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Abstract

Background: Cycling is known to be beneficial for human health. Studies have suggested significant associations of physical activity with macroscale built environment and microscale streetscapes. However, it remains unknown whether good streetscapes can amplify the benefits of favourable built environment.

Methods: This study examines the moderation roles of streetscape perceptions on the effects of land use mix and accessibility on cycling, using data from18,019,266 bike-sharing orders during weekends in Shanghai, China. Street-view images and a human–machine adversarial scoring system, was combined to evaluate lively, safety and wealthy perceptions.

Results: Negative Binomial Regression results showed that there were significant interactions of the land use Herfindahl–Hirschman index with each of the lively and safety streetscape perceptions, while lively perception also positively moderated the effect of road intersection density on the number of bike-sharing. Moreover, lively perception emerged as the most influential moderator among the three perceptual indicators, which is different from the findings of Western studies. The findings are robust in the three sensitivity analyses.

Conclusions: A safer and livelier streetscape can enhance the benefits of land use mix in promoting cycling, with the former also intensifying the effect of accessibility. The findings have dual implications. To better promote cycling, it is key to conduct interventions on streetscape perceptions, which can indirectly affect physical activity by enhancing the benefits of accessibility and land use mix. As a complement of built environment at macroscale, streetscape interventions are usually more timely and feasible than interventions targeting urban form.

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Moderation effects of streetscape perceptions on the associations between accessibility, land use mix and bike-sharing usage: Cross-sectional study

Abstract

Background: Cycling is known to be beneficial for human health. Studies have suggested significant associations of physical activity with macroscale built environment and streetscapes. However, it remains unknown whether good streetscapes can amplify the benefits of favorable built environment to physical activity.
Objectives: This study aims to examine whether streetscape perceptions can modify the associations between accessibility, land use mix and bike-sharing usage.
Methods: This cross-sectional study used data from 18,019,266 bike-sharing orders during weekends in Shanghai, China. A 500×500m grid is selected as the analysis unit to allocate data. Bike-sharing usage is defined as the number of bike-sharing origins. Street-view images and a human–machine adversarial scoring framework, was combined to evaluate lively, safety and wealthy perceptions. Negative Binomial Regression was developed to examine independent effects of the three perceptual factors in both the univariate model and fully adjusted model, controlling for population density, average building height, distance to nearest transit, number of bus stations, number of POIs, distance to the nearest park and distance to CBD. Then, the moderation effect was investigated through the interaction term between streetscape perception and accessibility and land use mix, based on the fully adjusted model. We also tested whether the findings of streetscape moderation effects are robust, when examinations are performed at different geographic scales, using a small-sample statistics approach, and utilizing different operationalization of land use mix and accessibility.
Results: High levels of lively, safety and wealthy perceptions were correlated with more bike-sharing activities. There were negative effects of the interactions between land use Herfindahl–Hirschman index with each of lively perception (β=−.63; *P*=.013) and safety perception (β=−.52; *P*=.001). The interaction between lively perception and road intersection density, was positively associated with the number of bike-sharing usage (β=.43; *P*=.078). Among this, lively perception showed the greatest independent effect (β=1.29; *P*<.001), followed by safety perception (β=1.22; *P*=.001), and then wealthy perception (β=.72; *P*=.001). The findings were robust in the three sensitivity analyses.
Conclusions: A safer and livelier streetscape can enhance the benefits of land use mix in promoting bike-sharing usage, with a safer streetscape also intensifying the effect of accessibility. The findings highlight that to better promote cycling, it is key to conduct interventions on streetscape perceptions, which can promote cycling behavior and enhance the benefits of accessibility and land use mix as well. The present study also contributes to the literature on potential moderators of built environment-healthy behavior associations from the perspective of microscale environmental perception.

Keywords
Built environment; Streetscape perceptions; Bike-sharing usage; Moderation effect; China

Introduction

A number of studies have demonstrated that favorable built environment can promote walking and bike-sharing usage, particularly in Chinese cities [1; 2; 3]. However, findings on the effects of built environment are usually mixed [4; 5; 6]. One potential explanation is that there may be interactions between built environments at different levels, including the moderation effects of streetscape perceptions [7; 8]. An in-depth understanding of streetscape perceptions as moderators, is not only an important methodological issue for environment-health research [9], but also informative for creating effective interventions in built environment. Despite some efforts [10; 11], however, it remains unclear whether and to what extent good perceptions of streetscapes can enhance the benefits of favorable built environment.

The Ecological Model of Physical Activity provides a theoretical foundation for streetscape moderation effects. According to this model, one's cycling behavior is determined by factors across multiple levels [9]. Such behavior is shaped by interactions among indicators at different levels [9]. Moreover, understanding the benefits of streetscapes in promoting health is highly important. Firstly, microscale streetscapes provide numerous benefits to people's physical activity [11; 12; 13]. Secondly, the built environment at the neighborhood level has essentially been established and fixed over time, while streets have become a key focus of high-quality urban development in the Era of Inventory Planning, particularly in Chinese cities.

However, little attention has been given to the moderation effects of streetscapes [14; 8; 15]. Furthermore, most studies examining environmental perception as moderators, focus on perceived safety [16; 17; 18], while little attention has been paid to other perceived aspects. Moreover, streetscapes as potential moderators, were usually examined from the objective side [10; 8], but less understood from a perceptual perspective. It is reported that residents' safety perceptions are more likely to be correlated with physical activity [8; 19], especially for those who do not perceive threats from neighborhoods with high crime rates. However, of studies exploring environmental moderations from the perception side, insufficient attention has been paid to streetscapes [8].

To fill the gaps above, this study aims to address whether streetscape perceptions can modify the effects of accessibility and land use mix on bike-sharing usage. To achieve this, we employed data from 18,019,266 GPS-based bike-sharing orders and conducted a cross-sectional study in Shanghai, China. This work contributes to the literature on potential moderation effect of urban environment from the perspective of microscale environmental perception [8; 20; 18]. On the other hand, the findings are derived from Chinese cities, where urban forms and the leading perception factors as moderators, differ significantly from those of western countries [10; 21], which all advance the development of Ecological Models of Health Behavior [9]. This cross sectional study, superior in its large data volume and spatial overage, also implicates that urban planning initiatives aiming to encourage residents' healthy behaviour, should be paid to microscale streetscapes, which can promote physical activities and enhance the benefits of accessibility and land use mix as well.

Methods

Research Area

We examined the moderation effects of streetscape perceptions in central Shanghai, China. The research area is delineated by the Outer Ring Highway of Shanghai (Figure), mainly because of the availability of street view images and bike-sharing usage data. As one of the four first tier cities in China, Shanghai stands among the largest cities in the world. As of 2017, there were 1.5 million dockless bikes in Shanghai. The terrain is flat, and the climate is relatively conducive, which provide favorable conditions for people's cycling activities.

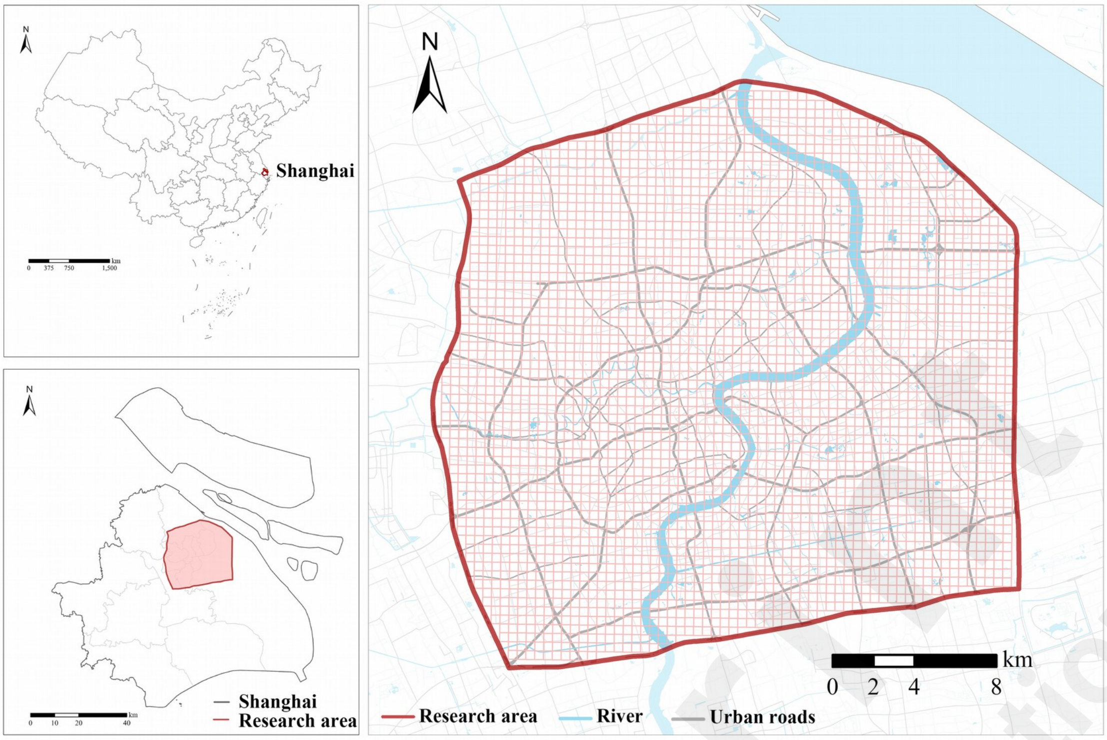

Figure 1. Research area delineated by the Outer Ring Highway of Shanghai, China.

Data Source and Research Design

This is a cross-sectional study in nature, with grids as analysis unit to allocate data. Data on bike-sharing usage were provided by the Mobike Technology Co. Ltd, spanning from 26 August to 8 September in 2018. Originally, the number of bike-sharing usage records is about 19.00 billion. Each record includes information on trip ID, start time and location, as well as the end time and location. As in many studies [2; 10], records on rainy day (i.e. 6 September, 2018) were not included. Meanwhile, we excluded records with abnormal duration or length, leaving records with the trip duration from two minutes to one hour. Then, after excluding trips with locations out of our research area, the final number of bike-sharing usage records in the present study is 18,019,266.

Data on street view images were obtained from the Baidu API (https://map.baidu.com), with the sampling points at 50m interval along with road network. Each sampling point contains street view images with four headings. Data used to measure macroscale built environment, included population data derived from the Easygo big data, as well as road network, building and POIs acquired from Baidu Maps (http://map.baidu.com).

Deriving Bike-sharing Usage

Bike-sharing usage is defined as the number of bike-sharing origins on weekends in each grid. Similar to studies examining environmental effects on bike-sharing usage [22; 10], a 500×500m grid is selected as the analysis unit to allocate each trip, primarily because the size of grids selected is usually considered to be the main activity space in Chinese neighborhoods [23; 21]. Table S1 presents the summary statistics of bike-sharing usage, streetscape perceptions and macroscale built environment. Figure (A) exhibits the spatial distributions of bike-sharing origins on weekends.

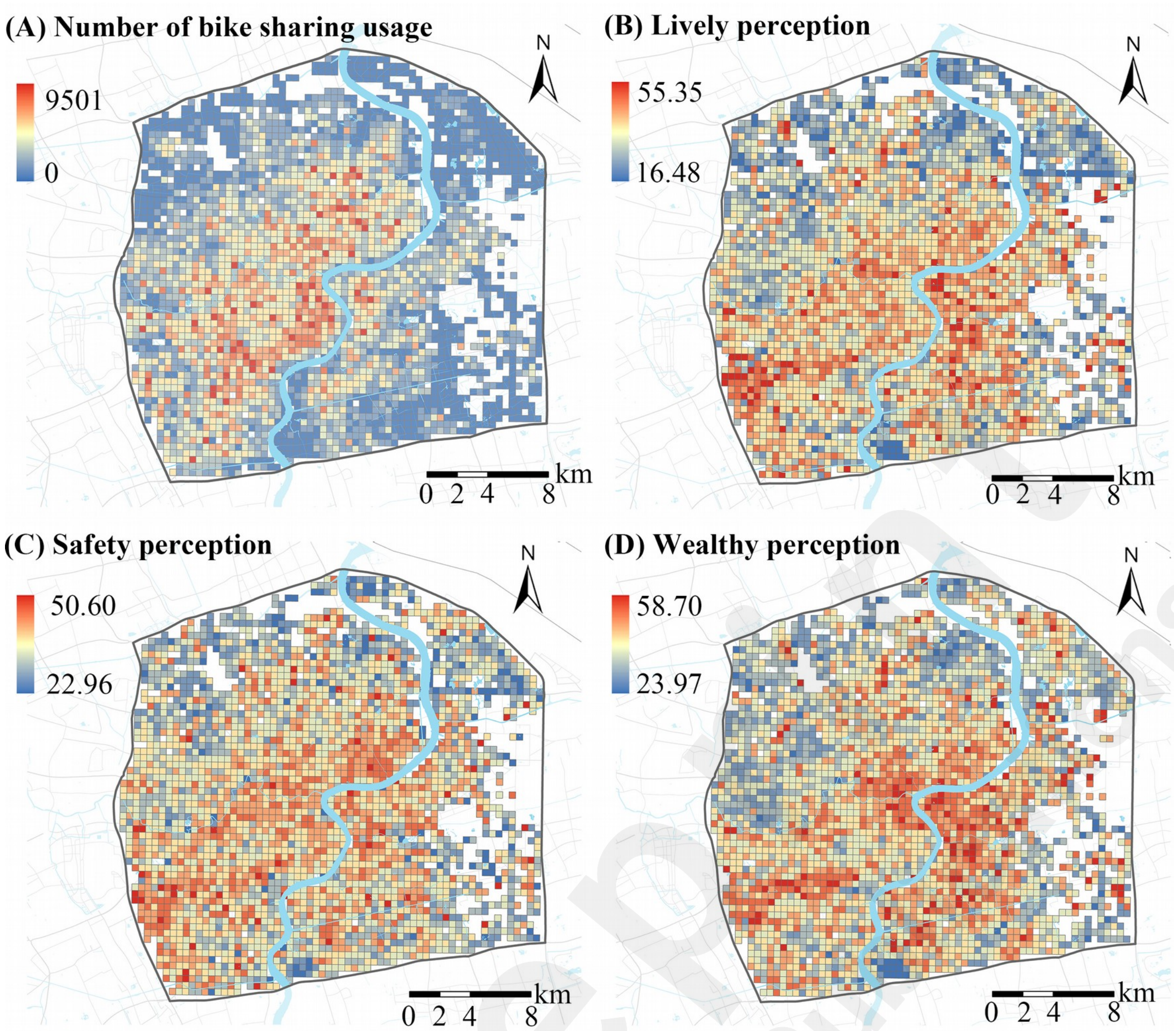

Figure 2**.** Spatial distributions of the number of bike-sharing usage and assessed streetscape perceptions during 2018 in Shanghai, China.

Assessing Streetscape Perceptions

Streetscape perceptions are three positive perceptual indicators, i.e. lively, safety and wealthy [24]. They were assessed according to a human–machine adversarial scoring framework developed by Yao et al [24]. More details of the assessment can refer to Yao et al [24]. Briefly, volunteers scored the perceptions based on the displayed street view image, with the scored values ranging from 0 to 100. Subsequently, a random forest model was used to fit the association of volunteer scorings with visual scenic features extracted by the segmentation approach of FCN-8s. Once the first 50 photos were scored by a volunteer, a random forest set was created to fit the perceived scores in the scoring software. When the volunteer rated the subsequent photos, the software provided the recommended scores, based on the rules learned from the volunteer’s previous rating. In this process, an iterative feedback module was employed to automatically adjust the recommended scores, according to the user scoring behaviors. When the difference between the recommended and scored values was lower than 5 points, the scoring procedure stopped and a human-machine adversarial scoring module was thus created.

As reported, errors in the estimated perceptions using the scoring framework was less than 10% [24]. In this situation, the created scoring module was used to assess the three perceptual indicators and then obtain the perceptual scores for each image, in terms of the street view images. Then, the perceptual scores for each sampling point, were calculated by averaging the perceptual scores of each of the four images. Finally, perception scores for each grid were calculated by averaging the perceptual scores of sampling points located in the grid. Figure (B-D) and Figure show the spatial distributions of the three perception indicators assessed and their examples.

Figure 3**.** Examples of the assessment for lively, safety and wealthy perceptions during 2018 in Shanghai, China.

Measuring Macroscale Built Environment

Macroscale built environments were measured in terms of the 5Ds framework [1]. Population and average building height was used to measure density. Land use Herfindahl–Hirschman index (i.e. Land use HHI) was employed to assess diversity, with a high value indicating a less mixed degree of different types of land use [25]. Destination accessibility was measured using number of POIs and distance to the nearest park. Distance to transit was assessed in terms of distance to the nearest metro station, and the number of bus stops. Design was measured through number of road intersections. Distance to CBD was operationalized as the distance between the centroid of a grid and CBD (km) to control the effect of location. Figure shows the spatial distributions of certain macroscale built environment factors.

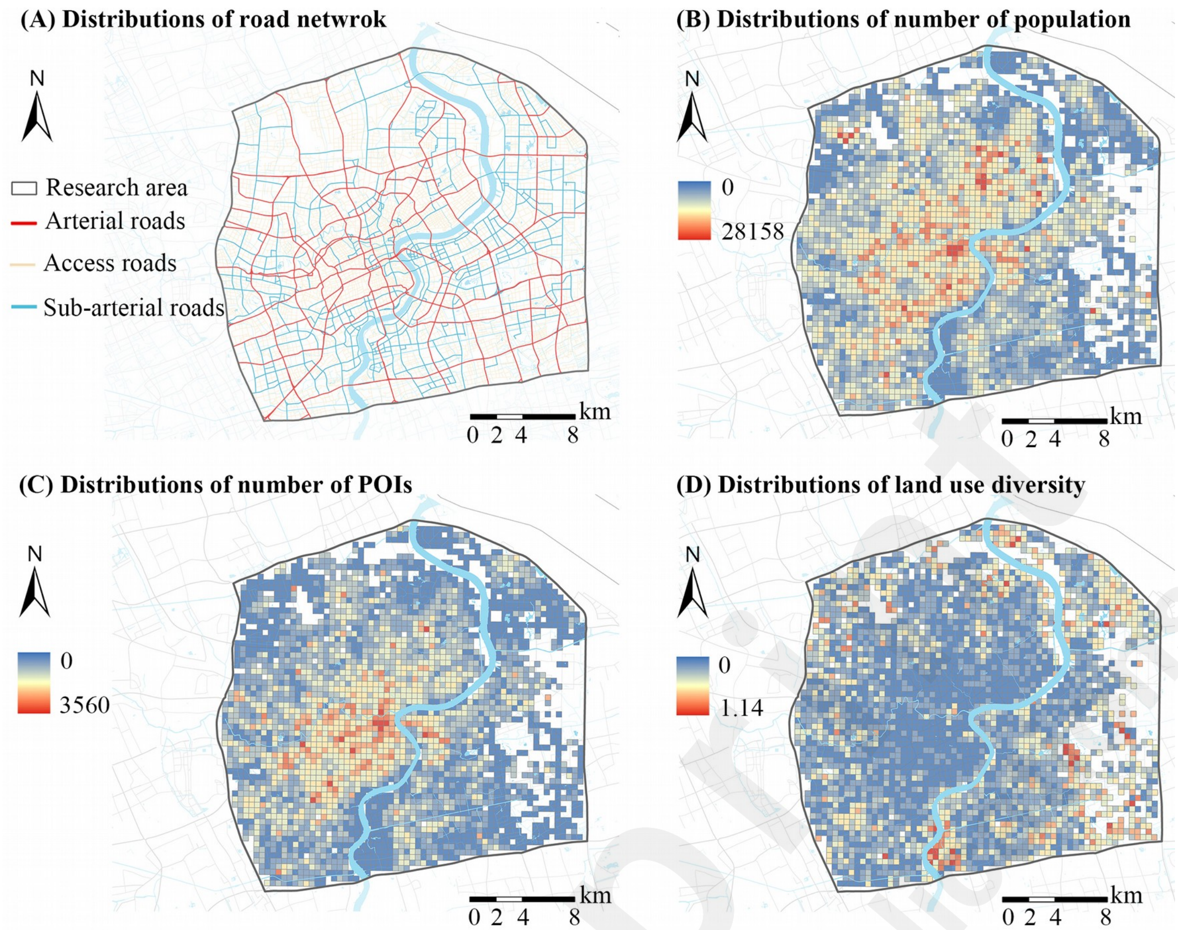

Figure 4. Spatial distributions of some built environment elements during 2018 at macroscale in Shanghai, China.

Statistical Analysis

The Negative Binomial Regression Model (NBRM) was used to firstly examine the independent effects of streetscape perceptions. This was performed in the univariate model and then the fully adjusted model, controlling for population density, average building height, distance to nearest transit, number of bus stations, number of POIs, distance to the nearest park and distance to CBD. The NBRM model was selected, primarily because the outcome variable, i.e. the number of bike-sharing origins, is in number format and also discrete in nature. Moreover, the variance of the outcome variable is greater than its mean value. Hence, as in many studies [26; 27], the NBRM model was chosen for the examination.

Subsequently, streetscape moderation effects were examined through the interaction term between macroscale built environment factors and streetscape perceptions using the fully adjusted NBRM model. Factors at macroscale included land use mix and accessibility, while three perceived indicators encompassed lively, safety and wealthy perceptions. Consequently, totally six models were produced, with each model examining different combinations of these factors. To mitigate multi-collinearity and facilitate comparison between independent variables, independent factors were all standardized into z-scores.

Finally, we conducted three sensitivity analyses. Recognizing the potential influence of uncertain geographic context problem [28], we examined whether the results of streetscape moderation roles are sensitive when investigations are performed at different geographic scales. Consistent with previous studies [29; 30], a1000×1000m grid was selected as the analysis unit. Furthermore, apart from the big data analysis, we further tested whether there are moderation effects of streetscape using the classic (small-sample) statistics approach. Similar to the sampling rate of prior studies [31; 10], 20% of the total grids were randomly chosen for further examination. Moreover, we tested streetscape moderation roles when land use mix and accessibility were operationalized differently. Road length and land use HHI calculated based on AOI data were used as further proxies, respectively.

Ethical Considerations

This study was approved by the Human and Artefacts Ethics Sub-committee, City University of Hong Kong (Reference No: 27609824). Data of bike-sharing records are anonymous and de-identified, which include information on trip ID, start time and location, as well as the end time and location in the present study.

Results

Effects of Streetscape Perceptions

In the univariate model, each of the three positive perceptual factors was positively associated with the number of bike-sharing usage on weekends (Table S2). Among this, lively perception showed the greatest effect (β=5.50; *P*<.001), followed by safety perception (β=5.38; *P*<.001), and then wealthy perception (β=4.45; *P*<.001). A similar pattern of results was observed in the fully controlled model (Table 1). In particular, the most influential effect was found for lively perception (β=1.45; *P*<.001), followed by safety perception (β=1.19; *P*<.001), and then wealthy perception (β=0.79; *P*<.001).

Table 1. Effects of lively, safety and wealthy perceptions on the number of bike-sharing usage on weekends during 2018 in Shanghai, China.

Independent variables	For lively		For safety		For wealthy	
	β (SD)	*P*	β (SD)	*P*	β (SD)	*P*
Perception	.16 (.02)	<.001	.12 (.02)	<.001	.08 (.02)	<.001
Population	.58 (.03)	<.001	.57 (.03)	<.001	.59 (.03)	<.001
Average building height	.08 (.01)	<.001	.09 (.01)	<.001	.09 (.01)	<.001
Land use mix	-.21 (.02)	<.001	-.22 (.02)	<.001	-.22 (.02)	<.001
Number of road intersections	.05 (.02)	.002	.05 (.02)	<.001	.05 (.02)	<.001
Distance to nearest transit	-.30 (.03)	<.001	-.30 (.02)	<.001	-.30 (.03)	<.001
Number of bus stations	.12 (.01)	<.001	.13 (.01)	<.001	.12 (.01)	<.001
Number of POIs	.11 (.02)	<.001	.11 (.02)	<.001	.12 (.02)	<.001
Distance to nearest parks	-.21 (.02)	<.001	-.20 (.02)	<.001	-.22 (.02)	<.001
Distance to CBD	-.17 (.03)	<.001	-.17 (.03)	<.001	-.17 (.03)	<.001

Moderation effects of streetscape perceptions

All streetscape perceptions positively moderated the association between land use Herfindahl–Hirschman index (i.e. Land use HHI) and the number of bike-sharing usage on weekends (Table). Specifically, streetscape perceptions and Land use HHI, were significantly associated with the number of bike-sharing usage on weekends; among the three perceptual indicators, lively perception showed the greatest effect. Regarding the moderation effect, the effect of the interaction between land use HHI and each of streetscape perceptions, was smaller than that of each of the two factors; lively perception presented the strongest moderation role on the effect of land use HHI, followed by the wealthy side and then safety perception. Specifically, the effect of the interaction between lively perception and land use HHI was −0.63 (*P*=.013), greater than those of interactions between Land use HHI with each of the wealthy and safety perceptions at −0.60 (*P*=.008) and −0.52 (*P*=.001), respectively. This means that livelier, safer and wealthier street environment, can enhance the benefits of land use mix to promote cycling behavior.

Table 1. Moderation effects of lively, safety and wealthy perceptions on the association between land use mix and bike-sharing usage on weekends during 2018 in Shanghai.

Independent variables	For lively		For safety		For wealthy	
	β (SD)	*P*	β (SD)	*P*	β (SD)	*P*
Perception	.13(.02)	<.001	.12(.02)	<.001	.07 (.02)	<.001
Population	.57(.03)	<.001	.57 (.03)	<.001	.58 (.03)	<.001
Average building height	.08(.01)	<.001	.09 (.01)	<.001	.08 (.01)	<.001
Land use mix	-.25(.03)	<.001	-.25(.02)	<.001	-.25(.02)	<.000
Number of road intersections	.04(.02)	.007	.05 (.02)	<.001	.05 (.02)	<.001
Distance to nearest transit	-.29(.03)	<.001	-.30 (.02)	<.001	-.30 (.03)	<.001
Number of bus stations	.12(.01)	<.001	.12 (.01)	<.001	.12 (.01)	<.001
Number of POIs	.12(.02)	<.001	.11 (.02)	<.001	.13 (.02)	<.001
Distance to nearest parks	-.16(.03)	<.001	-.17 (.03)	<.001	-.17 (.03)	<.001
Distance to CBD	-.24(.03)	<.001	-.23 (.02)	<.001	-.23 (.02)	<.001
Land use mix × Perception [a]	-.63(.03)	.013	-.52 (.02)	.001	-.60 (.02)	.008

[a] for value = original value×10

There were positive interactions of the number of road intersections with each of the lively and wealthy perceptions (Table). The effects of the number of road intersections, each of the two perceptions and their interactions were all positive. Different from that of land use mix, the effect of number of road intersections was close to the impact of the interaction with each of the lively and wealthy perceptions. With respects to the moderation role, lively perception showed the largest moderation effect, although no significant moderation effect was observed for safety perception. This means that good lively and wealthy perceptions of streetscapes are likely to magnify the role of accessibility in encouraging cycling activities.

Table 2. Moderation effects of lively, safety and wealthy perceptions on the associations between accessibility and bike-sharing usage on weekends during 2018 in Shanghai, China.

Independent variables	For lively		For safety		For wealthy	
	β (SD)	P	β (SD)	*P*	β (SD)	*P*
Perception	.14 (.02)	<.001	.12 (.02)	<.001	.08 (.02)	<.001
Population	.57 (.03)	<.001	.57 (.03)	<.001	.57 (.03)	<.001
Average building height	.08 (.01)	<.001	.09 (.01)	<.001	.08 (.01)	<.001
Land use mix	-.21 (.02)	<.001	-.22 (.02)	<.001	-.22 (.02)	<.001
Number of road intersections	.05 (.01)	.001	.05 (.01)	<.001	.06 (.02)	<.001
Distance to nearest transit	-.29 (.03)	<.001	-.30 (.02)	<.001	-.30 (.03)	<.001
Number of bus stations	.18 (.01)	<.001	.12 (.01)	<.001	.12 (.01)	<.001
Number of POIs	.11 (.02)	<.001	.11 (.02)	<.001	.13 (.02)	<.001
Distance to nearest park	-.17 (.03)	<.001	-.17 (.03)	<.001	-.17 (.03)	<.001
Distance to CBD	-.26 (.03)	<.001	-.21 (.02)	<.001	-.21 (.02)	<.001
Number of road intersections × Perception [a]	.43 (.02)	.078	.17 (.02)	.285	.39 (.02)	<.001

[a] for value = original value×10

Sensitivity Analyses

As indicated in the sensitivity analysis using a 1000×1000 m grid as analysis unit (Figure (A-C)), there were significant interactions between land use mix (i.e. land use HHI) and both lively and safety perceptions of streetscape, except for wealthy perception. Similarly, a moderation role on the impact of the number of road intersections, was found for lively perception but not for the wealthy perspective. Figure S1 (G-I) illustrates the sensitivity analysis in terms of a randomly selected small sample. Overall, positive moderation roles persisted for all streetscape perceptions on the effect of land use mix, as well as for lively perception on the impact of the number of road intersections. Furthermore, among the three perception indicators, lively perception still played the most substantial moderation role in relation to the impact of land use HHI.

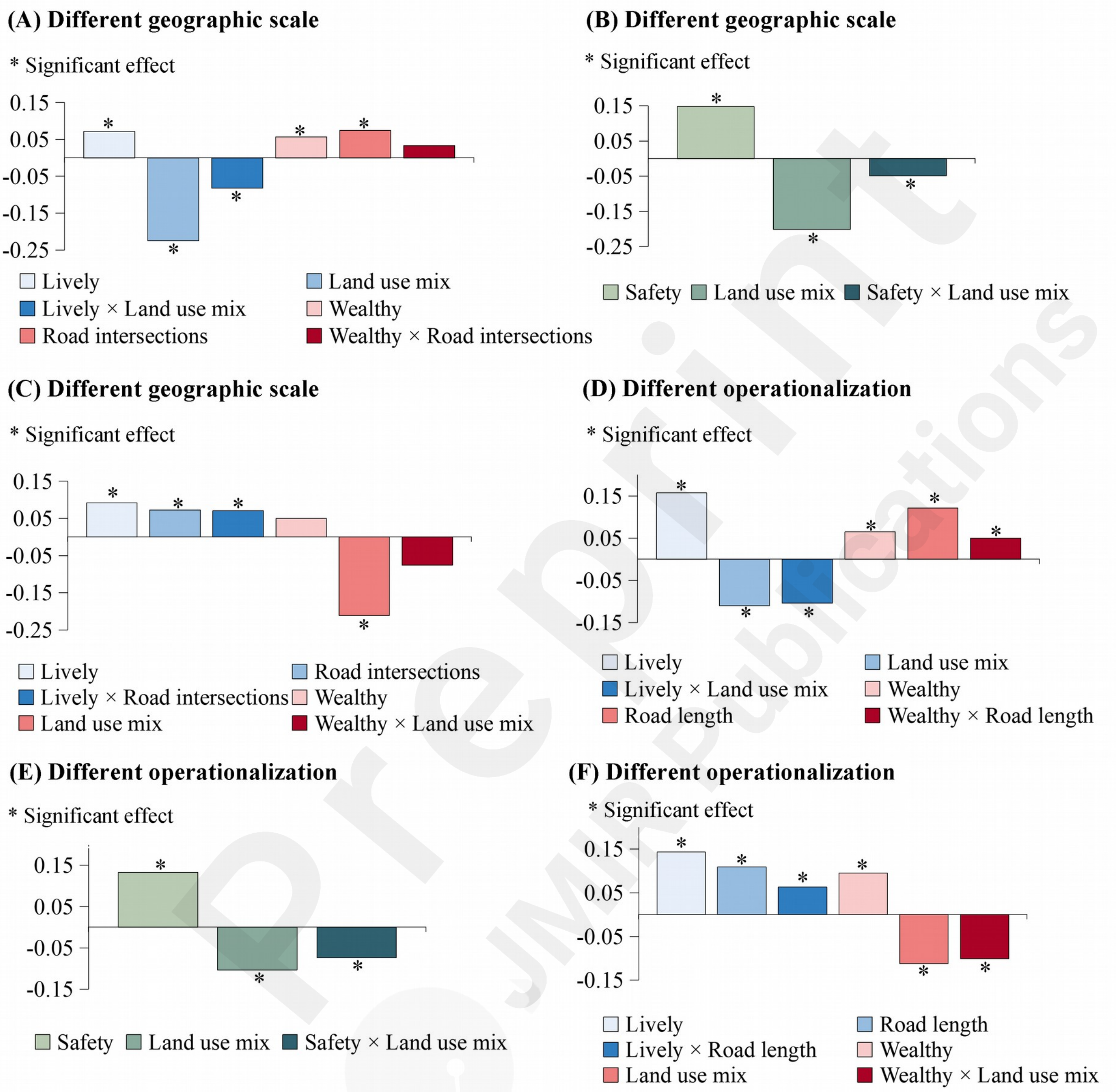

Figure 5. Sensitivity analyses of streetscape moderation effects examined at different geographic scales (A-C) and utilizing different operationalization (D-F) during 2018 in Shanghai, China.

Figure (D-F) exhibits the sensitivity analysis using land use HHI calculated by AOI data and road length as proxies for land use mix and accessibility, respectively. Generally, lively, wealthy, and safety perceptions of streetscapes continued to exhibit positive moderation on the effect of land use HHI. In particular, the absolute effect of the interaction between land use mix and lively perception was .10 (P=.001), accounting for 66.14% and 94.22% of the main effects of the two factors, respectively. With regards to accessibility, operationalized by road length in grids, its interactions with lively and wealthy perceptions were still correlated with the number of bike-sharing usage on weekends.

Discussions

Principal Findings and Comparisons With Prior Work

We found that streetscape perceptions are positively associated with bike-sharing activities. This is consistent with many prior studies [32; 33; 17]. In particular, a cross-sectional study conducted in Boston of USA using running data from the Strava Heatmap, suggested the positive effects of wealthy and safety perceptions on running amount [13]. The mechanisms linking environmental perceptions and physical activity are highly complex, and beyond the scope of this work. This highlights a great significance of investigating the pathway in the future work, especially those evidences from the perspective of Neuroscience.

However, we observed that among three perceptual factors, lively perception not only plays the strongest effect on bike-sharing usage, but also emerges as the most influential moderator, which is inconsistent with findings from western studies [7; 20; 13]. Typically, among environmental perceptions such as safety and lively, the former usually plays the strongest moderation role on the impact of macroscale built environment for studies outside mainland China [16; 20; 8]. In particular, an American study indicated that compared to perceived pleasure, safety perception plays a greater moderation role on the impact of accessibility on healthy behaviors [8].

The underlying mechanisms behind that lively perception not only plays the largest independent effect, but also shows the strongest moderation effect, are highly complex. Actually, there are two potential explanations. On one hand, among environmental perceptions (qualities), safety plays a crucial role in physical activity in many Western cities [7; 20; 13]. However, lively status usually takes precedence in residents' concerns about healthy behavior in the Chinese context [17; 34]. This is also consistent with the finding of the present study. Regarding accessibility, the main effect of lively perception on the number of bike-sharing usage on weekends was 1.39 (P<.001), higher than that of safety and wealthy perceptions at 1.12 (P<.001) and 0.75 (P<.001), respectively. A similar pattern of results was observed for land use mix, with the greatest main effect by lively perception（β=1.39; P<.001), and then by safety perception (β=1.22; P<.001) and wealthy perception (β=0.75; P<.001).

On the other hand, livelier places tend to provide various benefits beyond urban lively itself. In many Chinese cities, more vibrant and lively urban places are associated with large population inflow and increased greenery [35; 36]. A large number of people on the street and more green space can strengthen the sense of safety [37; 38; 39], thus promoting healthy behaviors more effectively [10; 8]. The findings extend prior studies by highlighting that in the Chinese context, it is lively perception rather than safety perception that usually plays the strongest moderation effect on the built environment-healthy behavior relationship.

This work provides significant implications for public health. Usually, urban planning initiatives aiming to promote residents' physical activities, target interventions in built environment at macroscale, which are time consuming and less actionable. Our findings suggest that favorable microscale environments can promote cycling behavior, and enhance the benefits of accessibility and land use mix as well. This underscores that sufficient attentions should be paid to interventions on microscale streetscapes, which are less time consuming and more readily modifiable than those on macroscale built environment.

Limitations

Several limitations should be well clarified. Firstly, similar to many studies [6; 19; 8], the use of 500×500 grids as the analysis unit to examine moderation effects of streetscape perceptions, may be susceptible to the uncertain geographic context problem, short for UGCoP [28]. In our study, the size of analysis unit selected was usually considered as the main activity space in most Chinese neighborhoods [23; 21]. Moreover, a 1000×1000m grid was used as the analysis unit to test the

robustness of streetscape moderation effects. However, careful research design is essential to well address the UGCoP in future work.
Secondly, this is an aggregated study in nature, with grids to allocate bike-sharing data. Hence, as in many bike-sharing studies [2; 19], the impacts of individual characteristics on cycling were not controlled. Furthermore, streetscape perceptions were assessed by the public in terms of street view images, which may collectively influence the findings. Despite the negligible differences between respondents' socioeconomic characteristics reported in some prior studies [40; 41], however, future research should associate environmental perceptions with riders to draw more scientifically grounded conclusions. Finally, further study can delve into the mechanisms of moderation roles by microscale urban environments, either on the objective or perceived side, which remain unclear and could be better understood with individual level data.

Conclusions

Livelier and safer perceptions of streetscapes can magnify the benefits of land use mix to cycling activity, so does lively perception on the effect of accessibility. The findings emphasize that to better promote physical activity, sufficient interventions should be paid to microscale streetscapes, which can encourage cycling behavior and amplify the positive effects of accessibility and land use mix as well.

Declarations
1. Ethics approval and consent to participate
This study was approved by the Human and Artefacts Ethics Sub-committee, City University of Hong Kong (Reference No: 27609824).
2. Consent for publication
Not applicable.
3. Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.
4. Competing interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
5. Funding
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6. Authors' contributions
H. Guo was responsible for the conceptualization, methodology, formal analysis and writing – original draft. S. Zhang was responsible for some of formal analysis and investigation. X. Xie provided part of data sources and wrote some parts. J. Liu was responsible for methodology and investigation. H. Hung was responsible for the conceptualization and writing – original draft. All authors reviewed the manuscript.
7. Acknowledgements
Not applicable.

Reference
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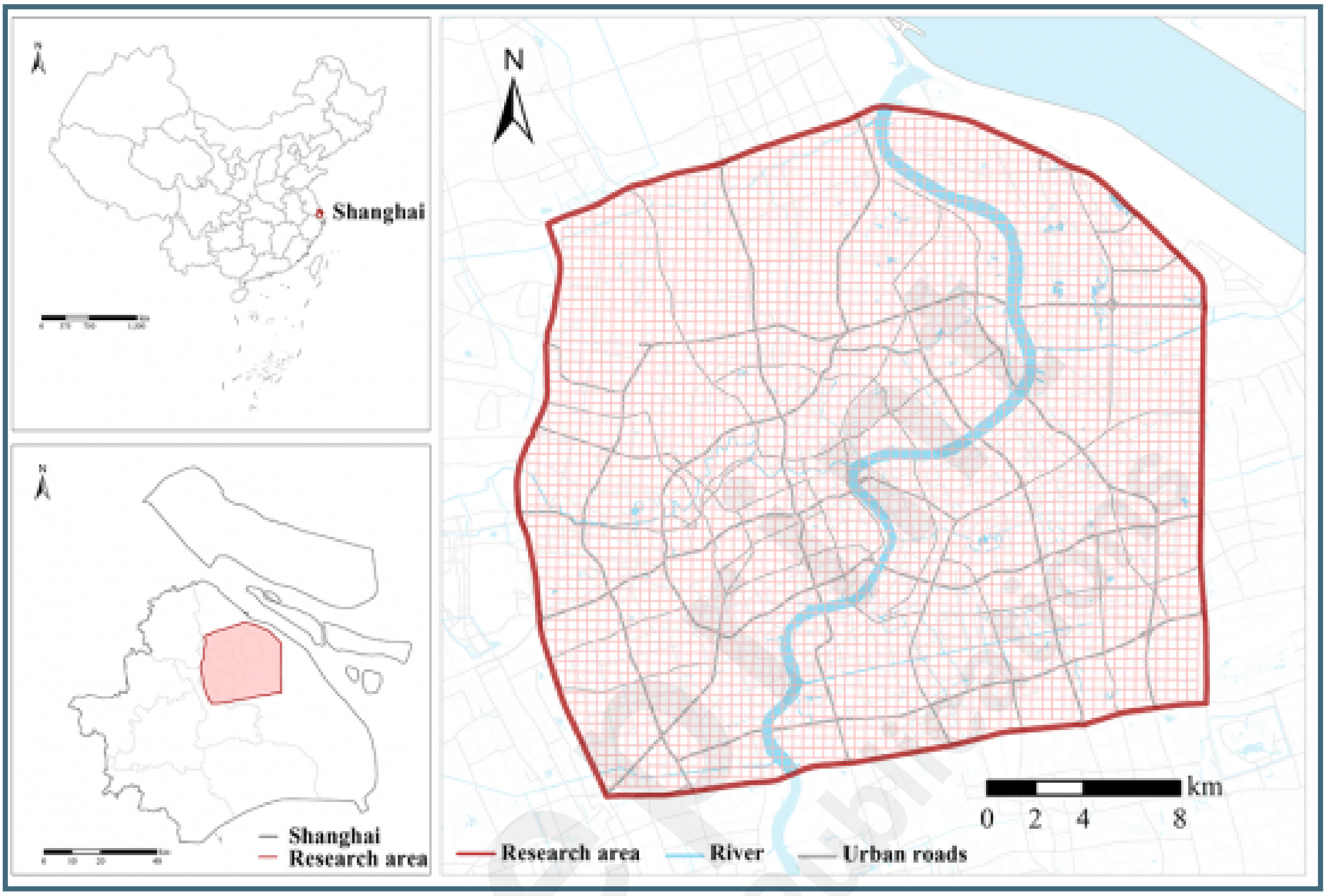
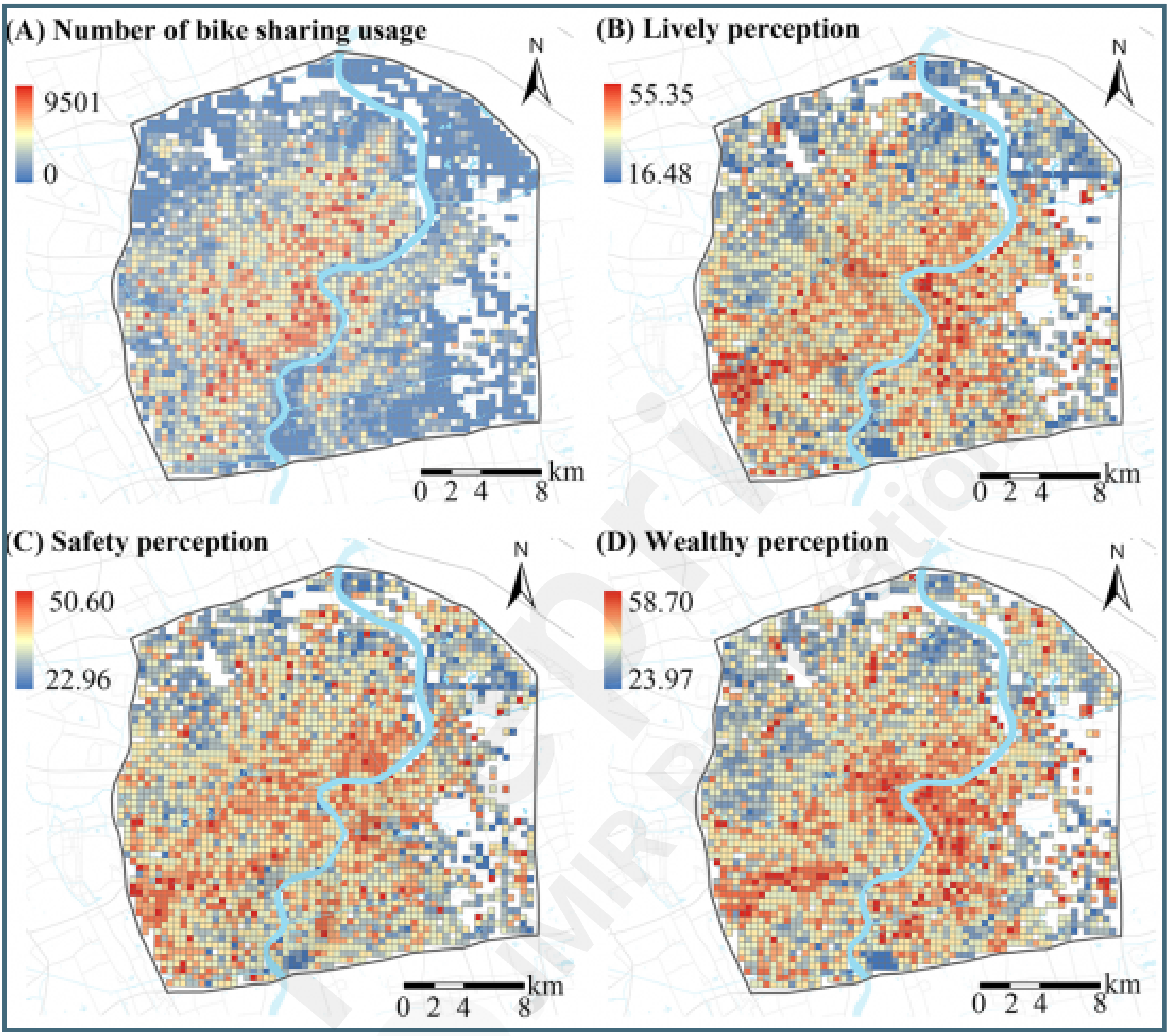
Supplementary Files

Figures

Research area delineated by the Outer Ring Highway of Shanghai, China.

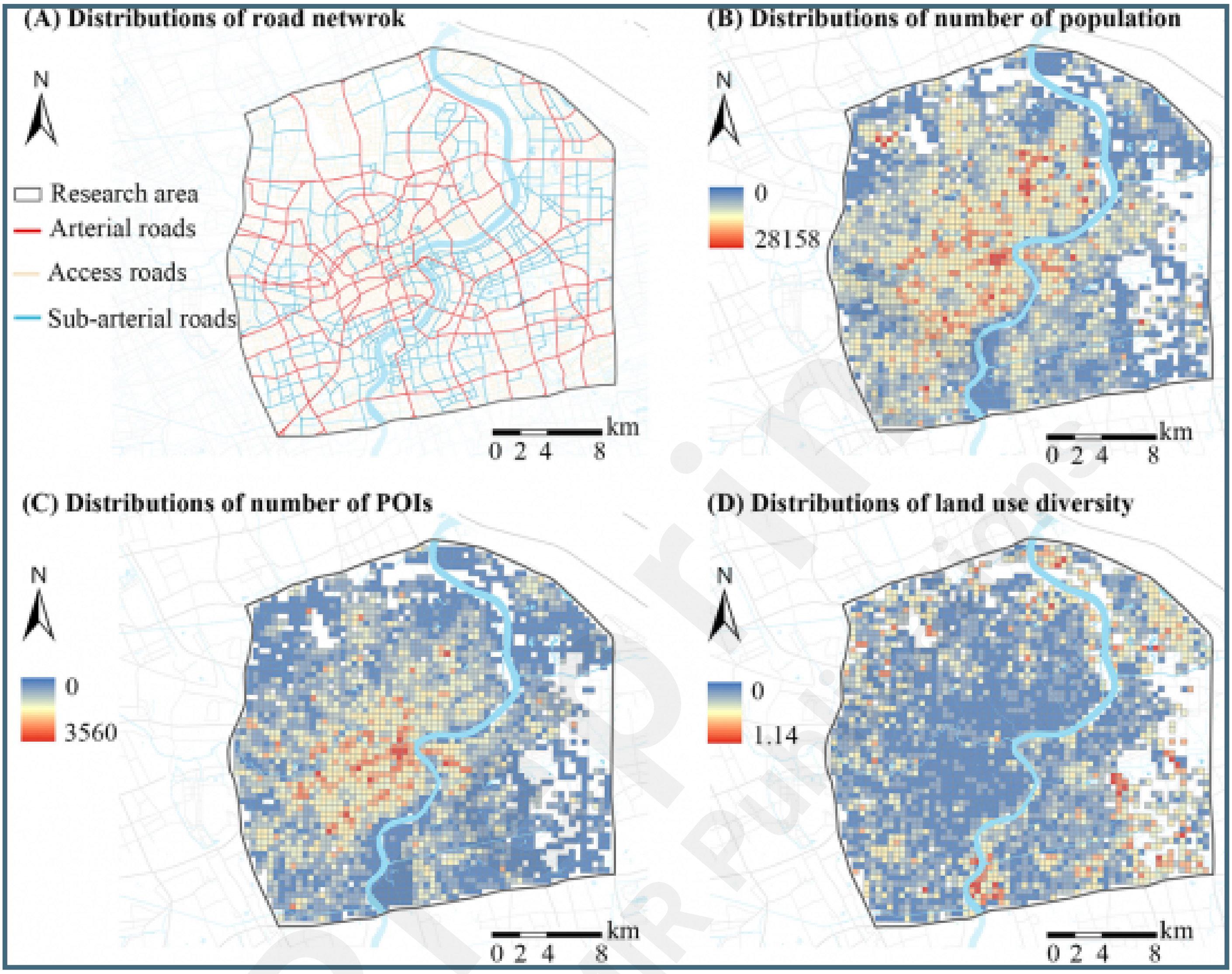


Spatial distributions of the number of bike-sharing usage and assessed streetscape perceptions during 2018 in Shanghai, China.



Examples of the assessment for lively, safety and wealthy perceptions during 2018 in Shanghai, China.

Spatial distributions of some built environment elements during 2018 at macroscale in Shanghai, China.



Sensitivity analyses of streetscape moderation effects examined at different geographic scales (A-C) and utilizing different operationalization (D-F) during 2018 in Shanghai, China.