PLEA SANTIAGO 2022
Will Cities Survive?

The Impact of Urban Forms on Psychological Restoration and Bioclimatic Performance in High-density Neighbourhoods

An Integrated Analysis in Shanghai

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ABSTRACT: This article presented an integrated study of the impact of urban form on the psychological restoration and the bioclimatic performance in high-density neighbourhoods in Shanghai. 24 typical urban layouts in Shanghai residential areas were studied in terms of the built period, location, and several architectural characteristics. First, a psychological experiment was conducted among 90 participants to test their responses to the visual stimuli of these urban layouts. Seven psychological variables were used including Restoration Likelihood, Familiarity, Complexity, Enclosure, Being Away, Fascination and Preference. A multiple mediation analysis can show that there were significant effects of urban form on restoration likelihood and preference, while these effects were partially or fully mediated by other psychological variables (e.g., familiarity, complexity, being-away). Second, the bioclimatic performance of these urban forms can be indicated via an analysis of Sky View Factor, which was achieved using Radiance simulation. It can be found that there was positive correlation between the Sky View Factor and the canyon width/height. Finally, it could be worth noting that improving the bioclimatic performance in these urban forms would benefit their psychological restoration. This integrated analysis was proved as an innovative approach to achieve a psychologically and physically sustainable urban development.
KEYWORDS: Urban Form, Psychological Restoration, Bioclimatic City, High-density Neighbourhood, Shanghai

1. INTRODUCTION

A rapidly growing urbanization combined with climate change has given rise to profound environmental problems in cities, such as land use shortage, urban heat island, energy crisis, air and noise pollutions, waste disposal, and relevant public health issues [1]. These are still the big challenges faced by municipalities and urban planners today.

As for the health issues, the urban design for mental health and wellbeing is being recognized as a new research focus in urban studies [2, 3], especially with the current situation of COVID-19 pandemic [1]. This research topic targets to inspire, motivate, and empower policymakers and practitioners to build mental health into their urban planning projects for a healthier, happier urban future [2]. Urban form, the key design issue in urban planning, refers to the main physical elements that structure and shape the city including streets, public spaces, street blocks, plots, and buildings [4]. It has been preliminarily noticed that there is influence of urban streets and buildings on environmental determinants of the public health (e.g., walkability) [3, 5]. However, it is still not fully understood how concrete configurations of specific urban form can impact on residents' mental health [5]. A psychological study has preliminarily exposed the opportunities to improve restorative quality of streetscapes in a low-density residential area [6], while a practical approach to investigate visual properties and affective appraisals in residential areas with only houses was produced [7]. It would be useful to further test the achieved findings from these studies [6, 7] in a highly dense urban neighbourhood (e.g., high-rise buildings in some mega cities in Asia).

On the other hand, the bioclimatic urban design has been well studied over 30 years, which generally focuses on the assessment of climatic implications of various physical structures of the city, such as street orientation, canyon height-to-width ratio, building density, and street shading [8, 9]. As mentioned in one study [9], the human thermal stress influenced by the urban form is the typical topic studied in this field. Depended on the urban form, the Sky View Factor can indicate that how much the urban area is shielded from the sky, which would response to the human thermal comfort and heat stress [9]. Studies in several cities have proved that the Sky View Factor had a linear relationship with urban heat island intensities [10, 11]. This has exposed a practical method to figure out the relationship between urban form and urban heat island effect in a high-density city.

This article presented an integrated study of the effect of urban form on the impact of urban form on the psychological restoration (linked to the potential to improve mental health) and the bioclimatic

performance in high density residential neighbourhoods in Shanghai. 24 typical urban layouts were studied in terms of location, built period, and other characteristics. A psychological experiment was conducted to test their restoration likelihood and preference, while the bioclimatic analysis was achieved using the simulation. This integrated analysis can be applied as an innovative way to achieve a sustainable urban development.

2. METHODS AND MATERIALS

Three various methods are presented in this section, including urban layout, psychological experiment, and bioclimatic analysis.

2.1 Urban residential layouts studied

This article selected 24 typical urban layouts in residential areas of Shanghai, with their characteristics and rendering images given in Table 1 & Figure 1, respectively. These layouts were first chosen as representatives in terms of the period when they were built, such as No.1 (1950s), No.4 (1960s), No.7 (1980s), No.11 (1990s), No.16 (2000s), No.20 (2010s), etc. These layouts were numbered according to their built periods. In addition, their locations were considered as another factor for this selection, varying in the distance to the centre of Shanghai city (e.g. Renmin square).

Table 1: Characteristics of 24 urban residential layouts.

No.	Built Period	Height (m)	Floor-Area-Ratio	Building-Coverage-Ratio	Canyon width/ height ratio
1	1950-1955	9	1.11	0.37	1
2	1955-1960	15	1.40	0.28	1.47
3	1955-1960	12	1.08	0.27	1.33
4	1960-1970	18	1.68	0.28	0.5
5	1970-1980	42	2.52	0.18	0.31
6	1980-1985	18	1.14	0.19	0.56
7	1980-1985	42	2.38	0.17	0.31
8	1985-1990	18	1.38	0.23	1.3
9	1985-1990	18	1.14	0.19	0.94
10	1985-1990	18	1.20	0.20	1.2
11	1990-1995	18	1.44	0.24	1.11
12	1990-1996	18	1.14	0.19	0.54
13	1995-2000	15	1.40	0.28	1
14	1995-2000	30	1.60	0.16	2
15	2000-2005	54	2.88	0.16	0.44
16	2000-2005	69	4.31	0.17	1.39
17	2000-2005	15	1.65	0.33	1.2
18	2005-2010	72	2.40	0.10	0.21
19	2005-2010	45	2.40	0.16	1.16
20	2010-2015	93	3.72	0.12	0.29
21	2015-2020	96	4.48	0.14	0.4
22	2015-2020	60	2.80	0.14	0.55
23	2015-2020	21	1.88	0.29	1.05
24	2015-2020	51	2.67	0.30	0.82

Four characteristics of these urban residential layouts [12] can be found as building height, floor-area-ratio (FAR), building-coverage-ratio and canyon width/height ratio (Table 1). Three types of residential layouts were studied in terms of building height [12] as: high-rise buildings (> 27 m), mid-rise buildings (> 10 m and ≤27 m), low-rise buildings (< 10 m). Mid-rise buildings were applied in half urban layouts (12), while only one layout (No. 1) used the low-rise building. Over 50% of the layouts had a FAR < 2.0 and the building coverage ratios of most layouts were < 0.30 (22). As for the canyon width/height ratio, half layouts had a value < 1.0.

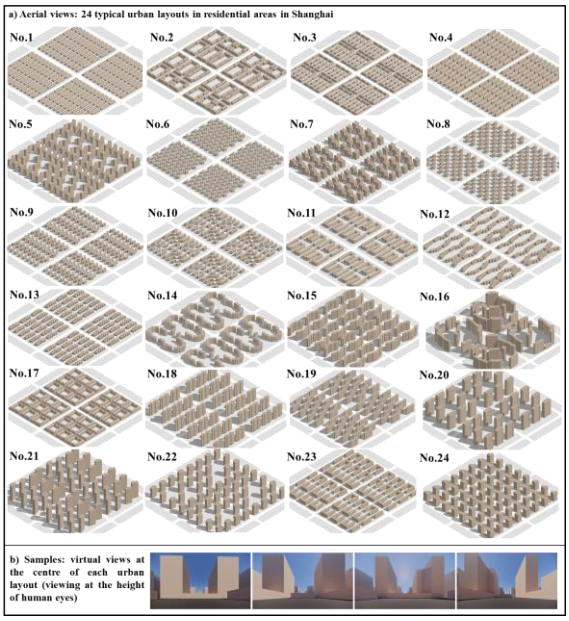

Figure 1: 24 typical urban residential layouts studied (a); samples of virtual view at the centre of one layout (b).

As shown in Figure 1, two types of virtual images of the 24 layouts were produced as the visual stimuli used in this study. Figure 1 (a) shows aerial views of these urban residential layouts, while figure 1 (b) presents samples of views at the centre of one layout. From 1950s to 2010s, there were three main types of urban form in these residential neighbourhoods: slab, enclosed and tower. In 1950s, most residential buildings were slabs and enclosed blocks. From 1960s to 1980s, the slab type was the main form. Some complex slab types can be found, such as serrated (No. 9) and curved types (No. 10). The types of urban form varied from 1990s to early 2000s, including slab, semi-enclosed, and complex enclosed types. Since 2000, no big changes can be found between the types of urban form applied in Shanghai high-density neighbourhoods. The most common types applied in this period were the high-rise slab and the high-rise tower. Over the 70 years, the urban form in Shanghai high-density neighbourhood has evolved from the simple models to the more complex models.

2.2 Psychological experiment

A psychological experiment was implemented to test human responses to the 24 urban forms (Table 1 & Figure 1). Seven psychological variables tested for each urban layout were: 1) Restoration Likelihood [6] ('Imagine that you are walking alone in this

neighbourhood. You are mentally tired from intense concentration at work, and you appreciate having a chance to stroll and recover before you have to go home to solve various matters. how do you feel ?'); 2) Familiarity [7, 13, 15] ('how you are familiar with this layout'); 3) Complexity [6, 7] ('how complex is this layout'); 4) Enclosure [6, 13, 14] ('how open is this layout'); 5) Restoration – Being Away [6, 15] ('how do you feel relaxed when living in this neighbourhood'); 6) Restoration – Fascination [6]: ('how do you feel relaxed when living in this neighbourhood'); 7) Preference [6, 14, 16]: ('how do you like this neighbourhood'). Each question was to be rated with an 11-point scale (0 = not at all, 10 = completely).

A total of 90 participants (age: 19.81±1.65) was recruited from a university in Shanghai to attend the psychological test. For each layout displayed by two types of visual stimuli (Figure 1. a & b). Participants were first asked to rate on the seven variables. After rating on all 24 layouts, they have completed a questionnaire to collect their background information, including demographics, and socioeconomics.

2.3 Bioclimatic analysis: Sky View Factor

For the bioclimatic analysis in an urban area, the Sky View Factor (SVF) was adopted as an indicator of urban heat island effect and human thermal stress [10, 11]. SVF can reflect the amount of sky that can be seen from the ground in an urban area and was also found to be correlated to the formation of urban heat island effect [10]. Several studies [10, 11] have found there is a linear relationship between SVF and urban heat island effect as follows:

$$UHI_{max} = a - b*SVF \quad (1)$$

Where, UHImax – maximum urban heat island (◦C); SV*F* – sky view factor; *a* – constant, relating to the climate condition at the location [10, 11]; *b* – constant, relating to the vegetation and climate condition at the location [11]. Thus, at a specific location, an increasing SVF can indicate a decreasing trend of the maximum urban heat island effect.

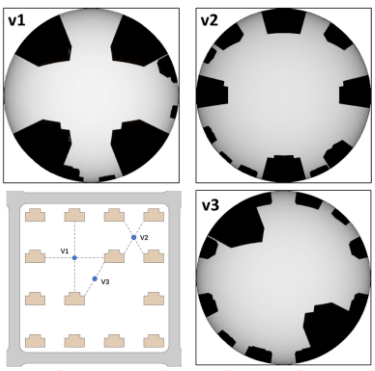

Figure 2: Radiance rendering hemispheric images used for SVF analysis in an urban layout (example: Model 22).

In this article, the urban heat island effect was not analysed directly, but the SVF values in various urban models were calculated using a method based on Radiance simulation under the uniform sky [17]. For each urban layout (Figure 1), typical positions were defined according to street orientation, canyon height-to-width ratio, building density. The SVF was calculated at each position and thus an average value was achieved based on these positions. The average SVF was used as a representative of this urban layout. Figure 2 presents a sample of SVF analysis of urban layout No. 22.

3. RESULTS

3.1 Psychological restoration: effect of urban form

Figure 3 displays the mean scores of restoration likelihood of the 24 urban layouts.

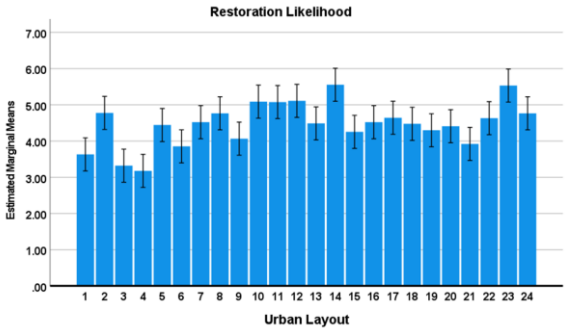

Figure 3: Mean scores of restoration likelihood on 24 urban layouts.

It can be found that the layouts 10, 11, 12, 14, and 23 can deliver a higher score of restoration likelihood (> 5.0), while the lower scores are for the layouts 1, 3, 4, 6 and 21. The highest scores are found at the layouts 14 and 23, which are contemporary enclosed type. Three layouts (No.1, 3 & 4) have the lowest scores than the other 21 layouts, two of which are simple slabs in the period of 1950 -- 1970. For the 12 layouts (No.2, 7, 8, 10 ,11, 12, 14, 16, 17, 18, 23, 24) with higher scores, eight are enclosed or semi-enclosed layouts. It seems that the enclosed layout can receive a relatively higher restoration likelihood than other urban forms.

A multiple mediation analysis of the effect of urban form on the restoration likelihood is displayed in Table 2 & Table 3. In Table 2, Model1 shows that the urban form has a significant predicting role for the restoration likelihood ($\beta = 0.0361$, $p < 0.01$), while several covariables also express similar effects, including age and gender, and three housing conditions (height, floor, and size) ($p < 0.05$). When five psychological variables (familiarity, complexity, enclosure, being away and fascination) are added into the regression (Model2), the predicting effect of urban form can be still found as significant ($\beta = -0.0141$, $p < 0.01$). However, this effect has been clearly reduced. Except for the gender, covariables have the significant predicting effect. The variables in Model 2 can explain 63.34% of the variance in restoration likelihood.

Table 2: Multiple regression analysis with Restoration Likelihood as outcome variable.

	Model1		Model2	
Predictors	B	β	B	β
Constant	8.8642		0.4308	
Age	-0.2828	-0.2092**	-0.0765	-0.0566**
Gender	-0.1934	-0.0426*	0.1105	0.0243
Hometown	-0.0216	-0.0130	-0.0579	-0.0348*
Housing_status	-0.1411	-0.0093	0.5828	0.0385**
Housing_height	-0.1957	-0.1212**	-0.0845	-0.0523**
Housing_floor	0.1792	0.0961**	0.0986	0.0528**
Housing_size	0.4786	0.1173**	0.2570	0.0630**
Urban_form	**0.0361**	**0.1119****	**-0.0141**	**-0.0438****
Familiarity			0.1079	0.1290**
Complexity			0.1268	0.1257**
Enclosure			0.1040	0.1013**
Being_Away			0.4652	0.4630**
Fascination			0.1353	0.1526**
R^2		*0.0763*		*0.6334*

*Significant: * p<0.05; ** p<0.01*

In addition, the indirect effects of the association between urban form and restoration likelihood were estimated using 5000 bootstrapped sample with the 95% bias-corrected confidence interval (Table 3). Clearly, there are partial mediating effects found at Familiarity (0.0032 0.0097), Complexity (0.0019 0.0082), Enclosure (0.0026 0.0103), Being_Away (0.0106 0.0263), and Fascination (0.0034 0.0133).

Table 3: Indirect effects of the association between urban form and restoration likelihood, through five variables.

		Bias corrected 95% Confidence Interval	
	Effect	Lower	Higher
Total	0.0502	0.0396	0.0609
Familiarity	0.0045	**0.0025**	**0.0068**
Complexity	0.0047	**0.0025**	**0.0074**
Enclosure	0.0068	**0.0031**	**0.0108**
Being_Away	0.0260	**0.0190**	**0.0338**
Fascination	0.0083	**0.0044**	**0.0126**

3.2 Psychological preference: effect of urban form

Figure 4 shows the mean scores of preference on the 24 urban layouts.

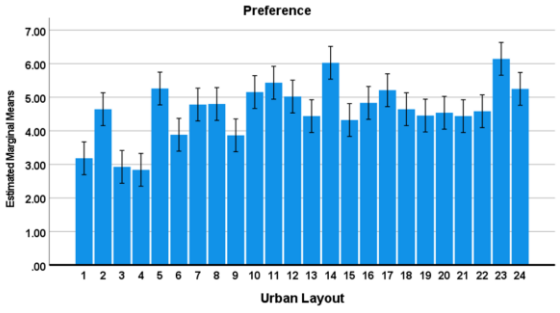

Figure 4: Mean scores of preference on 24 urban layouts.

It can be seen from Figure 4 that the layouts 14 & 23 have the highest scores of preference (≥ 6.0) while the layouts 1, 3 & 4 can receive the least preference (< 3.2). The layouts 5, 10, 11, 12, 17, 24 are still found with a higher preference score (> 5.0). In addition, other 13 layouts have a medium preference score (> 3.5 and < 5.0). For the layouts with high preference (No.5, 10, 11, 12, 14, 17, 23, 24), the enclosed or semi-enclosed types are applied.

Table 4 & 5 indicate a multiple mediation analysis of the effect of urban form on the preference.

Table 4: Multiple regression analysis with Preference as outcome variable.

	Model1		Model2	
Predictors	B	β	B	β
Constant	10.0423		-0.0756	
Age	-0.2332	-0.1575**	0.0166	0.0112
Gender	-0.3350	-0.0674**	0.0463	0.0093
Hometown	0.0821	0.0450*	0.0310	0.0170
Housing_status	-1.3708	-0.0826**	-0.3535	-0.0213*
Housing_height	-0.1160	-0.0656*	-0.0097	-0.0055
Housing_floor	0.0367	0.0180	0.0020	0.0010
Housing_size	0.1066	0.0239	-0.0768	-0.0172
Urban_form	**0.0610**	**0.1726****	**0.0027**	**0.0076**
Familiarity			0.4954	0.0935**
Complexity			-0.0367	-0.0332**
Enclosure			-0.0259	-0.0230
Being_Away			0.4946	0.4494**
Fascination			0.4954	0.5102**
R^2		*0.0728*		*0.8052*

*Significant: * p<0.05; ** p<0.01*

In Table 4, it can be found in Model1 shows that the urban form has a significantly positive predicting effect on the preference (β = 0.1726, p < 0.01). The significant predicting role is also found at age, gender, hometown and two housing conditions (p < 0.01). When five psychological variables (familiarity, complexity, enclosure, being away and fascination) enter the regression (Model2), the predicting effect of urban form tends to be insignificant (β = 0.0076, p > 0.05). For the covariables, only the effect of house status is significant (p < 0.05). The variables in Model1 can only explain 7.28% of the variance in the preference.

Table 5: Indirect effects of the association between urban form and preference, through five variables.

		Bias corrected 95% Confidence Interval	
	Effect	Lower	Higher
Total	0.0583	0.0453	0.0719
Familiarity	0.0035	**0.0020**	**0.0054**
Complexity	-0.0014	**-0.0028**	**-0.0001**
Enclosure	-0.0017	-0.0045	0.0011
Being_Away	0.0276	**0.0203**	**0.0357**
Fascination	0.0302	**0.0222**	**0.0387**

Table 5 gives the indirect effects of the five mediators, which were estimated using 5000 bootstrapped sample with the 95% bias-corrected confidence interval. The Enclosure cannot deliver significant effect (-0.0045 0.0011), while other variables have significant effects: Familiarity (0.0020 0.0054), Complexity (-0.0028 -0.0001), Being_Away (0.0203 0.0357), and Fascination (0.0222 0.0387).

3.3 Sky View Factor and urban form

Figure 5 indicates the SVF values of the 24 urban models, calculated using Radiance simulation [17].

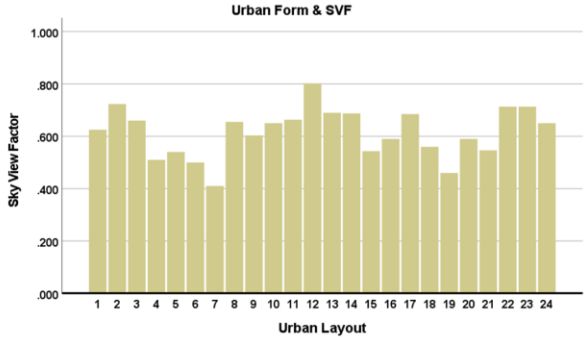

Figure 5: Variation of SVF of 24 urban layouts.

It can be found the distribution of SVF as: low SVF (< 0.5), urban model 7 & 19; medium SVF (> 0.5 and < 0.7), urban model 1, 3, 4, 5, 6, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 20, 21, 24; high SVF (> 0.7), urban model 2, 12, 22, 23. Most urban models (18) have the medium SVF, while only two and four models can see the low and high SVF values, respectively.

Table 6: Correlation matrix of five characteristics of 24 urban layouts (Pearson correlation, 2-tailed).

	Building Height (m)	Floor-Area-Ratio	Building-Coverage-Ratio	Canyon width/height ratio	SVF
1	1	0.932**	-0.696**	-0.485*	-0.353
2		1	-0.528**	-0.364	-0.351
3			1	0.387	0.361
4				1	0.451*
5					1

Significant correlation: ** p<0.01, * p<0.05

Table 6 gives the correlation analysis of five characteristics of 24 urban forms, including building height, floor-area-ratio, building-coverage-ratio, canyon width/height ratio, and SVF. SVF can significantly correlate with the canyon width/height ratio ($r = 0.451$, $p < 0.05$), but not other four values ($p > 0.05$).

3.4 Correlation: psychological performances and SVF

Table 7 shows the correlation analysis of SVF, restoration likelihood, and preference.

Table 7: Correlation matrix: restoration likelihood, preference and SVF (Pearson correlation, 2-tailed).

	Restoration Likelihood	Preference	SVF
1	1		
2	0.708**	1	
3	0.135**	0.113**	1

Significant correlation: ** p<0.01, * p<0.05

Apparently, the positive correlations can be found between the three values: SVF & Restoration Likelihood ($r = 0.135$, $p < 0.01$), SVF & Preference ($r = 0.113$, $p < 0.01$). Thus, a higher SVF would deliver higher scores of restoration likelihood and preference, particularly for the layouts of 12, 14, 23.

4. DISCUSSIONS AND CONCLUSIONS

This article shows that the urban form has significant effects on psychological performance (psychological restoration & visual preference) and bioclimatic performance (SVF) in 24 high-density neighbourhoods in Shanghai.

4.1 Psychological effects of urban form

First, the evidence achieved from this study can well support that there is the association between urban form, and psychological restoration and visual preference in terms of these typical urban layouts. This association has been clearly exposed in one study in low-rise residential buildings [6] and another study with general urban settings [14]. This study [6] concluded that urban residential areas with higher levels of architectural variation and lower building height have been proved to be more restorative. In the present study, we found similar trend that the higher SVF (a larger sky view) and complex layout types would lead to higher restoration likelihood. In addition, the positive correlation between SVF or larger sky view and preference can be considered to agree with the key findings [6].

Second, the effects of urban form on restoration likelihood and preference can be partially or fully mediated by relevant visual properties and affective appraisal (familiarity, complexity, enclosure) and restorative items (being_away and fascination). The mediation effect of being away and fascination has been well exposed for the relationship between physical factors of residential buildings and restoration potential [6]. The positive effects of being away and fascination on the preference were also in line with the findings of several studies [6, 14, 18].

4.2 Bioclimatic effects of urban form

It is normally found that SVF positively correlates with the canyon width/height ratio in these typical urban layouts. An urban neighbourhood with a larger canyon width/height ratio will have a bigger average SVF, indicating that there would be a lower maximum urban heat island effect [8, 9]. Thus, the canyon width/height ratio can take direct effect on the thermal comfort condition for residents in dense urban neighbourhoods, as mentioned in a study [8]. In urban design, the canyon width/height ratio can be regarded as a useful physical feature according to the aim to create comfortable thermal environment in a high-density residential area.

4.3 Urban form: an integrated analysis

Given the discussions in section 4.1 & 4.2, it can be found that there is a link between the physical and

psychological performances in these high-density urban areas, both of which receive effects of configurations of urban form. It could be worth noting that improving the bioclimatic performance (e.g. Sky View Factor) according to the optimization of urban form will directly benefit the psychological performance (e.g. psychological restoration).

However, in an urban area, only the green space or green infrastructure has been broadly investigated in terms of its impact on the health and wellbeing (e.g. mental, physiological), and the physical environmental performance (e.g. noise, air pollution, heat reduction) [19]. It is necessary to promote more studies into the effect of urban form, especially for the psychological performance (mental health).

4.4 Research limitations

For the psychological experiment, the method of rendering images enabled the creation of highly realistic urban environments, in combination with the systematic manipulation of independent variables and control for confounding variables [16]. However, for such complex urban neighbourhoods, the application of rendering image (2D) may still need a further validation.

The participants to attend the psychological experiment were recruited from current university students, which may have brought in limited sample diversities in age and socioeconomic status. It cannot be denied that there might be some divergence of psychological responses between students and other groups (e.g., professionals).

The 24 urban layouts used in this study were achieved based on current situation of Shanghai city and some available literatures. They might not be able to fully cover all possible typical urban forms found in the urban area of Shanghai.

4.5 Future work

Further studies will be carried out to test more possible urban forms and apply more psychological variables relevant to mental health problems in high-density neighbourhoods with various locations and socioeconomic statuses. To improve the participants' experiences during the experiment, the use of a complex audio-visual system could be considered at the next stage. In addition, the diversity in research participation would be enhanced through the applications of various recruitment approaches.

ACKNOWLEDGEMENTS

The authors thank NSFC (National Natural Science Foundation of China) for the funding support through a research project (Grant No. 51778438).

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