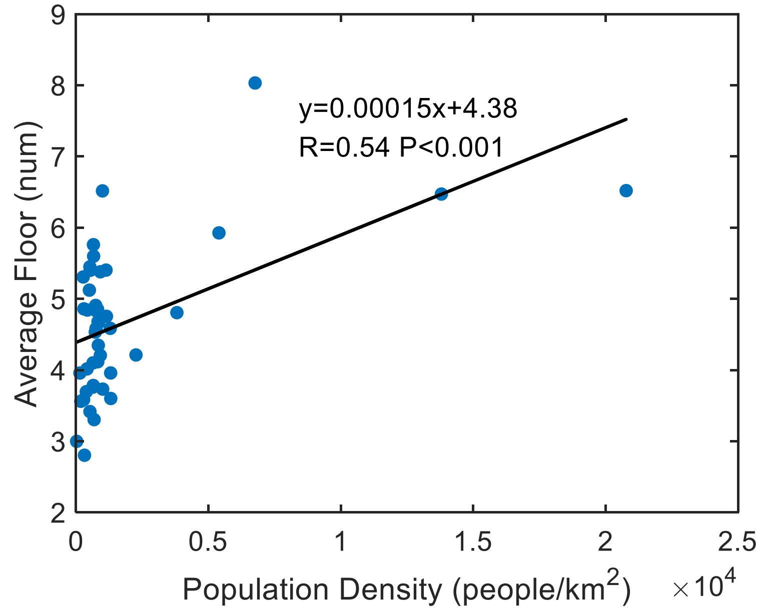
◻Ordos


鄂尔多斯
39.88
39.86
39.84
39.82
39.8
Latitude (°)
109.9
109.95
110
110.05
Longitude (°)
30
25
20
15
10
5
Floor (num)
鄂尔多斯
40
30
20
10
0
Percent (%)
0
5
10
15
20
25
30
Floor (num)
Frequency
Fiting Probability
X~N(3,2.84²)
鄂尔多斯
Latitude (°)
Longitude (°)
Height (m)
50-100
30-50
21-30
9-21
≤9
鄂尔多斯
80
60
40
20
0
Percent (%)
Low-rise building
Multi-story building
Middle-rise building
Small high-rise building
High-rise building
Ultra-high-rise building
Classfication of Buildings

☐The relationship between max floor and max height



☐The relationship between population and average floor



Thanks for your attention!