Supplementary data of

The significant contribution of three-dimensional building morphology to $PM_{2.5}$ concentrations in the Yangtze River Delta

Jing Zhang[a,1], Wenjian Zhu[a,1], Dubin Dong[a], Yuan Ren[a], Wenhao Hu[b], Xinjie Jin[c], Zhengxuan He[a], Jian Chen[a], Xiaoai Jin[a,*], and Tianhuan Zhou[d,**]

[a] *State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Hangzhou, 311300, China*

[b] *School of Landscape Architecture and Architecture, Zhejiang A&F University, Hangzhou, 311300, China*

[c] *College of Life and Environmental Sciences, Wenzhou University, Wenzhou, 325035, China*

[d]*Zhejiang Forest Resource Monitoring Center , Hangzhou, 310020, Chin*

[1]Jing Zhang and Wenjian Zhu contributed equally.

[*] Corresponding author Xiaoai Jin. Email address: jinxa@zafu.edu.cn

[**] Corresponding author Tianhuan Zhou. Email address: zhou_tianhuan@163.com

Table S1 The correlation coefficients between the 2D/3D building morphology indicators and $PM_{2.5}$ concentrations in 2018.

Buffer	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BO	BVD	HBI
100 m	-0.18	-0.18	0.02	**0.27***	**0.39****	-0.04	0.07	-0.23	**-0.39****	**-0.33****	-0.14	-0.07	**0.32****
300 m	-0.21	-0.13	**0.26***	0.23	**0.31****	-0.11	-0.02	-0.19	**-0.39****	-0.22	-0.01	-0.15	0.24
500 m	-0.14	-0.06	**0.35****	0.15	0.19	-0.13	-0.06	**-0.27***	**-0.34****	-0.15	-0.05	-0.18	0.19
1000 m	-0.06	-0.03	**0.25***	0.07	0.11	-0.12	-0.01	-0.19	**-0.35****	-0.07	0.03	-0.22	0.01
2000 m	0.04	-0.01	0.15	-0.04	-0.02	-0.15	0.05	**-0.25***	**-0.27***	-0.21	-0.07	-0.11	0.14
3000 m	0.08	0.04	0.20	-0.09	-0.07	-0.19	0.00	-0.23	-0.19	-0.25*	-0.03	0.03	0.01
4000 m	0.08	0.04	**0.29***	-0.07	-0.05	**-0.26***	0.04	**-0.25***	-0.19	-0.21	-0.01	-0.07	0.06
5000 m	0.09	0.00	**0.38****	-0.05	-0.02	**-0.31***	0.04	-0.21	**-0.25***	**-0.34****	0.07	-0.02	0.08

Notes: Significant correlation at 0.01 level were labeled with ** ($p < 0.01$), those at 0.05 level were labeled with * ($p < 0.05$). Correlation coefficient insignificant ($p > 0.05$) was labeled without *.

Table S2 The correlation coefficients between the 2D/3D building morphology indicators and $PM_{2.5}$ concentrations in spring.

Buffer	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BO	BVD	HBI
100 m	-0.17	-0.23	-0.08	0.21	**0.36****	0.10	-0.03	**-0.24***	**-0.33****	**-0.34****	-0.15	-0.09	0.22
300 m	-0.19	-0.15	0.13	0.07	**0.31***	-0.10	0.02	-0.20	**-0.38****	**-0.25***	-0.03	-0.13	**0.25***
500 m	-0.13	-0.09	0.21	-0.02	0.18	-0.10	0.02	**-0.27***	**-0.36****	-0.19	-0.06	-0.13	0.16
1000 m	-0.04	-0.05	0.15	0.19	0.11	-0.08	0.06	-0.20	**-0.36****	-0.14	-0.03	-0.14	0.10
2000 m	0.06	-0.02	0.14	-0.08	0.00	-0.01	0.03	**-0.27***	**-0.29***	**-0.28***	-0.11	-0.07	0.12
3000 m	0.13	0.07	0.19	-0.07	-0.08	-0.06	-0.07	**-0.27***	-0.19	**-0.27***	-0.07	0.08	0.00
4000 m	0.14	0.09	**0.34****	0.14	-0.06	-0.06	-0.12	**-0.28***	-0.16	-0.20	-0.06	0.00	0.05
5000 m	0.16	0.08	**0.45****	-0.08	-0.06	-0.08	-0.16	-0.20	-0.06	-0.21	-0.03	0.08	-0.07

Notes: Significant correlation at 0.01 level were labeled with ** ($p < 0.01$), those at 0.05 level were labeled with * ($p < 0.05$). Correlation coefficient insignificant ($p > 0.05$) was labeled without *.

Table S3 The correlation coefficients between the 2D/3D building morphology indicators and $PM_{2.5}$ concentrations in summer.

Buffer	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BO	BVD	HBI
100 m	-0.05	-0.11	-0.04	0.07	0.14	-0.04	0.08	-0.16	**-0.26***	-0.18	-0.01	-0.13	0.23
300 m	-0.10	0.05	0.21	0.10	0.08	-0.06	0.05	-0.12	**-0.29***	-0.14	-0.05	-0.14	0.13
500 m	-0.06	0.08	**0.25***	0.04	0.17	-0.03	-0.09	-0.12	**-0.34****	-0.08	-0.06	-0.19	**0.30***
1000 m	-0.05	0.06	0.17	0.17	0.14	-0.01	0.05	-0.09	**-0.35****	-0.02	0.18	**-0.29***	-0.09
2000 m	-0.03	0.06	0.17	0.04	0.05	-0.07	0.08	-0.11	**-0.29***	**-0.29***	-0.12	-0.02	0.12
3000 m	-0.01	0.08	**0.27***	0.06	0.04	-0.11	0.06	-0.06	**-0.26***	**-0.37****	-0.03	0.13	0.02
4000 m	-0.02	0.05	**0.32****	0.16	0.07	-0.12	0.13	-0.07	**-0.27***	**-0.33****	0.18	0.04	0.08
5000 m	-0.02	0.02	**0.29***	0.09	0.11	-0.14	0.15	-0.02	-0.20	**-0.35****	0.27*****	0.07	-0.02

Notes: Significant correlation at 0.01 level were labeled with ** ($p < 0.01$), those at 0.05 level were labeled with * ($p < 0.05$). Correlation coefficient insignificant ($p > 0.05$) was labeled without *.

Table S4 The correlation coefficients between the 2D/3D building morphology indicators and $PM_{2.5}$ concentrations in autumn.

Buffer	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BO	BVD	HBI
100 m	-0.13	-0.13	0.05	**0.31***	**0.45****	0.13	-0.01	-0.22	**-0.37****	**-0.30***	-0.07	-0.02	**0.35****
300 m	-0.15	-0.10	**0.28***	-0.01	**0.31****	-0.05	-0.12	-0.23	**-0.32****	**-0.25***	-0.04	-0.02	0.12
500 m	-0.09	-0.04	**0.37****	-0.14	0.16	-0.09	-0.15	**-0.30***	**-0.30***	-0.20	-0.06	-0.12	0.11
1000 m	0.02	0.02	0.20	0.20	0.03	-0.06	-0.12	**-0.25***	**-0.30***	-0.07	0.03	-0.21	-0.09
2000 m	0.14	0.06	0.12	-0.19	-0.13	-0.04	-0.14	**-0.26***	-0.20	-0.14	-0.04	-0.13	0.13
3000 m	0.19	0.11	0.16	-0.18	-0.17	-0.07	-0.16	**-0.27***	-0.14	-0.19	0.02	0.00	0.00
4000 m	0.19	0.11	**0.25***	0.11	-0.16	-0.05	-0.22	**-0.33****	-0.14	-0.18	0.04	-0.09	0.04
5000 m	0.20	0.06	**0.36****	-0.16	-0.13	-0.02	**-0.27***	**-0.30***	**-0.24***	**-0.28***	0.12	-0.08	0.10

Notes: Significant correlation at 0.01 level were labeled with ** ($p < 0.01$), those at 0.05 level were labeled with * ($p < 0.05$). Correlation coefficient insignificant ($p > 0.05$) was labeled without *.

Table S5 The correlation coefficients between the 2D/3D building morphology indicators and $PM_{2.5}$ concentrations in winter.

Buffer	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BO	BVD	HBI
100 m	-0.22	-0.16	0.06	**0.28***	**0.35****	-0.01	-0.03	-0.22	**-0.36****	**-0.30***	-0.15	-0.03	**0.29***
300 m	-0.24	-0.15	**0.28***	0.10	**0.31***	0.03	-0.13	-0.17	**-0.37****	-0.18	0.01	-0.18	0.22
500 m	-0.18	-0.07	**0.36****	-0.01	0.20	0.02	-0.16	**-0.25***	**-0.30***	-0.11	-0.03	-0.21	0.17
1000 m	-0.11	-0.05	**0.30***	**0.25***	0.15	0.04	-0.16	-0.17	**-0.32****	-0.04	0.05	**-0.24***	0.00
2000 m	-0.02	-0.07	0.12	-0.05	0.01	0.12	-0.19	-0.22	**-0.25***	-0.16	-0.04	-0.14	0.14
3000 m	0.01	-0.03	0.16	-0.03	-0.03	0.05	-0.22	-0.19	-0.18	-0.20	-0.01	-0.03	0.02
4000 m	0.00	-0.04	0.23	0.17	0.00	0.10	**-0.27***	-0.19	-0.18	-0.17	0.01	-0.13	0.06
5000 m	0.01	-0.08	**0.31***	-0.01	0.01	0.08	**-0.32****	-0.15	**-0.36****	**-0.41****	0.08	-0.07	0.17

Notes: Significant correlation at 0.01 level were labeled with ** ($p < 0.01$), those at 0.05 level were labeled with * ($p < 0.05$). Correlation coefficient insignificant ($p > 0.05$) was labeled without *.

Table S6 Descriptive statistics of 2D building indicators.

Buffer	PD		PLAND		LPI		MPS		PSSD		MSI		CONTAG	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100 m	4.632	3.518	22.882	14.100	7.748	12.249	0.108	0.351	0.067	0.092	1.377	0.386	52.040	24.628
300 m	3.813	2.714	22.040	10.614	2.564	2.986	0.077	0.061	0.118	0.140	1.401	0.216	65.449	18.788
500 m	3.450	2.196	12.894	8.494	1.280	1.237	0.079	0.059	0.120	0.124	1.424	0.105	69.752	16.664
1000 m	3.109	1.784	14.108	8.043	0.640	0.482	0.076	0.042	0.139	0.124	1.418	0.084	75.517	11.426
2000 m	2.828	1.438	18.436	6.190	0.314	0.222	0.076	0.034	0.159	0.114	1.418	0.070	78.833	5.718
3000 m	2.690	1.347	17.759	5.878	0.178	0.099	0.076	0.033	0.163	0.102	1.420	0.066	79.824	5.330
4000 m	2.546	1.243	16.985	5.480	0.129	0.076	0.076	0.030	0.170	0.093	1.416	0.062	80.748	4.926
5000 m	2.388	1.122	14.718	6.526	0.098	0.056	0.077	0.031	0.177	0.097	1.415	0.059	81.530	4.701

Table S7 Descriptive statistics of 3D building indicators.

Buffer	AH		BHD		BHR		BVD		BO		HBI	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
100 m	13.577	8.744	0.011	0.013	24.537	21.206	0.134	0.122	0.470	0.253	0.133	0.096
300 m	14.539	6.789	0.008	0.006	52.030	31.310	0.069	0.043	0.672	0.275	0.038	0.040
500 m	14.675	6.765	0.007	0.004	63.851	30.979	0.050	0.028	0.733	0.246	0.017	0.014
1000 m	14.459	5.951	0.007	0.004	76.836	34.692	0.041	0.020	0.989	0.366	0.010	0.011
2000 m	14.237	5.692	0.006	0.004	110.821	42.110	0.025	0.010	0.902	0.200	0.002	0.001
3000 m	14.099	5.169	0.006	0.004	131.597	53.039	0.021	0.009	0.946	0.185	0.001	0.001
4000 m	13.916	4.463	0.005	0.003	141.179	58.996	0.018	0.007	1.145	0.264	0.001	0.000
5000 m	13.640	3.931	0.004	0.002	141.403	61.235	0.015	0.007	1.151	0.265	0.001	0.002

Table S8 The 2D and 3D indicators within 5000 m in different cities.

City	PD	PLAND	LPI	MPS	PSSD	MSI	CONTAG	AH	BHD	BHR	BVD	BO	HBI
Hangzhou	1.72	15.14	0.09	0.09	0.17	1.40	82.44	15.45	4.00E-03	129.00	0.02	1.03	4.50E-04
Hefei	1.62	15.59	0.11	0.12	0.30	1.40	82.88	18.09	4.00E-03	114.67	0.02	1.31	5.33E-04
Jiaxing	1.62	16.15	0.12	0.08	0.21	1.38	83.72	12.32	3.00E-03	97.50	0.02	1.25	4.50E-04
Jinhua	2.04	15.93	0.09	0.07	0.16	1.38	83.79	12.62	4.00E-03	117.00	0.02	1.29	4.50E-04
Nanjing	2.78	16.16	0.07	0.06	0.13	1.50	81.07	12.51	1.00E-03	93.86	0.01	1.10	3.83E-03
Nantong	3.80	15.81	0.06	0.05	0.13	1.40	82.05	9.88	4.00E-03	167.00	0.01	1.20	5.67E-04
Ningbo	1.65	17.37	0.11	0.10	0.24	1.46	81.15	16.01	3.00E-03	139.50	0.02	1.48	5.50E-04
Shanghai	2.83	19.58	0.10	0.07	0.14	1.48	78.00	17.36	7.00E-03	228.38	0.02	0.84	5.00E-04
Shaoxing	1.94	13.56	0.05	0.07	0.14	1.29	81.86	10.42	2.00E-03	87.00	0.01	1.33	8.00E-04
Suzhou	2.94	18.78	0.10	0.07	0.15	1.36	79.93	10.49	4.00E-03	146.63	0.02	1.03	5.00E-04
Taizhou	1.69	13.53	0.08	0.08	0.18	1.32	85.11	13.96	3.00E-03	177.00	0.01	1.53	9.00E-04
Wenzhou	2.01	15.67	0.05	0.08	0.12	1.44	81.18	13.76	5.00E-03	175.00	0.02	1.14	4.33E-04
Wuxi	3.03	16.60	0.10	0.06	0.14	1.42	82.21	11.36	4.00E-03	141.00	0.02	1.44	5.00E-04
Wuhu	1.72	15.14	0.09	0.09	0.17	1.40	82.44	13.75	4.00E-03	129.00	0.02	1.03	4.50E-04
Xuzhou	1.62	15.59	0.11	0.12	0.30	1.40	82.88	8.74	4.00E-03	114.67	0.02	1.31	5.33E-04
Yangzhou	1.62	16.15	0.12	0.08	0.21	1.38	83.72	10.80	3.00E-03	97.50	0.02	1.25	4.50E-04

Table S9 The results of regression analysis of $PM_{2.5}$ concentrations and two-dimensional landscape

Time	Variables	Estimate	Std. Error	Adjusted SE	Z	P	Relative Importance
Annual	Intercept	82.144	26.780	27.081	3.033	0.002	—
	PSSD100	5.907	2.534	2.582	2.287	0.022	1
	LPI500	1.629	0.682	0.696	2.341	0.019	1
	CONTAG1000	-0.148	0.071	0.072	2.050	0.040	1
	MSI5000	-29.964	15.286	15.593	1.922	0.055	0.75
	SHDI100	-7.366	3.596	3.668	2.008	0.045	0.79
Spring	Intercept	64.938	16.574	16.786	3.869	< 0.001	—
	PSSD100	5.531	2.205	2.249	2.459	0.014	1
	LPI4000	26.402	9.816	10.011	2.637	0.008	1
	CONTAG1000	-0.213	0.064	0.065	3.264	0.001	1
	SHDI100	-8.223	3.234	3.298	2.493	0.013	1
	MSI5000	-14.868	13.982	14.265	1.042	0.297	0.35
Summer	Intercept	24.081	1.508	1.530	15.741	< 0.001	—
	PSSD100	2.378	1.409	1.434	1.658	0.097	0.55
	LPI5000	17.584	8.532	8.690	2.024	0.043	0.81
	CONTAG100	0.029	0.020	0.020	1.435	0.151	0.53
	SHDI100	-2.773	2.174	2.216	1.251	0.211	0.13
Autumn	Intercept	67.315	27.367	27.628	2.436	0.015	—
	PSSD100	7.914	2.426	2.473	3.200	0.001	1
	LPI500	1.568	0.673	0.687	2.284	0.022	1
	CONTAG1000	-0.141	0.070	0.071	1.987	0.047	1
	MSI5000	-29.203	15.183	15.485	1.886	0.059	0.68
Winter	Intercept	179.858	45.483	46.300	3.885	< 0.001	—
	LPI500	3.803	1.363	1.388	2.739	0.006	1
	CONTAG1000	-0.209	0.139	0.141	1.478	0.139	0.50
	MSI5000	-79.312	30.067	30.657	2.587	0.010	1
	SHDI100	-13.979	7.086	7.219	1.936	0.053	0.76
	PSSD100	8.389	4.966	5.059	1.658	0.097	0.63

Table S10 The results of regression analysis of $PM_{2.5}$ concentrations and three-dimensional landscape

Time	Variables	Estimate	Std. Error	Adjusted SE	Z	P	Relative Importance
Annual	Intercept	41.417	2.378	2.412	17.168	< 0.001	—
	BHD100	153.487	84.951	86.626	1.772	0.076	0.63
	BHR100	-0.142	0.049	0.050	2.824	0.005	1
	HBI100	38.061	10.209	10.376	3.668	< 0.001	1
	AH500	-0.167	0.124	0.127	1.315	0.188	0.44
Spring	Intercept	49.198	2.715	2.760	17.823	< 0.001	—
	AH2000	-0.340	0.148	0.151	2.257	0.024	1
	BHR100	-0.096	0.044	0.045	2.132	0.033	0.65
	HBI100	28.488	8.368	8.529	3.340	< 0.001	1
	BVD100	-8.580	6.670	6.802	1.261	0.207	0.37
	BO100	-6.910	4.164	4.226	1.635	0.102	0.47
Summer	Intercept	21.622	2.392	2.426	8.913	< 0.001	—
	BHD1000	241.884	139.003	141.756	1.706	0.088	0.68
	BHR3000	-0.037	0.010	0.011	3.499	< 0.001	1
	BO3000	4.689	2.370	2.417	1.940	0.052	0.80
	HBI500	122.274	39.211	39.812	3.071	0.002	1
Autumn	Intercept	36.571	3.338	3.379	10.823	< 0.001	—
	AH4000	-0.355	0.177	0.181	1.969	0.049	0.71
	BHD100	182.600	82.533	84.168	2.169	0.030	1
	BHR100	-0.164	0.045	0.046	3.567	< 0.001	1
	HBI100	45.487	9.414	9.601	4.738	< 0.001	1
Winter	Intercept	71.153	6.107	6.196	11.483	< 0.001	—
	BHR5000	-0.075	0.026	0.027	2.769	0.006	1
	BO100	-10.275	6.339	6.464	1.590	0.112	0.55
	HBI100	64.177	17.071	17.399	3.689	< 0.001	1
	AH2000	-0.409	0.284	0.290	1.410	0.158	0.48

Table S11 The regression model for $PM_{2.5}$ concentrations in small and large cities

size	Variables	Estimate	Std. Error	t	P	Contribution. Per (%)
Small cities	Intercept	71.851	52.615	1.365	0.180	—
	BHR100	-0.113	0.097	-1.163	0.261	19.13
	HBI100	29.933	14.307	2.091	0.051	57.42
	CONTAG1000	-0.113	0.096	-1.169	0.258	22.24
	SHAPE_MN5000	-14.307	37.743	-0.379	0.709	1.21
Large cities	Intercept	75.081	22.028	3.408	0.001	—
	BHR100	-0.062	0.031	-2.035	0.048	44.42
	HBI100	13.015	8.491	1.533	0.133	23.93
	CONTAG1000	-0.065	0.097	-0.671	0.506	0.74
	SHAPE_MN5000	-19.647	13.368	-1.470	0.149	30.92