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Impact of the quality and quantity of eye-level greenery on park usage

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ABSTRACT

Urban parks have well-documented health benefits for urban residents. To increase the use of parks and enhance the physical activity level of city-dwellers, recent studies have explored the link between the amount of greenery in parks and the level of park usage. However, the results have been inconsistent, partly due to different measurements of park greenery. In this study, we developed a novel method to assess both the quantity and quality of park greenery from eye-level photographs taken along major paths in parks. The quantity of greenery in these photographs was objectively assessed with advanced machine learning techniques (PSPNet), and the quality of greenery was assessed by virtual audit. The associations between greenery and usage of 43 urban parks were further explored with regression models. The results showed that the quality of greenery has stronger association with total number of park visitors than the quantity. Both the quantity and quality of greenery had stronger associations with the number of elderly visitors (apparent aged 65 or above) than with the numbers of children or adults. Our results bring new insights into how park greenery can encourage park usage and contribute to healthy cities.

1. Introduction

1.1. Urban parks and its benefits

Rapid urbanization during the last several decades has profoundly affected the health and well-being of the world's urban population, which now numbers in the billions (World Health Organization, 2007, 2016). Urban inhabitants benefit from the development of sanitation, infrastructure, amenities, and access to better health care in cities and towns. At the same time, they face challenges including unhealthy diets and physical inactivity, environmental pollution, high risk of non-communicable diseases, and high rates of alcohol misuse (Eckert and Kohler, 2014; Moore et al., 2003). Urban populations may also be subject to higher risks of infectious disease outbreaks, as highlighted by the COVID-19 pandemic. The growth of the world's urban population makes it imperative to understand how urban forms affect health and well-being. Knowledge of such effects can inform evidence-based policies and urban planning to promote public health in cities around the world.

Increasing evidence suggests that the built environment plays a role in influencing public health (Takano, 2007; Vlahov and Galea, 2002). In particular, provision of green spaces, such as parks, promotes the physical, mental, and social health of urban populations. Parks provide opportunities for engaging in physical activity, enjoying nature, interacting with others, and escaping from stress (Cohen et al., 2006; Hayward and Weitzer, 1984; Kazmierczak, 2013). Studies have found that the availability of nearby parks and natural settings is associated with enhanced sustainability of cities (Standish et al., 2013), better social cohesion (Kazmierczak, 2013), improved mental health (Liu et al., 2019; R. Wang et al., 2020), positive affect and reduced anxiety (More and Payne, 1978; Wood et al., 2017), better physical health (Payne et al., 2005), and healthier weight among children (Potwarka et al., 2008).

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1.2. Parks usage and proximity

To increase the use of urban parks and enhance the physical activity level and health of city residents, a large number of studies have examined the characteristics of parks that promote their use, including accessibility, size, the quality and quantity of natural elements, and the characteristics of surrounding neighborhoods (D. Wang et al., 2015; Xiao et al., 2017).

Park accessibility is often measured as the travel distance from the location of a park to where residents live. Some governments have set standards for park provision, such as 3–10 acres per 1000 people or access within a 15-min walk (Michigan Department of Natural Resources, 2009; National Recreation and Park Association, 1996; Waunakee Parks Department, 2012). Researchers have found that distance is one of the most important factors associated with the likelihood of using public parks (Giles-Corti et al., 2005). Similarly, perceived long travel distances were found to be the main reasons for infrequent visits to urban parks (Byrne and Wolch, 2009; Žlender and Ward Thompson, 2017). A study conducted in the United States and Belgium provided evidence that parks in highly walkable neighborhoods attracted more users as well (Van Dyck et al., 2013).

Size has also been considered as an important feature related to the park usage (Giles-Corti et al., 2005; Holman et al., 1996; Sugiyama et al., 2010). Several studies found that people tend to visit larger parks, since they may provide more facilities for users. In a study conducted in Odense, Denmark, researchers found that park size predicted whether a park was frequently used or not (Schipperijn et al., 2010). Another study conducted in Perth, Australia, provided similar evidence, which suggested that compared with simply having closer distance, a larger open space within walking distance may be more important (Sugiyama et al., 2010).

Other park characteristics also predict park use. A number of studies show that attributes such as the presence of sports fields (Floyd et al., 2008), wooded areas, trails, paths, and sidewalks (Julian et al., 2008; Kaczynski et al., 2008), and the total number of features and amenities (Giles-Corti et al., 2005; Kaczynski et al., 2008) may promote park use and physical activity, whereas the presence of litter, vandalism, and unclean washrooms may deter use (Gobster, 2002). Features such as playgrounds, basketball courts, walking paths, running tracks, swimming areas, lighting, shade, and drinking fountains may also be particularly important for encouraging physical activity among children and their caregivers in parks (Cohen et al., 2006). Researchers have found that the standard of park maintenance is related to park use (Loukaitou-Sideris and Sideris, 2009; Rung et al., 2011). Thermal comfort and sky-view factor also may affect the park attendance (Lin et al., 2012). Such research provides important insights into how urban parks may be designed to deliver better experiences and services in terms of both physical activity and leisure activity.

1.3. Greenery in the urban parks

As the most essential component of parks, both the quantity and quality of greenery can attract people to visit. The theories of environmental psychology, including the stress reduction theory (SRT) (Ulrich et al., 1991) and attention restoration theory (ART) (S. Kaplan, 1995), suggest that elements of nature have the effect of improving restoration from mental fatigue, stress, and negative moods. SRT suggests that natural environments can activate the parasympathetic system and cause relaxation to reduce stress and decrease the heart rate and blood pressure (Ulrich et al., 1991). ART deems that green landscapes capture people's spontaneous attention and require little mental effort to process, allowing them to rest from directed attention and recover from mental fatigue (Kaplan, 1995). Parks with vegetation and tree cover are likely to provide important locations for experiencing nature. Indeed, experiencing nature in urban environments is a commonly stated reason for people to visit parks, as they are a source of positive feelings and other psychological benefits, which fulfill immaterial and non-consumptive human needs (Chiesura, 2004).

Although people often express a desire to interact with nature (Bowler et al., 2010; R. Kaplan and Kaplan, 1989; Keniger et al., 2013), empirical studies investigating the associations between greenery and park use have so far delivered inconsistent results. Some research has reported significant associations. For example, both the perceived and objective greenery have been shown to be associated with physical activity, such as walking, cycling, or jogging (Kaczynski et al., 2009; Neuvonen et al., 2007). Poor maintenance of greenery can discourage use of urban parks (Jim and Chen, 2006). However, other research has reported mixed results. A field observation in Sheffield, U.K. revealed that once inside parks, visitors tended to prefer locations with lower tree cover (Irvine et al., 2010). In a study conducted in the Netherlands, no relationship was found between the amount of greenery and whether people met the Dutch public health recommendations for physical activity and walking (Maas et al., 2008). In recent studies, researchers have demonstrated the importance of greenery quality over quantity (Zhang et al., 2015). Some research questions remain unanswered: for example, the extent of independence between the effects of the quality and quantity of park greenery in attracting park users, and the specific greenery characteristics that encourage park use.

The inconsistency in the results may be due to differences in how researchers have defined and measured urban greenery. Surveys are widely used in both health and urban studies to collect subjective self-reported data, such as the perceived quantity, quality, and accessibility of parks and public green spaces. Field audit is another popular method, which is often conducted by trained researchers to measure the quantity and quality of greenery directly with standardized auditing instruments. However, recently, researchers have argued that such methods are often too time-consuming and labor-intensive to allow sufficiently large sample sizes or scales of study (Seresinhe et al., 2017).

Previous planning and design theory indicated that different levels of greenery, for example, the green ground cover, the eye-level greenery, and tree canopies, may influence the experience and perception of urban green space (Appleton, 1996; Dee, 2001; Gehl, 2011; Robinson, 2016). Eye-level can provide a direct perception for visitors to experience the environment exposure, thus the eye-level greenery may play a significant role in the green space attractiveness. To date, there is few studies to discuss the link between eye-level greenery and green space visitors. One of the indispensable functions of the community park is provide space for people to engage in physical activity. Several studies already found the positive association between the quantity of eye-level greenery and physical activity level (Lu et al., 2018, 2019; Yang et al., 2019). Besides, other studies also found the positive correlation between eye-level visibility of vegetation and perceived safety and privacy, which are both important components for the restoration effect of urban parks (Li et al., 2015; Nordh et al., 2009).

1.4. New measuring methods of urban greenery

In the emerging era of big data and advanced techniques, researchers are now able to objectively assess various features of greenery with a large geographic reach, such as tree cover (Irvine et al., 2010) and overall vegetation coverage from satellite imagery, e.g., the normalized difference vegetation index (NDVI). However, the characteristics of greenery measured by park area or tree counts, NDVI, or other overhead-view measures often differ from greenery as perceived by people at eye level, especially in locations with dense vegetation (Lu, 2019; Lu et al., 2018). For instance, satellite imagery often fails to detect fine-grained vegetation or vertical greenery. A study in the United States quantifying NDVI found that this measure did not predict residents' walking behaviors (Tilt et al., 2007). Therefore, overhead-view greenery measures may be inadequate to assess people's exposure to greenery.

In recent studies, researchers have found that eye-level greenery assessed using Google Street View (GSV) images has stronger association with physical activity behaviors than traditional metrics (Lu et al., 2019; Yang et al., 2019). GSV images are captured by cars moving along streets and enable eye-level streetscape images of various locations to be recreated. GSV images may capture a variety of vegetation, such as street trees, shrubs, lawns, green walls, and front gardens next to streets, which are difficult to assess accurately from satellite imagery (Anguelov et al., 2010). Thus, GSV images bear a close resemblance to what pedestrians see and perceive, allowing people's exposure to greenery in daily life to be more accurately characterized.

1.5. Gaps and current study

Although the assessment of urban greenery using GSV has several advantages, the method is affected by three major gaps:

1) GSV images are not available along walking paths within most urban parks. Some urban parks are captured by only a few GSV images taken at limited locations, which do not fully represent the greenery within the parks.
2) The use of eye-level photographs to assess the quality of greenery has rarely been attempted, as researchers have mainly used GSV images to assess only the quantity of greenery.
3) GSV images are recorded and updated infrequently; thus, the available GSV images may not match the planned study period. For example, the level of greenery in winter, as captured in GSV, would be less than in summer. Hence, the mismatch between GSV and the planned study period could result in errors.

In this study, we addressed the above-mentioned research gaps with a novel method to assess both the quantity and quality of eye-level greenery in parks. Specifically, we examined the relationship between park usage and the quantity and quality of eye-level park greenery in 43 urban parks of Hong Kong. We manually collected eye-level photographs along major walking paths in parks and then assessed the quantity of park greenery with machine learning methods, while the quality was judged by trained auditors using standard research tools. The standardized data collection and measurement ensure the consistence and generalizability of our novel method, which can be used in further studies. In addition to the methodological contribution, this study can improve our understanding of the impact of greenery quality on park usage and provide insights into how park greenery can encourage park usage and contribute to healthy cities.

2. Methods

2.1. Sampling parks

In current study, we selected Hong Kong as our study case. Hong Kong is a high-density city with hilly terrain, over 70 % of land were reserved as country parks or natural areas. Green space in Hong Kong is mainly comprised of country parks and community parks. The formers are often far away from residential areas, thereby community parks play a significant role in urban residents' daily life. We first used a geographic information system (GIS) to select parks that were closed to residential communities and with an area of within 7500 m^2 to 13,500 m^2 (ESRI, 2014). The facility and size information of a park was obtained from a Geo-community database from the Land Department of Hong Kong Government. We selected parks with similar size and similar facilities, therefore park size and facilities were not major factors leading to potential variation in park usage. We identified 50 parks as potential candidates.

A total of 43 medium-size community parks were finally selected with a stratified sampling technique (Fig. 1). Considering the geographics characteristics of Hong Kong, approximately equal numbers of parks were randomly selected in three major regions, including Hong Kong Island, Kowloon, and the New Territories. The sample size is comparable to other studies (Evenson et al., 2016).

2.2. Park usage

Before the assessment of park usage, we conducted a pilot study to observe the physical attributes (entrances, amenities, facilities) and usage in our selected community parks, to make sure the parks were accessible and open to the public. In general, there are only a handful visitors during the daytime of weekdays since most of the residents were in work or at school, thus we selected weekend as the observation period.

Following the proposed assessment guideline, the auditors were required to stay in the central of playground within the parks and record the number of park visitors in three different broad age groups: children

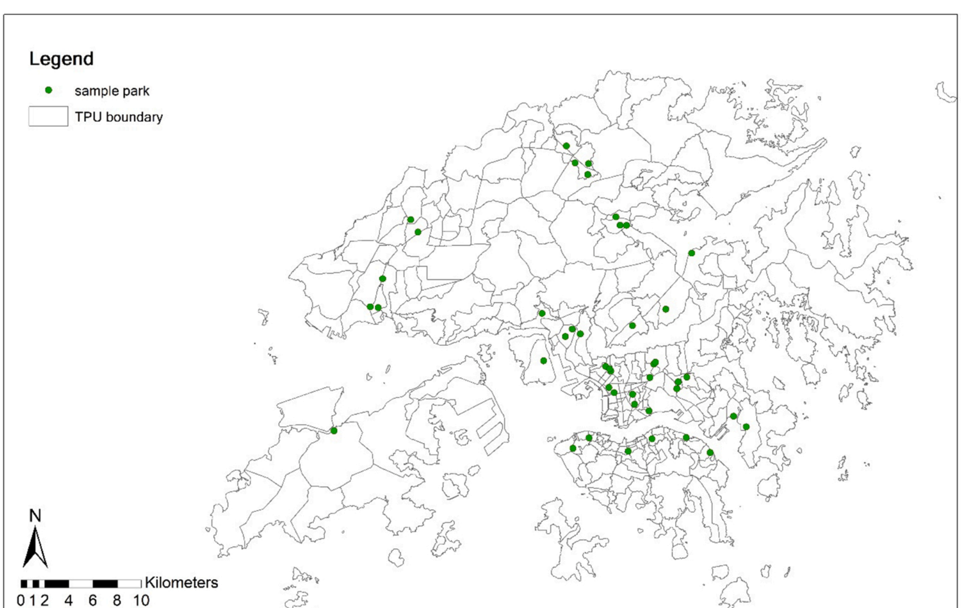

Fig. 1. Map of sampled parks in this study. A total of 43 medium-size urban parks in Hong Kong were randomly selected.

(apparent age under 18 years old), adults (apparent age 18–64 years old), and elderly (apparent age 65 years old or above). Each park had two auditors to record the number of visitors and their apparent age. Data were collected in weekends afternoons, during 3pm-5pm on April 6–20, 2019. The average number of park visitors and the numbers of visitors by different age groups, were recorded as dependent variables.

2.3. Quantity and quality of greenery

To measure the quantity and quality of greenery in the parks, sampling points for taking photographs were selected based on two guidelines: 1) along all major paths in the parks; 2) with 10-m spacing between these points (Fig. 2a). Before park assessment, these points were created and mapped using the Geography Information System (GIS) and GEOINFO MAP system of the Lands Department, the Government of HKSAR. The auditors started the observation from the main entrance and walked along all major paths within the park to take four photographs with a 90° field of view, facing forward, back, left, and right at each sampling point (Fig. 2b).

The quantity of greenery was assessed by two methods: 1) Green view index (GVI) and 2) the normalized difference vegetation index (NDVI).

The first method, GVI, was extracting the green view index from the photographs with a machine learning technique (PSPNet) to automatically predict pixels representing greenery (Fig. 2c) (Zhao et al., 2017). The PSPNet model was based on a deep convolutional neural network and trained on a cityscape dataset comprising 5000 annotated streetscape images (Cordts et al., 2016). The trained model can achieve an outstanding pixel-level accuracy of 93.4 % in identifying vegetation (Zhao et al., 2017). The automated greenery extraction was validated with manual extraction in this study and achieved a similar accuracy rate. The ratio of greenery pixels to the total pixels from the four images at each sampling point was used to measure the green view index for that point, as shown in the following equation:

$$Green\ view\ index = \frac{\sum_{i=1}^{4} Greenery\ pixels_i}{\sum_{i=1}^{4} Total\ pixels_i}$$

The green view index ranges between 0.0 and 1.0, with higher values representing more greenery. The average green view index of all sampling points in a park was used to quantify the eye-level greenery of that park.

The second method of measuring greenery quantity within parks was NDVI, which was extracted from the LANDSAT 8 satellite imagery available in the Global Visualization Viewer from the United States Geological Service (USGS). NDVI is widely used to quantify the overall vegetation by calculating as ratio between the red band (R) and near-infrared band (NIR) values using following equation:

$$NDVI = (NIR - Red)/(NIR + Red)$$

The NDVI ranged between −1.0 and 1.0, with higher values

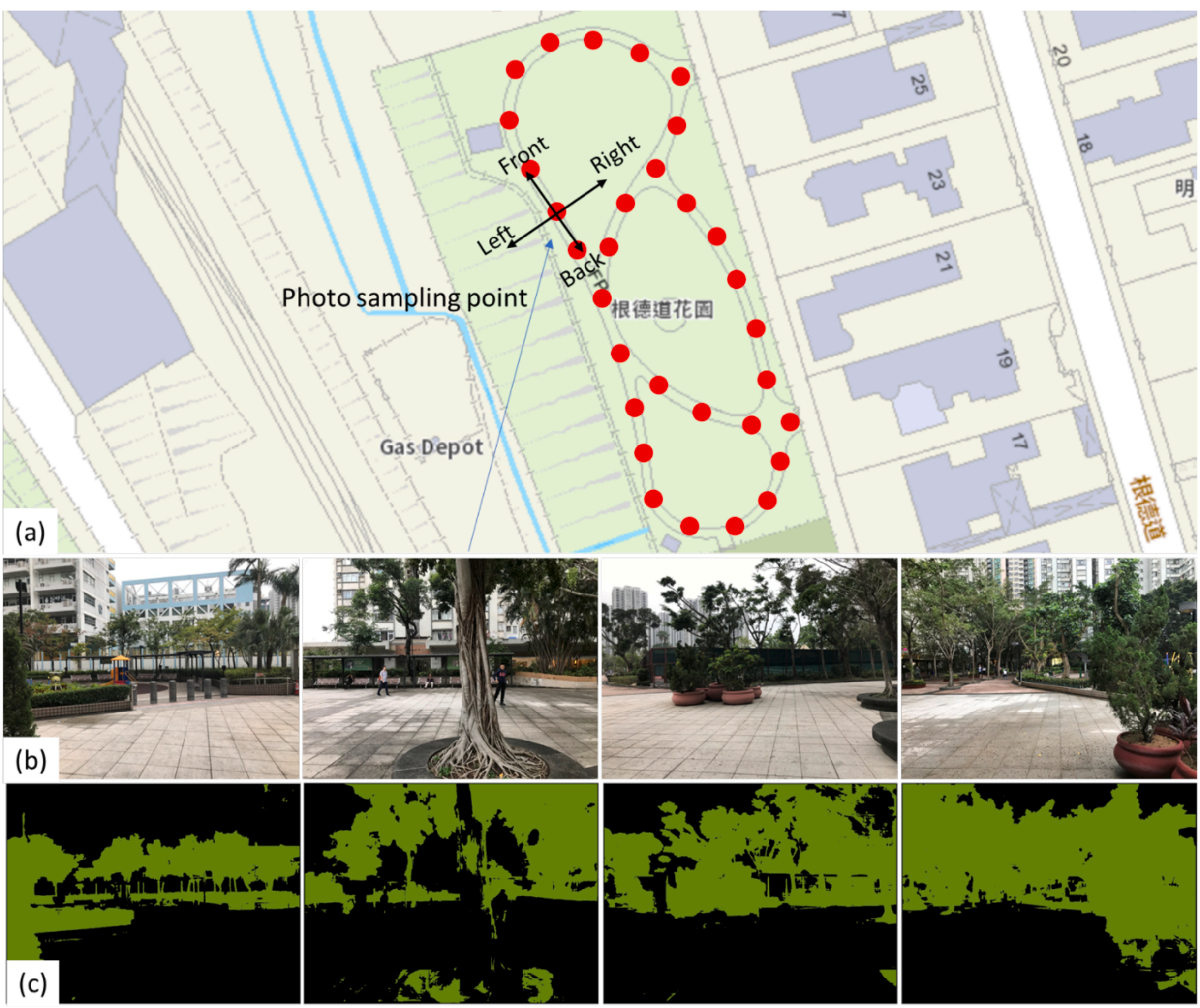

Fig. 2. (a) Photograph sampling points were identified with 10-m spacing along major paths in each park. (b) Four photographs were taken facing forward, left, back, and right at each photograph sampling point. (c) Greenery was extracted from the photographs with a machine learning technique.

representing higher levels of vegetation. The average NDVI value within a park was used to quantify the overall greenery of that park.

To measure the quality of greenery, we adopted a 6-item assessment tool from previous research (van Dillen et al., 2012) to measure the six aspects of greenery quality (Cronbach's $\alpha = 0.71$). Each item was rated on a 5-point scale (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree) by five trained reviewers. All the reviewers have the urban planning background learning for more than 5 years. Reviewers observed each photograph collected from the auditors and rated based on the assessment guidelines. To avoid the bias of first impression, all the reviewers did not visit the sampling parks before. The average score was calculated as the quality outcome of sampling parks. The description of items is listed below:

Item	Description
Variation	Are the species of vegetation within the park varied?
Maintenance	Is the greenery well maintained (e.g., the park is trim and clean, verges and trees are well cared for)?
Rich arrangement	Is the greenery well arranged (e.g., the design of the landscape is rich and layered)?
Absence of litter	Is the greenery free of litter?
Sense of safety	Can park users be observed through passive surveillance?
Aesthetic impression	Are there multiple diverse and interesting sights in the park?

2.4. Covariates

We also included the built environment attributes of the sampled parks as model covariates: the population density, land use mix, and number of bus stops within buffer zones around the parks, the park size (area), and the facilities in the parks. Population density and land use mix were measured at the spatial level of Tertiary Planning Units (TPUs), which are the census units defined by the Planning Department of the Hong Kong Special Administrative Region. The whole territory of Hong Kong is divided into 289 TPUs. Population density was defined as the residential population per unit of land area within the TPU where the park was located. Land use mix was calculated by measuring equal distributions of land use types within the TPU where the park was located. Three land use types were considered: residential, office, and commercial. The number of bus stops was calculated as the total numbers within the 400-m and 800-m street network buffer zones of a park. The park area was obtained from the Planning Department of the Government of Hong Kong S.A.R. The facilities in the parks were counted from the photographs taken by the trained auditors.

2.5. Analysis

Linear regression models were performed to examine the relationship between the park usage and the quantity and quality of greenery. In Model 1, the quantity and quality of greenery were separately added into the model: Model 1a contained the covariates and quantity of greenery, whereas Model 1b contained the covariates and quality of greenery. In Model 2, the quality and quantity of greenery were simultaneously added. All models controlled for built environment covariates. The data were further analyzed by the different park user groups: children, adults, and elderly visitors. The same two models as above were implemented for this part of the analysis. The coefficients and standard errors (SE) were reported. Fig. 3 illustrated the flow of study design.

3. Results

During our observation period, the most visited park was Fung Tak Park, which is located in Kowloon and surround by several large public housing estates. The average quantity of eye-level greenery within the Fung Tak Park is 0.33, the greenest quartile among all the sample parks. All the quality items were rated 4 points or above, among which the items "rich arrangement" and "sense of safety" were rated 5 points. As shown in Fig. 4, the greenery in this park is well designed and maintained.

Table 1 shows that the total number of park users was significantly and positively associated with the GVI, but not the NDVI, in both the 400-m and 800-m buffers. It was also positively associated with the level of the richness of arrangement ($p < 0.05$) and aesthetic impression of the greenery ($p < 0.1$) in both buffers.

When quantity and quality were added to Model 2 simultaneously, the total number of park visitors was still significantly and positively related to the level of richness of arrangement ($p < 0.05$) and aesthetic impression ($p < 0.1$) in both buffers (Table 2). However, the association between total visitors and greenery quantity became insignificant in both buffers.

Table 3 shows the associations of the number of park visitors in different age groups with the quantity and quality of greenery separately in the 400-m buffer. All age groups were associated with rich arrangement of park greenery (children group: $p < 0.1$, adults and elderly group: $p < 0.05$). In addition, the numbers of adult and elderly visitors were significantly associated with the quantity (GVI) of greenery. The number of elderly visitors was strongly associated with the aesthetic impression ($p < 0.01$).

Table 4 shows the associations of the number of park visitors in different age groups with the quantity and quality of greenery simultaneously in the 400-m buffer. All age groups were associated with rich arrangement of park greenery (children and elderly group: $p < 0.1$, adults group: $p < 0.05$). The number of elderly visitors was also strongly associated with the aesthetic impression ($p < 0.01$) and quantity of greenery.

4. Discussion

In this study, we investigated 43 medium-size community parks in Hong Kong to explore the relationship between the quantity and quality

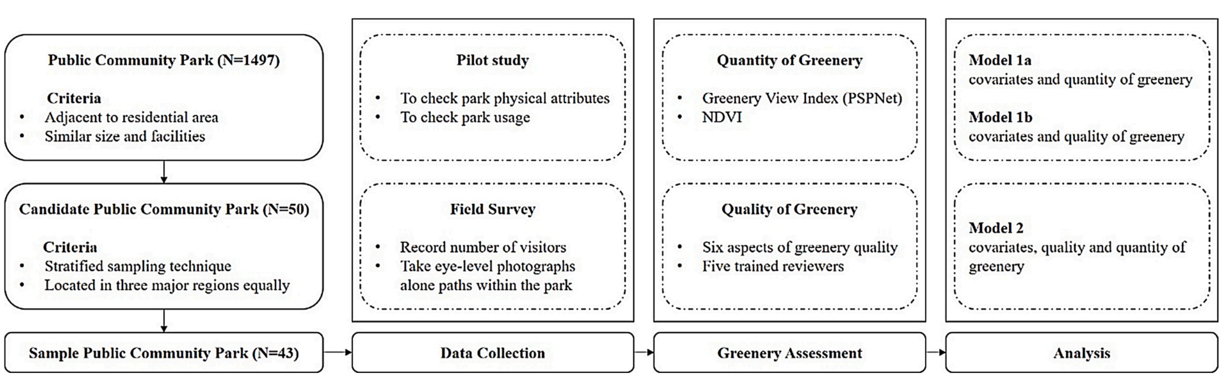

Fig. 3. Study design.

Fig. 4. Photographs of Fung Tak Park, which is the most visited park in our study.

Table 1
Regression model (Model 1) to predict total park visitor numbers from the quantity and quality of greenery separately in both the 400-m and 800-m buffers. Model 1a includes only quantity of greenery and Model 1b includes only quality of greenery. Both models control for built environment covariates.

Model Predictors	400-m buffer Coef. (SE)	800-m buffer Coef. (SE)
Greenery quantity (Model 1a)		
Green view index	204.277* (116.451)	240.588* (123.068)
NDVI	115.793 (110.653)	149.377 (106.590)
Greenery quality (Model 1b)		
Variation	2.239 (19.715)	2.484 (18.885)
Maintenance	11.267 (22.574)	4.445 (22.252)
Rich arrangement	61.004** (23.343)	56.538** (22.266)
Absence of litter	11.243 (22.131)	9.873 (21.541)
Sense of safety	7.557 (15.776)	6.655 (15.275)
Aesthetic impression	56.468* (29.702)	50.154* (28.126)

Note: $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

Table 2
Regression model (Model 2) to predict total park visitor numbers from the quantity and quality of greenery simultaneously in both the 400-m and 800-m buffers. Both models control for built environment covariates.

Model Predictors	400-m buffer Coef. (SE)	800-m buffer Coef. (SE)
Greenery quantity (Model 2)		
Green view index	149.137 (127.458)	164.451 (134.354)
Greenery quality (Model 2)		
Variation	7.517 (20.111)	5.417 (18.887)
Maintenance	10.217 (22.459)	3.809 (22.081)
Rich arrangement	56.873** (23.472)	50.467** (22.640)
Absence of litter	7.434 (22.240)	5.859 (21.620)
Sense of safety	4.241 (15.937)	4.370 (15.268)
Aesthetic impression	55.150* (29.548)	47.913* (27.963)

Note: $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

of park greenery and park usage. Previous empirical studies have shown mixed results regarding the impact of greenery on park usage, perhaps due to the different definitions and measures of park greenery used. Recent studies have harnessed eye-level greenery assessed by Google Street View (GSV) images to accurately assess people's daily exposure to greenery. However, GSV images are not available for most urban parks. In addition, GSV images have been rarely used to assess greenery quality. To address these research gaps, we collected eye-level photographs along major paths in parks and assessed both the quality and quantity of park greenery.

Both the quality and quantity of greenery were found to be positively associated with the total number of park visitors when they were entered into the regression models individually. This result is consistent with previous evidence that greenery within parks plays an important role in attracting visitors (Akpinar, 2016; Maas et al., 2008; van Dillen et al., 2012). In terms of the quantity of greenery, findings from our study suggest that greenery measured by Green View Index, but not by NDVI, may predict the park usage. The superior performance of eye-level greenery over overhead-view greenery, suggests that greenery perceived by residents was more related to the human activity than overall vegetation in a park. Moreover, the quality of greenery was more critical than the quantity in predicting the number of park visitors. In Model 2, the quantity became insignificant when both quality and quantity were simultaneously entered into the regression model. The superior predicting power of quality may explain the inconsistent results in previous studies. Studies measuring the quality of greenery have reported the significant associations of greenery with park use or physical activity (Giles-Corti et al., 2005; van Dillen et al., 2012). However, those

Table 3
Regression model (Model 1) to predict park visitor numbers in different age groups from the quantity and quality of greenery separately in the 400-m buffer. Model 1a includes only quantity of greenery and Model 1b includes only quality of greenery. Both models control for built environment covariates.

Model Predictor	Children Coef. (SE)	Adults Coef. (SE)	Elderly Coef. (SE)
Greenery quantity (Model 1a)			
Green view index	7.193 (46.920)	141.839** (62.397)	55.245* (29.875)
NDVI	19.2 (43.214)	100.783 (58.057)	29.314 (27.409)
Greenery quality (Model 1b)			
Variation	−4.226 (8.080)	7.603 (10.776)	−1.138 (4.701)
Maintenance	8.840 (9.252)	1.730 (12.339)	0.698 (5.383)
Rich arrangement	17.135* (9.567)	32.190** (12.758)	11.679** (5.567)
Absence of litter	−7.935 (9.070)	17.996 (12.096)	1.182 (5.278)
Sense of safety	−3.208 (6.465)	9.053 (8.623)	1.711 (3.762)
Aesthetic impression	16.749 (12.173)	18.808 (16.234)	20.912*** (7.083)

Note: $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

Table 4
Regression model (Model 2) to predict park visitor numbers in different age groups from the quantity and quality of greenery simultaneously in the 400-m buffer. Both models control for built environment covariates.

Model Predictor	Children Coef. (SE)	Adults Coef. (SE)	Elderly Coef. (SE)
Greenery quantity (Model 2)			
Green view index	−22.813 (53.253)	113.292 (68.168)	58.658* (29.178)
Greenery quality (Model 2)			
Variation	−5.034 (8.403)	11.613 (10.756)	0.938 (4.604)
Maintenance	9.000 (9.384)	0.932 (12.012)	0.285 (5.141)
Rich arrangement	17.767* (9.807)	29.052** (12.553)	10.054* (5.373)
Absence of litter	−7.352 (9.292)	15.102 (11.894)	−0.316 (5.091)
Sense of safety	−2.701 (6.658)	6.534 (8.523)	0.407 (3.648)
Aesthetic impression	16.950 (12.345)	17.807 (15.803)	20.393*** (6.764)

Note: $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

measuring only the quantity of greenery have often reported nonsignificant or negative results (Ball et al., 2007). Our study confirms that the quality of greenery, especially the richness of arrangement, is a key factor to improve the attractiveness of parks. Previous studies have indicated that a rich and diverse arrangement of greenery in a park is a desirable feature (Ćwik et al., 2018). Different measures of greenery may have different associations with park usage or other outcomes. Therefore, it is important to use multiple measures to assess various aspects of greenery in further studies.

We observed that only the rich arrangement of greenery was significantly associated with the number of children within the parks. We also found this in the adult group, possibly because children, especially those of kindergarten or primary school age, usually visit the park with their parents. Other aspects of greenery were not related to the number of children in a park. It seems intuitive that children would mainly use a park for its sports fields, such as football pitches or basketball courts. However, neither the quantity nor the quality of greenery is essential for children's park usage.

In terms of the elderly user group, both the quantity of greenery and the aesthetic impression of greenness have significant associations with the number of older adults. Research investigating park use patterns has found that older adults are more likely to engage in stationary activities in parks, such as sitting on benches and playing board games, rather than vigorous physical activities such as bicycling and jogging (T. Sugiyama et al., 2008). Therefore, older adults may pay more attention to both the quantity and quality of park greenery than children and adults do. Other research has also suggested that appealing environments can attract older adults and stimulate their physical activity (Moran et al., 2014).

Based on findings from our study, we can provide some tentative planning implications for park improvement and future design. First, in terms of the greenery quantity, park usage is more affected by eye-level greenery, rather than the overall greenery (NDVI). Therefore, to enhance the usage of urban parks, designers might need to consider improving the greenery exposure for visitors, instead of focusing on the conventional greenery index, such as green space area, either in total or per capita. Second, the quality of greenery significantly predicts the park usage, especially the rich arrangement and aesthetic impression. Therefore, park designers should consider the composition of different species plants, to create impressive and pleasant landscapes in parks. Additionally, findings from our study contributed a better understanding of the park usage and park preference in Hong Kong, a densely populated city with rapid aging population. Park is one of the important public spaces for older adults to engage in physical activity and social interactions. Our results can shed light on the future design of aging-friendly community parks in high dense cities.

This study has several innovative strengths. One strength is that we measured both the quantity and quality of urban greenness in parks using eye-level photographs taken by field auditors, which is much more accurate than the conventional method, such as site plan or satellite images. Traditional assessment method generally evaluated parks or greenspace from an over-head view, which was totally different with the daily viewpoint from visitors. Using eye-level image can objectively measure the perception of greenery, both the quantity and quality, thus may help urban planners to better understand which kind of attributes is important to visitors. Our method overcomes the limitation of current GSV images, which are often unavailable inside urban parks. The quantity of greenery in these photographs was extracted and calculated with advanced machine learning techniques PSPNet. We also conducted virtual audit of the collected photographs to assess the quality of greenery instead of relying on perceived quality self-reported by participants. Our study demonstrated that such methods can objectively measure the perception of quantity and quality of greenery reliably, accurately, and efficiently. With the development of street view images, future study may complete the assessment from the online database without the manual collection process.

However, several limitations in our study should be noted. We did not distinguish the purposes of visitors within the parks. It is feasible some visitors may just pass by a park if there are more than two park entrances. Further studies need to reduce such bias by removing such visitors. Second, we also did not conduct multiple observation sessions in each observation day. We observed park usage in the weekend afternoon to ensure fair comparison. However, using single observation time window may miss out variation of park usage across different time in a day or different days. It is necessary to conduct multiple observations in the future studies. Third, we cannot automatically assess some aspects of greenery quality, e.g., species, physical features, and aesthetic attributes, due to the currently limitation of machine learning technique. Future methodological developments with such capacities are needed to advance the field. Another limitation is the cross-sectional nature of the current study. It remains difficult to infer any causal relationship in this study. Natural experimental studies are needed to establish strong evidence between park greenery and park usage.

5. Conclusion

In this study, we developed a novel method to assess both the quantity and quality of park greenery from an eye-level perspective. The associations of greenery and usage of 43 urban parks were further explored with regression models. The results showed that both the quantity and quality of urban greenery affect the number of park visitors, while the quality of greenery plays a more significant role in predicting park visitors than the quantity. In addition, elderly visitors are more sensitive to both the quantity and quality of park greenery than adults and children are. With increasing concerns over the public health of urban populations, the findings from our study may help planners and designers develop urban parks that stimulate greater park usage by a wide range of urban residents.

CRediT authorship contribution statement

Yiyang Yang: Methodology, Investigation, Software, Formal analysis, Writing - original draft. **Yi Lu:** Conceptualization, Supervision, Writing - review & editing. **Haoran Yang:** Writing - review & editing. **Linchuan Yang:** Writing - review & editing. **Zhonghua Gou:** Writing - review & editing.

Declaration of Competing Interest

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.

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