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Assessing the Impact of Urban Greenery Captured by Street View Imagery on Fear of Crime in Guangzhou, China

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Abstract: Previous literature has examined the relationship between the amount of green space and perceived safety in urban areas, but little is known about the effect of street-view neighborhood greenery on fear of crime. Using a deep learning approach, we obtained the street-view greenery data from massive street view images in central Guangzhou and tested the relationships and mechanisms between street-view greenery and fear of neighborhood crime. Results demonstrated that street-view greenery was associated with a lower fear of crime, and its relationship was mediated by perceived physical incivilities and moderated by perceived social integration. This study provides a solution for decreasing fear of crime by handling a microenvironmental characteristic. Moreover, we concluded that both physical design and social factors should be considered in attempts to understand the fear of crime and urban greenery planning.

Keywords: fear of crime; street-view greenery; neighborhood incivilities; social integration; China

1. Introduction

Many people are afraid of densely vegetated places. For instance, in the studies on urban parks, densely wooded areas have consistently been related to fear [1,2]. However, well-maintained or high-visibility vegetation is associated with a lower fear [3,4]. Recently, there is a rising interest in studying the relationship between the amount of urban green space and perceived neighborhood safety [5-7].

The urban green space data based on satellite images are widely used by scholars [8,9]. Although satellite images are continuous, timely, and informative, some small objects are difficult to detect due to the medium spatial resolution. More importantly, the downward-facing satellite represents a bird-eye view, and cannot accurately reflect people's perceived green space from the ground-level perspective. In recent years, the Street View Index (SVI) at eye-level [10] has been widely used. Eye-level street greenery can reflect more actual exposures to green space, including small-sized and vertical natural elements (e.g. trees along a street, small plants, and grasses, etc.) [11]. Besides, most street-view greenery represents highly visible vegetation, which might is a type of greenery that is beneficial to safety perception.

As the most populous country, China has experienced unprecedented rapid urbanization in recent decades, which reduces the opportunities for urban residents to be exposed to natural outdoor environment [12]. Thus, clarifying the underlying linkage between residential street-view greenery and fear of crime will not only fill the knowledge gap about the Chinese context but also provide guidance for police departments, urban planners, and policymakers on how to improve neighborhood safety perception via urban environment design programs.

More research is desired in this area. Using massive street view data, this study evaluates the street-view greenery in Guangzhou neighborhoods via a deep learning technique and examines the relationships and paths between street-view greenery and fear of crime in the Chinese setting under the guidance of environmental criminology theories.

1.1. Determinants of the fear of crime

Fear of crime is a criminological concept and its definition is not uniform. Abundant criminological studies suggest that fear of crime refers to resident's concerns and worries about encountering criminal incidents [13-15]. The dominant theoretical perspective of fear of crime is the vulnerability model. According to this model, those physically or socially vulnerable people are expected to report higher levels of fear of crime. Women and the elderly are typically regarded as physically vulnerable populations, meanwhile, those with a lower level of personal income and/or education are considered as socially vulnerable populations. Research has demonstrated that the groups of women, the elderly, the lower-income, and the less educated tend to report higher levels of fear [16-18]. The second influential theory is the disorder model which directly focuses on community characteristics. A neighborhood with physical deterioration (e.g. damaged public facilities) reflects residents in this neighborhood are lack social control, thereby causing fear of crime [19,20]. The third model, known as the social integration model, focuses on social integration, which is defined as people's sense of belonging to their local community as well as their attachment to the neighborhood [21]. The social integration model posits that the more socially integrated the person, the lower their vulnerability and fear of crime [22].

These findings are critical and can provide policy recommendations and practical program guidance. However, another type of urban characteristics has also attracted the attention of researchers and policymakers, namely, the physical characteristics of urban neighborhoods themselves.

1.2. Urban greenery and fear of crime: evidence

Traditionally, due to the closed space environment, green spaces contribute to higher levels of fear in several studies [1,2,23]. Some research use images to test the relationship between green space and fear in residential settings. A study on the safety ratings for vegetation photographs showed that pictures with closed woodland space and natural shrubby edge space are unsafe for participates [1]. Similar results were obtained from an experiment using computer-based photo simulations [3]. Some explored this relationship by questionnaires or surveys in the actual residential settings. Mak & Jim [24] reported that people were afraid of becoming a victim of crime when visiting the parks in Hong Kong. Meanwhile, several studies have found that people's fear of crime depends on the visibility of green space. Woodland vegetation with good visual accessibility is beneficial to people's perception of safety [3,4]. That is, closed green space (such as dense woodland and natural shrubby) are associated with high fear levels, while open green space (such as grassland) is associated with low fear levels. Moreover, literature has demonstrated that fear in green space is associated with people's age, gender, household composition, ethnicity, socioeconomic status, and prior victimization [25-27]. Residents in Kuala Lumpur, Malaysia, had some defensive behaviors against crime in parks, but this behavior was observed only among women [28].

A basic concept can easily be misunderstood. In many of the above studies, fear is a universal feeling (not crime-specific fear), or a situational fear (it will disappear soon after leaving that environment) [29]. Indeed, some research also involved the association between vegetation and situational fear of crime and showed similar findings [28]. Regarding the stable fear of crime in the

neighborhood, Maas and her colleagues [5] first illustrated the relationship between the amount of green space and perception of neighborhood safety, with a case in the Netherlands. Their findings suggested that residents living in a greener surrounding environment reported increased feelings of social safety. In the highly urbanized areas, women and older people had higher levels of social safety, while men were generally not affected by green space. Then, Mouratidis [7] verified the relationship between urban tree cover and increased perceived safety in 45 neighborhoods of the Oslo metropolitan area.

Some circumstantial evidence also suggests a possible relationship between green space and fear of neighborhood crime. Although crime and fear of crime are not similar and even not correlated, a series of research has demonstrated that more residential vegetation can reduce crime rates [30-32]. Moreover, studies have examined the relationship between vegetation and lower levels of incivilities [33,34]. For example, fewer problems are reported in neighborhoods with higher levels of maintained gardening. Additional evidence from studies that examine the relationship between residential vegetation and residents' levels of aggression, violence, physical and mental health [35]. The majority have illustrated the positive effect of green space on residents' wellbeing and physical health [8,9]. The higher the feeling of wellbeing and the healthier the body, the less likely the person will become a vulnerable individual, and thus might a lower fear of crime.

In sum, residential vegetation has been linked with a lower crime rate, fewer incivilities, and less aggressive and violent behavior. There is a variety of evidence suggesting that vegetation may be linked to a lower fear of crime in residential neighborhoods. But empirical evidence is still lacking in the street-view greenery field, as well as in non-Western contexts.

1.3. Urban greenery and fear of Crime: Theory

Not merely on direct and indirect evidence, there are some theoretical signs that the greater perception of safety is justified. In criminological research, surveillance is an inhibitor of criminal activities. One of the earliest and most influential statements is Jacobs's *Death and Life of Great American Cities* [36]. Jacobs [36]suggested that the presence of more 'eyes on the street' would deter criminal activities. In urban areas, it has shown that outdoor spaces with more trees are consistently greater used by residents than spaces without trees [37,38]. The more trees in an area, the greater the number of ambient population. Offenders avoid areas with a greater likelihood of surveillance and intervention because their activities might easily be observed in these areas. Thus, a greater amount of vegetation might increase surveillance. Furthermore, Newman [39] proposed the 'defensible space' and developed the concept of 'eyes on the street'. Newman [39] suggested that criminals might be deterred by environmental signs even if no one is present. This may be a function of territorial marking, as Kuo & Sullivan [40] proposed that well-maintained vegetation may constitute a particular territorial marker/sign. Therefore, implied surveillance can also prevent crime, and possibly the fear of crime.

Moderation. Increased street-view greenery might reduce people's fear of walking through their neighborhood because of a higher level of neighborhood social control. If residents are in a socially integrated community, it can provide an informal social fabric that will enforce local social control of urban streets and might make the beneficial role of green space more significant. Thus, the usage of the street is very critical, especially when it involves a certain degree of local social integration [41]. Jacobs [36] highlighted the need for design and social factors to ensure vibrant and diverse street usage to enhance urban safety. Once the social and physical structure of the neighborhood's streets is fully integrated, the harmful effects of strangers on the street will be eliminated and possibly begin to provide help. For instance, in a report on the interaction effect of street traffic and social integration on fear of crime [42], street traffic inhibited fear of crime when social integration was high.

Mediation. The relationship between the micro-environment and fear of crime is in two ways. First, direct signs of crime can indicate the possibility of crime. Second, environmental clues might arouse fear of crime, and the environmental clues symbolize the neighborhood's ability to exercise informal social control. Collective efficacy and neighborhood incivilities may be driven by neighborhood structural characteristics, such as neighborhood poverty level, ethnic diversity, and

crime rates. Brunton-Smith, Jackson & Sutherland [43] suggested that collective efficacy and neighborhood incivilities are the bridges by which neighborhood structure characteristics affect fear of violence. On one hand, urban street-view greenery might provide opportunities for neighborhood interaction, and contribute to social integration and attachment [44]. Meanwhile, social integration is a typical predictor of inhibiting fear of crime, so green space in neighborhoods might reduce the level of fear among residents. On the other hand, a higher level of street-view greenery heralds a more orderly and low-incivility neighborhood, thus might lead to a lower level of fear of crime.

Therefore, we propose that street-view greenery may deter fear of crime in the following ways: by increasing informal and implied surveillance of the neighborhood, and by increasing the probability of intervention. Moreover, perceived conditions (such as neighborhood incivilities and social integration) might moderate or mediate the relationship between the street-view green space and fear of crime.

1.4. The present study

The aim of this study to analyze the associations and mechanisms between street-view greenery and fear of crime among residents, by using street-view greenery extracted from massive street-view pictures in central Guangzhou, China. The following are the research questions:

1. Is street-view greenery associated with a lower fear of neighborhood crime?
2. What are the potential moderating and mediating roles of perceived conditions (physical and social incivilities, and social integration) on the relationship between street-view greenery and fear of crime?

2. Materials and Methods

2.1. Description of the study area

Guangzhou (112°57'E – 114°30'E; 22°26'N – 23°56'N) is located in southern China, adjacent to the South China Sea. It is the capital and largest city of Guangdong province and the third-largest city in China, with an estimated population of 15 million in 2019. Guangzhou contains 11 administrative districts over an area of 7,434 km^2. As the area within the *S81 Guangzhou Ring Expressway* is the central and most urbanized area of Guangzhou, and the street view data is fully covered, we choose this area (central Guangzhou) as the sample area. This area covers an area of 380 km^2 (Figure 1a).

2.2. Data

2.2.1 Fear of crime data

The current study employs data from the Project on Public Safety in Guangzhou Neighborhoods (PPSGN), an interdisciplinary study aimed at understanding how neighborhood contexts affect the safety perception of residents in Guangzhou, China. The survey was designed by the research team and was distributed from January to April 2016 by the HOUSONWELL market research (http://www.hswell.com/), a professional and well-known market research company in China. Since college students and people under the age of 18 are greatly affected by the campus environment, they were politely declined to participate in the questionnaires. Using a probability sample procedure, the PPSGN collected information from 1,994 Guangzhou residents in 91 neighborhoods, with a response rate of 87.4%. As the case area in this study was central Guangzhou, finally, 773 participants from 37 neighborhoods in the total sample were selected (Figure 1b).

2.2.2 Street-view greenery data

We evaluated green space per neighborhood based on a series of street view images collected in December 2018. The images were crawled from Baidu Map, the Chinese equivalent of Google Maps (Google products cannot be accessed in mainland China). It is China's leading map services provider, has the largest image coverage, and providing street view pictures taken from various positions. Several

studies involving Chinese cities have used Baidu Map data [45,46]. Based on the Guangzhou road map, we constructed point transects along with the road network (Figure 1 c & d). The sampled points are 50m apart, which is a compromise between the detail and the cost. Given these locations, the closest pictures in the horizontal direction were queried through an URL link and crawled through the API (application programming interface). To include the entire streetscape at each sampling point, we acquired images taken in the four directions (i.e., 0, 90, 180, and 270 degrees) (Figure 2). The size of each image is 512×512 pixels with a vertical angle of 0 degrees (pitch=0). In total, through the Python programming language, 73,289 street view images with four directions were obtained.

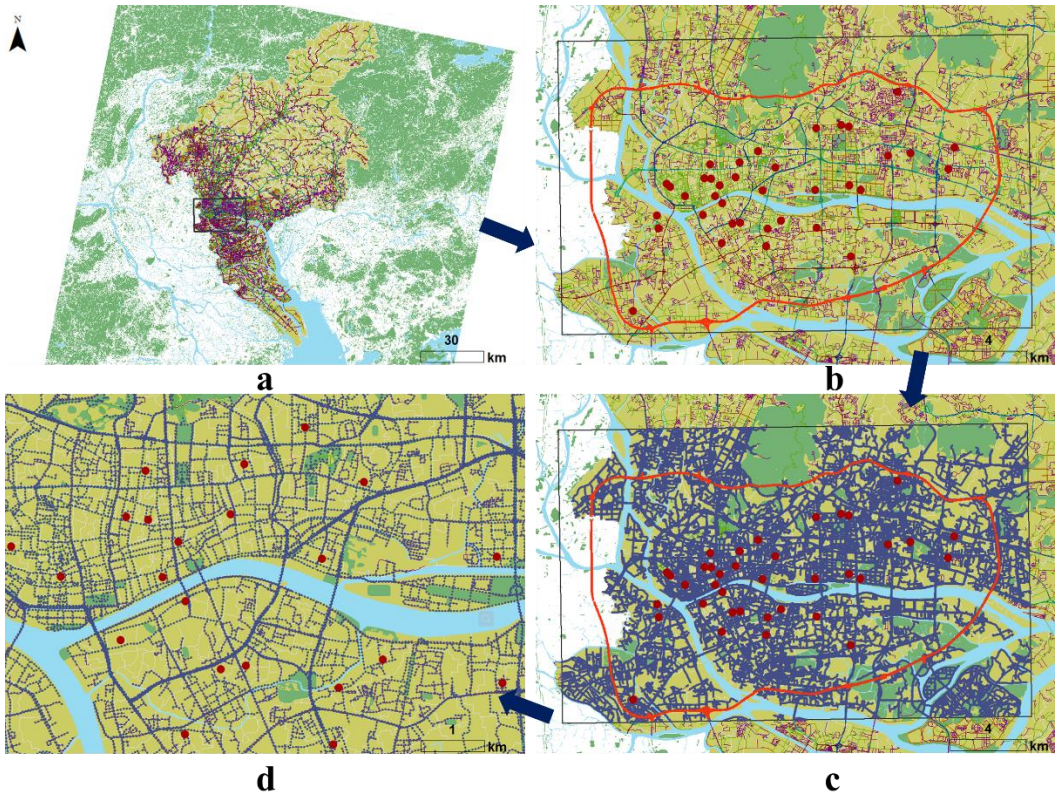

Figure 1. Distribution of sampled points for capturing street greenery images. (a. Guangzhou map; b. Central Guangzhou (red circles refer to sampled neighborhoods; red ring refers to S81 Guangzhou Ring Expressway); c. purple points refer to street-view sample points; d. a magnified area with street-view sample points.)

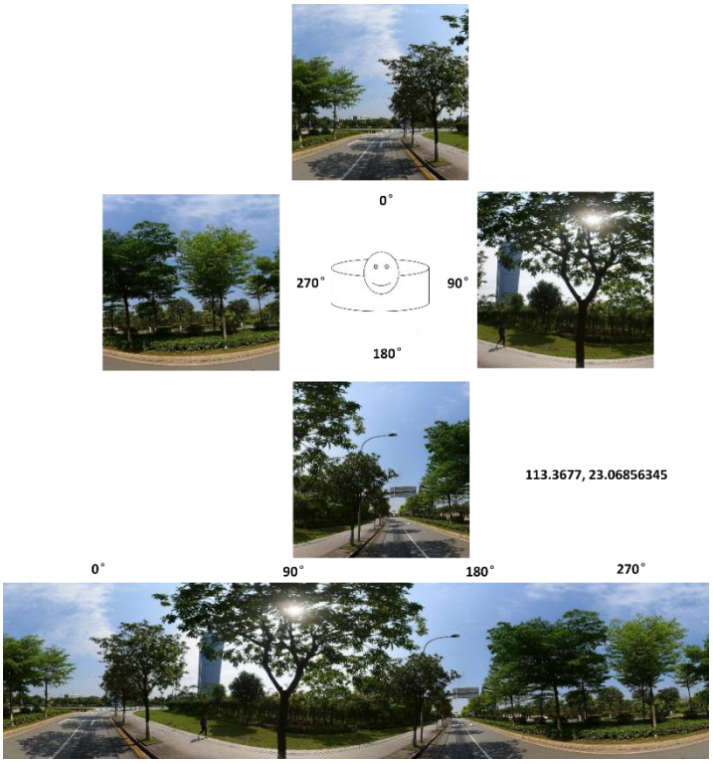

Figure 2. Street-view greenery images capturing example

2.3. Measures

2.3.1. Self-reported fear of crime indicator

Fear of crime. Consistent with previous work [47,48], fear of crime was assessed using a question with two items from the PPSGN survey: 'how fearful are you to walk around the neighborhood after 10 p.m. (a. fear of robbery; and b. fear of harassment)?' Respondents were asked to indicate a response to the above question on a 5-point Likert-type scale, where 1 stands 'not fearful', to 5 stands 'very fearful'. Higher values indicate a greater feeling of fear (M = 2.34, SD = 1.03, α = .79).

2.3.2. Individual-level variables

Demographic Information. In general, female and old people might have high levels of fear, so gender (female=1) and age (continuous variable) were assessed. This study also measured personal income (ordinal variable, ranging from 1 to 7, meaning from low to high) and the education level (ordinal variable, ranging from 1 to 8, meaning from low to high). The measure of prior victimization was to ask whether the respondent had previously been victimized in the last three years (1 = yes).

Perceived physical and social incivilities. Respondents were asked about a series of conditions separately and whether it was present in their surroundings. Perceptions of neighborhood incivilities are composite variables (summed across several variables). The variable perceived physical incivilities reflects a scale ranging from 0 to 5, including the following four items: abandoned cars and/or trash, damaged public facilities and/or poor lighting, graffiti and/or disordered advertisements, and noisy neighborhood environment (α=.82). The variable perceived social incivilities reflects an increasing scale ranging from 0 to 5, including the following four items: drunken persons on the streets, teenagers gathering on the streets, suspicious strangers, and residents conflicting on the streets (α=.84). In the total sample, the mean is 2.82 and 1.85 for physical incivilities and social incivilities, respectively.

Social integration. Respondents were asked four items about their perception of social integration in their neighborhood. It reflects a scale ranging from 0 to 5, comprised of visiting informally with

neighbors, chatting with neighbors, borrowing things like tools from neighbors, and belonging to a network in which neighbors help each other (M = 3.42, SD = .83, α = .77).

2.3.3. Neighborhood-level variables

Neighborhood street-view greenery. Using a buffer around the neighborhood to define the neighborhood boundary can reflect more realistic walkable distances, which has been widely adopted by prior studies [49,50]. Thus, we measured .5 km, 1 km, and 1.5 km buffer area of each neighborhood by ArcGIS 10.3 software. Then, average street-view greenery within a .5 km (M = .27, SD = .07), a 1.0 km (M = .25, SD = .05), and a 1.5 km (M = .25, SD = .04) radius around each neighborhood centroid were calculated. The street-view greenery within a 1.0 km radius is for main effect analysis, while the street-view greenery within the radius of .5 km and 1.5 km is for sensitivity analyses to ensure the reliability of the results.

When investigating the relationship between fear of crime and the visibility of green space in a person's living environment, other neighborhood-level factors that could influence fear of crime ought to be controlled. People tend to feel less safe in neighborhoods with higher concentrated disadvantages [51]. Concentrated disadvantages are related to the percentage of immigrants, neighborhood income level, and crime rates [52], which leads us to include the percentage of population with a bachelor's degree or higher[1], the percentage of migrant population, and the robbery rate in the neighborhood.

Proportion of population with a bachelor's degree or higher. In a neighborhood, percentage of population with a bachelor's degree or higher was calculated as the ratio between the number of people with a bachelor's degree or higher and the number of neighborhood inhabitants (M = .19, SD = .22). Relevant population data were obtained from the 2010 Census[2].

Proportion of migrant population. In a neighborhood, migrant population percentage was calculated as the ratio between the number of non-local hukou population (migrants from outside Guangzhou) and the number of neighborhood inhabitants (from 2010 Census) (M = .17, SD = .13).

Robbery rate. Robbery rate (per 100,000 of the population) was calculated for each of the 37 neighborhoods in the sample by averaging official police counts of robbery for 2014 and 2015, dividing by the total neighborhood population (from 2010 Census), and multiplying by 100,000. Robbery crime data was obtained from Guangzhou Public Security Bureau (M = 53.68, SD = 81.30).

2.4. Deep learning for image segmentation

Yang et al. [10] proposed a Green View Index (GVI) to evaluate the visibility of urban greenery, which was defined as the ratio of the total green area of four pictures taken at a street intersection to the total area of the four pictures. Then, Li et al. [53] assessed the street-view greenery by pixel-wise classification based on massive google street view imagery. However, there are some limitations in pixel-wise classification using additive colors of the picture, such as the indistinguishable natural and artificial green objects. To overcome the limitation, the present study implemented a deep learning approach to extract street-view greenery from massive street images.

We applied a semantic segmentation technique called FCN-8s (full convolutional network for semantic segmentation) to identify green space from street view image data [11,54]. The FCN-8s was trained based on the ADE_20K dataset. This approach can identify 150 elements, including common ground objects such as trees, sky, persons, cars, roads, and buildings. The trained FCN-8s displayed good performance for street image scene segmentation, and a series of research has used the trained FCN-8s to assess streetscapes in Chinese cities with desirable results [11,50]. For the technical details of the trained FCN-8s model, see the work of Yao and his colleagues [55]. After the image segmentation, the proportion of green space (including trees, grass, and plants) was calculated (Figure 3).

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[1] There is no neighborhood-level income data in China, so we choose neighborhood education level as a substitute variable, because the personal income and the education level are usually considered to be highly related.

[2] The 2010 Census refers to the 2010 National Census, which is the latest census data in China so far, with various attribute data of the smallest administrative unit.

In each sampling point, streetscape green space represents the ratio of the number of green space pixels per image summed over the four directions to the total number of pixels per image summed over the four directions. Then, the data of points were aggregated to the neighborhood by average method, and the neighborhood-level street-view greenery was obtained.

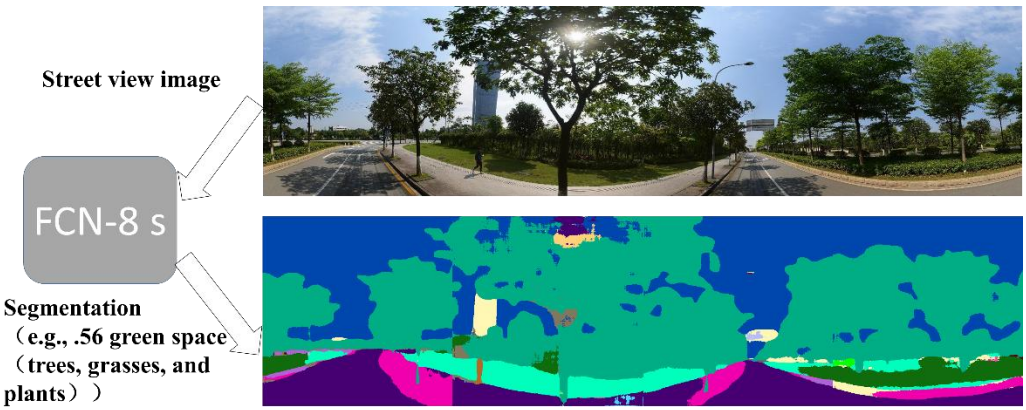

Figure 3. Street view image segmentation by a fully convolutional network (FCN-8s).

2.5. Analytical Strategy

As the dataset shows a nested structure, this study evaluated the associations between street-view greenness and fear of crime through multilevel regression modeling, with controlling several individual and neighborhood variables. Numerous studies on fear of crime have illustrated the satisfactory performance for multilevel modeling [5,20]. The multilevel analysis was performed with HLM 6.08 [56] in this present study. Here, the models were expressed as follows:

$$Fear\ of\ crime = \beta_0 + \sum_q \beta_q X_{qi} + r_i \quad (1)$$

$$\beta_0 = \gamma_{00} + \sum_s \gamma_s W_s + \mu_0$$

$$\beta_q\left(Mean\ X_{qi}\right) = \gamma_{q0} + \mu_q$$

In the equation, β_0 was the intercept; β_q was the slope of the factor q on the fear of crime; X_{qi} was the factor q for individual i; and r_i was the error term that was represented to the random effects. Where β_0 was modeled as a function of neighborhood contextual characteristics W_s (residential surrounding street-view greenery, etc.); W_s was the factor s for neighborhood j; the models were specified with a random error coefficient μ_q. This allowed the intercept to vary as a function of neighborhood features and any unique neighborhood effects.

First of all, the present study estimated a one-way analysis of variance with random effects, to explore how much influence was produced by the neighborhood-level factors. Consistent with Wyant [57], the intraclass correlation coefficient indicated that 15.19% variation of the fear of crime can be explained by neighborhood-level variables, and the rest was attributed to individual-level change and random error. Then, separate analyses were conducted for surrounding green space within a .5 km, a 1.0 km, and a 1.5 km radius. In a multilevel regression model, a variable with no meaningful zero value needs to be centered. Therefore, all individual-level variables were mean grouped, and all neighborhood-level variables were grand mean centered in this current study.

2.5.1. Moderator analyses

Moderation analyses, which were performed to examine the moderation effects of perceived conditions on fear of crime, were conducted using HLM models. Before the analyses, all variables were centered to avoid potential multicollinearity problems [58]. At the first step, after the operation

of the level-1 model, the error terms of perceived perceptions (perceived physical and social disorder, and social integration) were checked. If the error term of the perceived condition variable does not vary significantly in the equation ($p > .05$), it indicates that the effect of the variable on fear of crime is mainly explained by individual-level variables, and the role of the neighborhood environment is not important. If the variance component of the variable significantly varies across neighborhood context, a series of neighborhood variables would be entered to the intercept to detect the variance of the effect of the perceived condition, exploring the function of the neighborhood-level street-view greenery after controlling for the effects of other neighborhood variables [52,59,60]. The equations are below:

$$Fear\ of\ crime = \beta_0 + \sum_q \beta_q X_{qi} + r_i \quad (2)$$

$$\beta_0 = \gamma_{00} + \sum_s \gamma_s W_s + \mu_0$$

$$\beta_q\left(Mean\ X_{qi}\right) = \gamma_{q0} + \sum_s \gamma_s W_s + \mu_q$$

2.5.2. Mediated analyses

Mediation analysis was undertaken in four steps following Baron & Kenny [61] and previous research [62]. Conditions for mediation are that the predictor variable (street-view greenery) must influence the mediator; and that the mediator must influence the outcome variable (fear of crime); and that the association between the predictor and outcome is eliminated or weakened when the mediator is included in the model. The mediating role of the perceived condition on the relationship between street-view greenery and fear of crime was assessed by conducting three separate statistical models. First, the correlations were calculated between the possible mediators (physical and social incivilities, and social integration) and fear of crime. Only for combinations with statistically significant correlations are possible mediation considered. In these cases, the second step was to compute a linear regression where the possible mediator was entered as the dependent variable and street-view greenery was taken as the independent variable. The last step was to perform a multiple regression using a saturation model, in which both the mediator and street-view greenery were entered as independent variables, and the fear of crime was input as the dependent variable. 5,000 bootstrap samples were used to examine the statistical significance of the mediating variable. This method achieves 95% confidence intervals (CI) of the indirect effect. A bootstrapped 95% CI not straddling 0 is considered statistically significant [63]. Mediation analysis was conducted using the PROCESS v3.5 for SPSS Statistics 22 (Model 4, Hayes [63]).

3. Results

3.1. Descriptive statistics

Among the finally chosen 73,289 image sites in central Guangzhou, street-view greenery scores vary from 0 to .86, with a mean value of .234. The histogram distribution of street-view greenness for all image sites in Guangzhou is shown in Figure 4c. Compared with the vegetation greenness by satellite imagery (NDVI, the normalized difference vegetation index), the visualization of greenness in the street shows similar but different spatial characteristics (Figure 4 a & b). Converged to a planar spatial scale, street-view greenery of neighborhood under different radii show similar values, with .27, .25, and .25 respectively.

The descriptive statistics of participants' individual and neighborhood characteristics were presented in Table 1. The sample was composed of 49.1% women, with an average age of 40.42 years. The average fear of participants was not high (Mean = 2.34). We also took the correlation analysis for the individual and neighborhood characteristics, separately. No problems with colinearity were detected.

355 **Table 1.** The characteristics of the study variables

	Mean	SD	Min	Max		% (N)
Individual level						
Age	40.21	14.68	19	84		
Gender (female=1)	.49	.50	0	1	Female	49.3% (381)
					Male	50.7% (392)
Level of education	4.46	1.64	1	8		
Personal income	3.67	1.24	1	7		
Prior victimization experience (yes=1)	.35	.48	0	1	Victimization	35.2% (272)
					Non-victimization	64.8% (501)
Perceived physical incivilities	2.82	.83	1	5		
Perceived social incivilities	1.85	.76	1	5		
Perceived social integration	3.42	.83	1	5		
Neighborhood level						
Street-view greenery (0.5 km buffer)	.27	.07	.07	.47		
Street-view greenery (1.0 km buffer)	.25	.05	.10	.39		
Street-view greenery (1.5 km buffer)	.25	.04	.14	.36		
Percentage of population with a bachelor's degree or higher	.19	.22	.01	.86		
Percentage of migrant population	.17	.13	.02	.65		
Robbery rate (per 100,000 people)	53.68	81.30	.00	304.16		
Dependent variable						
Fear of crime	2.34	1.03	1	5		

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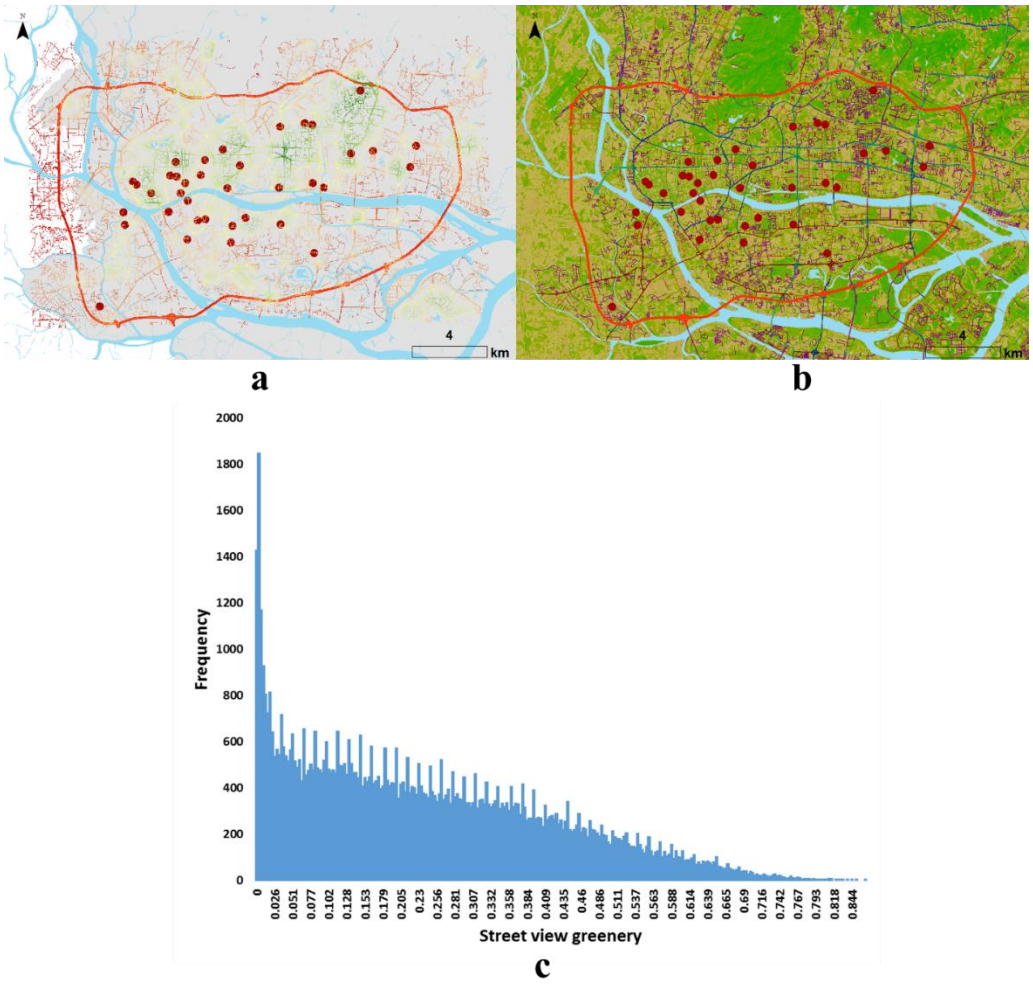

Figure 4. Descriptive statistics (a. visualization of street-view greenery in the street; b. vegetation greenness by satellite imagery on February 7, 2016; c. histogram distribution of street-view greenery.)

3.2. Main effects of street-view greenery

In line with expectations, after controlling relevant variables, street-view greenery within 1.0 km was significantly related to fear of crime (coeff. = -3.25, $p < .05$, Model 1, Table 2), thus, respondents exposed to more street-view greenery in the living environment reported lower levels of fear than respondents exposed to less street-view greenery in the living environment.

To evaluate the robustness of our findings to our selection of 1.0 km buffer size, we repeated the aforementioned main analyses using street-view greenery in buffers of .5 km and 1.5 km. Sensitivity analyses showed consistent results for different buffer sizes. Surrounding street-view greenery within .5 km was associated with lower levels of fear of crime, while street-view greenery within 1.5 km was not statistically significantly associated with fear of crime. That is, higher street-view greenery in the distant environment did not impact people's fear of crime in their neighborhood. This is in line with the assumption that cumulative opportunity metrics.

Some of the controls were statistically significant. Women were more fearful than men, while the older reported a lower fear level than young people. Perceived physical and social incivilities were positively correlated with fear of crime. Respondents who perceived higher physical or social incivilities in the neighborhood had a higher fear level. Perceived social integration was associated with a lower fear of crime. At the individual level, we found no evidence that levels of education, personal income, and prior victimization were significantly related to fear of crime. At the neighborhood level, neighborhood migrant population is statistically associated with a lower fear of crime.

Table 2. Multilevel results of the effect of street-view greenery on fear of crime (with robust standard errors)

	Model 1			Model 2		
	Coeff.	**SE**	**T**	**Coeff.**	**SE**	**T**
Intercept	2.22**	.08	29.47	2.22**	.08	29.50
Level 1 – Between individuals						
Age	-.01*	.00	-2.30	-.01*	.00	-2.27
Gender (female=1)	.38**	.08	4.87	.37**	.08	4.59
Level of education	.01	.03	.23	.01	.03	.36
Personal income	.03	.03	1.00	.03	.03	.92
Prior victimization experience (yes=1)	.10	.11	.93	.09	.11	.89
Perceived physical incivilities	.14**	.05	2.82	.13*	.05	2.64
Perceived social incivilities	.26**	.08	3.37	.26**	.08	3.38
Perceived social integration	-.10*	.04	-2.48	-.09*	.04	-2.27
Level 2 – Between communities						
Street-view greenery (SVG) (1.0 km buffer)	-3.25*	1.59	-2.05	-3.51*	1.63	-2.16
Percentage of population with a bachelor's degree or higher	-.31	.34	-.92	-.37	.33	-1.10
Percentage of migrant population	-1.33*	.66	-2.05	-1.31*	.69	-1.89
Robbery rate (per 100,000 people)	.00	.00	1.07	.00	.00	.88
Cross-level Interaction						
Social integration × SVG				-1.42*	.78	-1.82
Percentage of population with a bachelor's degree or higher × SVG				.31	.26	1.18
Percentage of migrant population × SVG				-.02	.34	-.07
Robbery rate × SVG				-.00	.00	-.63
Variance components	Var.	$\chi 2$	*P*	Var.	$\chi 2$	*P*
Between individuals	.92			.93		
Between neighborhoods β_0	.20	176.85	.00	.20	176.12	.00
Slope of the perceived social integration	.01	28.75	.02	.01	27.64	>.5

Note: SVG = street-view greenery (1.0 km buffer). *p< .05, **p < .01.

3.3. Moderator analyses

After the operation of the level-1 model, only the error terms of social integration varied significantly in the equations ($p < .05$), which indicated that the effect of social integration on fear of crime was partly explained by neighborhood-level environment. Then, a series of neighborhood variables were entered to the intercept to detect whether the effect of social integration on fear of crime was influenced by neighborhood street-view greenery within 1 km. Analyses (Model 2, Table 2) revealed that fear of crime was significantly predicted by the interaction of street-view greenery × informal social integration (coeff. = -1.42, $p < .05$). The results demonstrated that informal social integration magnified the beneficial effect of street-view greenery on reduced fear of crime (see Figure 5a for the theoretical framework). As shown in Figure 5b, when social integration is higher, the streetscape greenery has a stronger inhibitory effect on fear of crime, and vice versa.

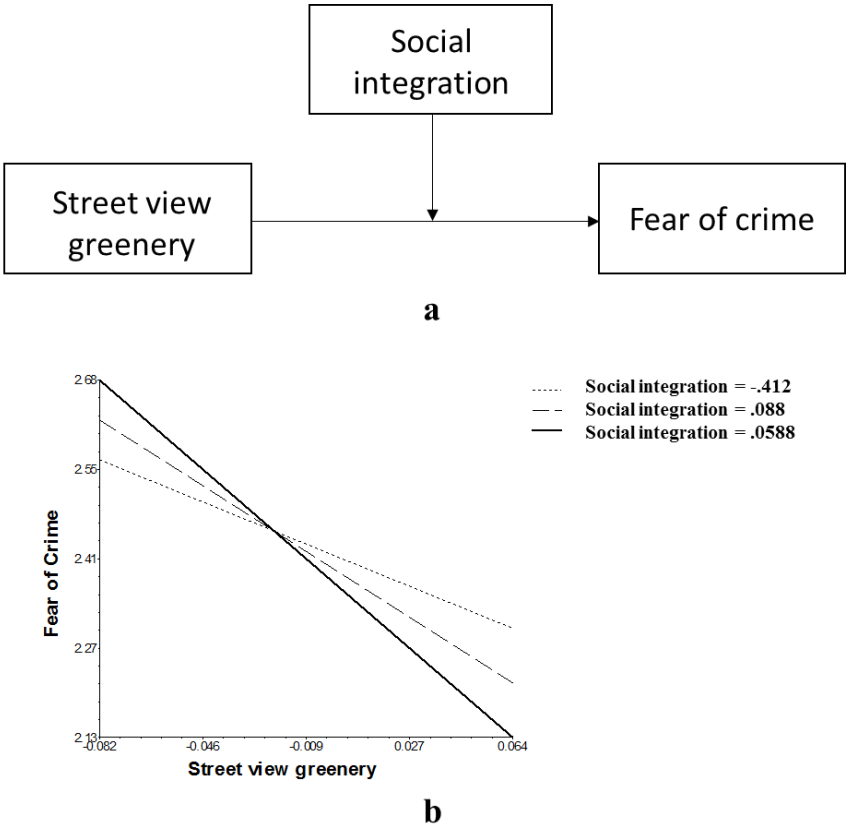

Figure 5. The results of moderator analyses (a. the theoretical framework of the moderating effect. b. moderating effect of social integration and street-view greenery on fear of crime (negative values appeared because of variables centered. Graphed by HLM software).)

3.4. Mediated analyses

We conducted a series of mediation effect analysis to test whether perceived conditions (physical and social incivilities, social integration) mediate the relationship between street-view greenery within 1 km and fear of crime. A mediation analysis PROCESS v3.5 for SPSS was performed.

Demographic and socioeconomic factors were included as covariates for models presented in this study, as they showed associations with certain variables of the present study. The mediation results of physical incivilities showed (see Figure 6) that: (1) street-view greenery predicted perceived physical incivilities ($b = -2.28$, $p < .001$); (2) physical incivilities predicted fear of crime ($b = .20$, $p < .001$); and (3) street-view greenery predicted fear of crime (the direct effect, $b = -3.10$, $p < .01$). It was also reported that street-view greenery as a predictor of fear of crime was mediated by physical incivilities (the indirect effect, b = -.45, CI (confidence interval) (-.88 to - -.14), SE = .19). The mediation test was performed by calculating CI (confidence interval) for the 'indirect effect' using bootstrap methods. For the size of the effect, all CI (confidence interval) did not contain zero point estimates, thus, 0 can be excluded as a probable value for the direct and indirect effects.

When other perceived conditions (perceived social incivilities and social integration) were included as the mediator for models separately, the mediation effect was not significant. Thus, no empirical evidence demonstrates the effect of street-view greenery on fear of crime via social incivilities or social integration.

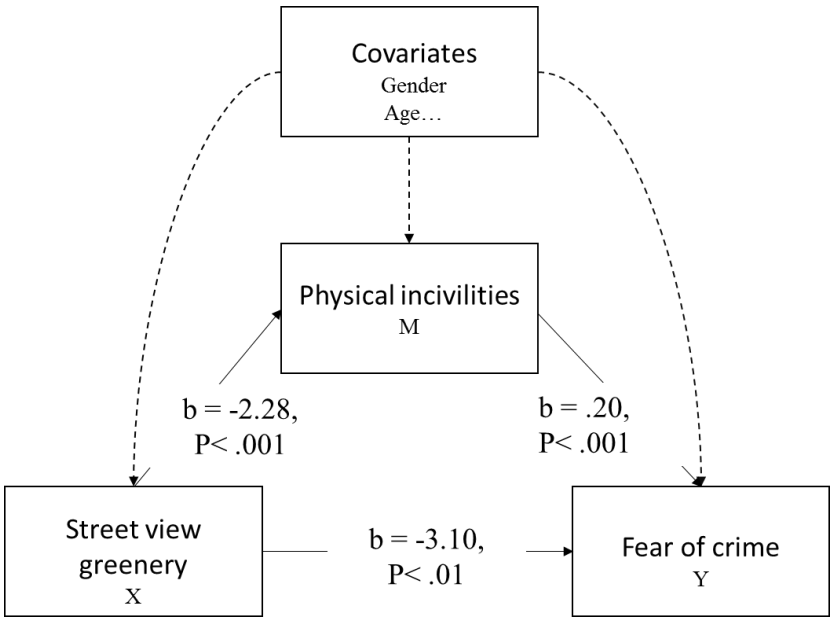

Figure 6. Mediation model of street-view greenery as a predictor of fear of crime, mediated by physical incivilities (b is an unstandardized regression coefficient, and CI is the confidence interval for the bootstrap approaches between BootLLCI and BootULCI).

4. Discussion and Conclusions

This study is the first to examine the linkage between fear of crime and exposure to green space at the street level among residents in China. Although remote sensing-based metrics of green space are widespread in criminological studies, we take an alternative avenue to assess green space, relying on deep learning technique and street view data. The results lead us to conclude that street-view greenery in people's living environment is generally associated with a lower fear of neighborhood crime. This relationship is concurrent with the positive relationship between green space and people's health and previous research. Enhancing urban green space not only makes people healthier but also helps to make them feel safer. The moderation and mediation analyses show that social integration magnifies the beneficial effect of street-view greenery on fear of crime, and perceived physical incivilities partially mediates the relationship between street-view greenery and fear of crime. It makes a further understanding of the relationship between green space and fear of crime, and guides that the safety improvement programs need to consider both the physical design and social factors.

4.1. Contributions to the understanding of green space and fear of crime

One contribution of this work is to further illustrate an environmental criminological perspective, that is, surrounding urban green space is associated with lower fear levels. Greener streets receive greater use, thereby increasing informal surveillance. Also, many forms of street vegetation preserve visibility and therefore it does not promote fear of crime in the neighborhood. This finding suggests that fear of crime prevention concerns do not justify removing street vegetation in highly urbanized areas.

Although this is the first study to demonstrate such a link, the findings are consistent with previous work linking vegetation with lower levels of incivilities [33], perceived social safety [44], as well as previous work linking vegetation with lower levels of crime rates [40]. Consistent with the findings of Maas et al. [5] and Mouratidis [7], we found that the positive relationship with safety

perception is linked to green space. The results obtained here are based on street-view greenery and neighborhood perception of safety, whereas previous literature is based on satellite imagery and social safety perception. The convergence of findings from such different measures lends confidence that in urban residential settings, the relationship between street-view vegetation and fear of crime in the neighborhood is negative. The higher the percentage of street-view greenery index, the less fear of crime.

Based on the deep learning approach, some scholars [53,64] collected perceived safety data and did some research on the relationship between perceived safety and environmental characteristics. The principle of street-view safety perception scores is to show participants two geotagged images and ask them to choose the image that looks safer. Then, any picture can get a safety perception score by the trained model based on the crowdsourced data. Li, Zhang, and Li [53] found that the visibility of green vegetation plays an important role in enhancing perceived streetscape safety. Different from the perceived safety by deep learning, in our study, fear of crime refers to the respondents' perception of safety in the neighborhood where they live. Even so, the work of Li and his colleagues indicated that green space contributes to enhanced safety perception of images. It provides support for explaining the impact mechanism of street green space on residential fear of crime.

Another contribution of the work here was to help resolve a previous puzzle on residential vegetation and feelings of safety. It is generally believed that objective or perceived green space is related to fear of crime because densely-vegetated urban neighborhoods represent lower levels of poverty and incivilities/disorder. This makes people mistakenly believe that green space itself is not associated with safety perception. The finding here shows that street-view greenery is systematically and independently associated with a lower fear of neighborhood crime, after controlling other individual and neighborhood characteristics. Moreover, this study demonstrates that neighborhood physical incivilities/disorder partially but not completely mediates the relationship between street-view greenery and fear of crime. Thus, in essence, street-view greenery has direct and indirect effects on fear of crime.

When considering the interaction between social integration and street-view greenery, it shows that in the high street-view environment, people with high social integration are likely to have a higher safety perception compared with people with low social integration. Thus, the effect of street-view greenery on fear of crime is related to social factors of the neighborhood. However, mediation analyses did not reveal that social integration mediates the relationship between street-view greenery and fear of crime. Based on our results, which display a stronger case for social integration act as a moderator than a mediator. In fact, social integration is a frequently mentioned moderator, which moderated the relationship between street traffic and fear of crime [42] and the relationship between perceived neighborhood disorder and fear of crime [65]. This finding demonstrates that the effect of street-view greenery on fear of neighborhood crime might be linked to both individual and neighborhood characteristics.

4.2. Practice implications and further research directions

As street vegetation does not necessarily promote fear of crime and may even inhibit fear in urban neighborhoods, it seems appropriate to increase street greenery in crowded inner-city areas to create safer neighborhoods for residents. Further, a series of street greenery strategies are recommended. High-visibility trees and grassland should be planted more, because of providing good visibility. Then, green space strategies should continuously maintain the street green space to avoid the negative impact of green space on fear of crime. Finally, since green space can be used as a sign of territory, so planting green space in main road nodes can promote a greater beneficial effect.

The findings also have implications in other aspects. Research results show that fear of crime is simultaneously influenced by physical environment and social factors (moderation and mediation effects). Ultimately, the largest reductions in fear of crime will come from strategies that address the social and cultural factors, such as reducing intense poverty, improving the level of collective efficacy, and reducing the level of incivilities in the neighborhood. These strategies can help play a positive role in physical design such as planting street greenery on the safety perception.

Our findings set the stage for further exploration of the relationship between urban street vegetation and fear of crime. With the development of deep learning technique, the results of image segmentation are constantly enriched. Future studies might use a deep learning approach to detect the maintenance level and specific characteristics of vegetation (e.g. height, living vegetation volume, and vegetation health) in the street scenes in large quantities, and examine the fear of neighborhood crime associated with these factors. More detailed street-view greenery can examine more sophisticated relationships.

Street view images and machine learning are powerful tools for environmental exposure assessments in urban landscapes. As companies such as Baidu Map and Google Map provide geo-referenced and publicly available street view image databases with broad spatial coverage, the development of novel location-based environmental exposure measures (e.g. sky view index, street-view water space, etc.) to explore environment–crime relations is also meaningful.

Our moderator and mediator models partially explained the mechanism of green space – fear of crime linkage. Future research is needed to examine more potential moderators and mediators, such as perceived neighborhood attachment, informal social control, and physical activity. Also, the effect of green space on fear of crime might vary across types of neighborhoods. The effect of green space in high-income areas and low-income areas might be inconsistent or even opposite. The next step should compare the effect of street green space on fear of crime in different types of neighborhoods. Finally, even if street green space reduces the fear of crime, is this relationship linear or curvilinear? Living in an area with very high green space exposure, the benefits of greenery may be reduced because of the desensitization effect. Future research might also focus on the possible nonlinear relationship between green space and fear of crime.

4.3. Limitation

The present research has a limited ability to make causal inferences regarding our evaluated associations. The first limitation is the temporal and spatial resolution of street view data. We did not obtain the street view during the same period of the questionnaire survey because of the technological restriction of Baidu street view rules. Street view is not updated every year, which does not accurately reflect the changes in the street environment. Besides, there are some small roads or alleys that people often walk, but street view cars cannot enter to capture images. The spatial distribution of street view is not even in some areas. Secondly, our data do not provide any information on the actual use of green space by the respondents, such as the frequency of visiting green space and time during the green space. It limits to reveal the relationships between objective street green space, perceived street green space, and fear of crime. Although several limitations need yet to be overcome, the present study demonstrates the relationships and mechanisms of a novel street-view greenery and fear of crime.

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