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Which communities have better accessibility to green space? An investigation into environmental inequality using big data

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ABSTRACT

Green space accessibility is widely acknowledged as a crucial aspect of a livable environment and human well-being. Whether green space accessibility is equitable among communities is increasingly considered as an issue of environmental justice. Therefore, this study focuses on the possible environmental inequality of green space accessibility that can be found among residential communities in the context of Chinese booming housing market. The case study of Shanghai, China was conducted with the use of big data. A real-time navigation route measurement based on Amap application programming interface (AAPI) was developed to calculate green space accessibility, and housing price was used to indicate dwellers' socioeconomic status. Bivariate Moran's I, multiple regression, and spatial lag regression were adopted to explore inequality of green space accessibility among residential communities. The results reveal a spatial inequality of green space accessibility between communities in central portion of the city and those in *peri*-urban areas. We further found a spatial mismatch between green space accessibility and housing price. Environmental inequality is evident within the inner and middle ring road wherein wealthier communities benefit more from green space accessibility than disadvantaged communities. We attribute these findings to spatial restructuring and green gentrification process in Shanghai. The findings can inform planners and policymakers to determine where and how to implement greening strategies and to gain awareness to prevent environmental inequality.

1. Introduction

The fundamental role of urban green spaces in sustainable urban development has been widely acknowledged. A plethora of literature has emphasized the proactive role of green spaces in an urban environment, including air pollution reduction (Kroeger et al., 2014; Yang, McBride, Zhou, & Sun, 2005), water drainage (Bolund & Hunhammar, 1999), noise sequestration (Fang & Ling, 2003), and heat mitigation (Bowler, Buyung-Ali, Knight, & Pullin, 2010). Moreover, green spaces contribute to human well-being by providing recreational value (Coombes, Jones, & Hillsdon, 2010; Thompson, 2002) and promoting mental and physical health (Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Wolch, Byrne, & Newell, 2014). Therefore, sufficient accessibility to green spaces is increasingly recognized as an essential criterion of a livable urban environment. Interestingly, given the uneven distribution of green spaces, not all urban dwellers and communities can have the same degree of access to green spaces (Krekel, Kolbe, & Wüstemann, 2016; Zhou & Rana, 2012). Green space accessibility is thus intensified as a topic of environmental justice issues.

The concept of environmental justice is based on the general principle that all people have a right to be protected from specific environmental issues (i.e. pollution, climate changes) and have access to the same services (greenspaces, social services, transportation) (Agyeman & Evans, 2004). It includes different fields of research that integrate social dimensions (age, race, gender, and income), exposure to environmental risks (e.g., air pollution, greenspace, climate change), and accessibility issues (Boone, 2008; Walker, 2012). In terms of access to green space, environmental equality refers to the equitable access of residents to green space, regardless of diverse residents' factors; environmental inequality indicates the disproportionate distribution of green space among residents (Nesbitt, Meitner, Girling, Sheppard, & Lu, 2019; Nicholls, 2001; Wüstemann, Kalisch, & Kolbe, 2017).

During the last decades, access to green space has attracted considerable attention from Western authorities and planners. For example, the European Environment Agency suggests that urban dwellers should have access to green spaces within a 15-min walking distance (Stanners & Bourdeau, 1995). The Dutch Green City Guidelines project

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states that people should have an accessible green space < 500 m from their homes (Roo, 2011). However, such greening proposals are impracticable to be achieved, given that a greener environment is more livable but has higher criteria to acquire (Kong, Yin, & Nakagoshi, 2007), which may trigger environmental inequality. Therefore, a growing body of literature has focused on whether the inequitable green accessibility was associated with ethnicities (Hughey et al., 2016; McConnachie & Shackleton, 2010; Nesbitt et al., 2019; Zhou & Kim, 2013), ages (Gupta, Roy, Luthra, Maithani, & Mahavir, 2016; Kabisch & Haase, 2014; Loukaitou-Sideris, Levy-Storms, Chen, & Brozen, 2016; Reyes, Páez, & Morency, 2014), religions (Comber, Brunsdon, & Green, 2008), and incomes (Astell-Burt, Feng, Mavoa, M, & Giles-Corti, 2014; Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Sister, Wolch, & Wilson, 2010). Western scholars have ample knowledge of environmental inequality in access to green space, whereas related works in developing countries remain relatively scarce. Considering that specific urbanization processes may manifest in the process of green resource distribution, an investigation into environmental inequality in access to green space should be given greater attention in developing countries.

Green space has been emphasized as an element for high-quality life as cities moved up the ladder of urbanization in developing countries. In China, green space accessibility has been a planning goal since the reform and opening-up launched, with minimum distance, green space per capita, and time consumption considered as indicators. However, green space in Chinese cities is experiencing not only under-supply but also spatial deprivation. On the one hand, rapid urbanization and the resulting inadequate provision for green spaces are prevalent in Chinese cities. As urbanization has accelerated at an unprecedented rate, green spaces are subjected to be displaced by built-up land. For example, Yin et al. (2011) reported that 30.95% of green land was lost to the built-up area from 2000 to 2009 in Shanghai. Particularly, central urban districts are inclined to have low green space per capita (Yue, Fan, & Qi, 2014) due to their high-density population. On the other hand, green spaces are increasingly regarded as an environmental superiority of luxurious housing areas over disadvantaged communities in the context of soaring housing prices. In China, affluent communities are mostly close to parks, plazas, and forests (Kong et al., 2007). However, disadvantaged communities in urban villages and suburban areas are likely to share limited environmental amenities. In this regard, the housing price can represent the inhabitants' affordability to acquire a green environment. Consequently, growing concerns have emerged about whether green spaces are distributed unequally across communities.

Unfortunately, limited literature has focused on whether green spaces are distributed unequally at community level in China, due to the lack of fine-scale accessibility measurement and data source (Xiao, Wang, & Fang, 2019; You, 2016a). On the one hand, the measurements for green space accessibility rely heavily on spatial geographic units, such as census tracts, which may underestimate the number of accessible green spaces (La Rosa, 2014; Nicholls, 2001; Xiao et al., 2019). On the other hand, users' socioeconomic attributes in previous literature are mostly derived from census data at the sub-district level (Shen, Sun, & Che, 2017; Wei, 2017; Xiao, Wang, Li, & Tang, 2017; Xing, Liu, Liu, Wei, & Mao, 2018), which may fail to match green accessibility measurement at pixel-level. Similarly, using questionnaire data to explore user characteristics may cover finite samples, which cannot reflect the comprehensive attributes of different social groups (D. Wang, Brown, Zhong, Liu, & Mateo-Babiano, 2015; Yung, Conejos, & Chan, 2016). Under the circumstance, the applications to combine green accessibility measurements and user socioeconomic attributes at fine-scale are needed to be improved (Boone, 2008).

For addressing these limitations, multi-source big data is expected to explore environmental inequality in green space accessibility. Currently, an increasing body of literature has proved that geospatial big data can provide possibilities for measuring environmental inequality of green space accessibility at a finer-scale (Guo et al., 2019; Wu, He, Chen, Lin, & Wang, 2018; Xiao et al., 2019). In this paper, we firstly developed a real-time navigation route measurement based on Amp application programming interface (API), which was used to calculate travel time from communities to nearby green spaces. Secondly, we used housing prices extracted from the Lianjia website to characterize dwellers' socioeconomic status. Moreover, we used spatial correlation analysis and regression models to detect the spatial inequality pattern and environmental inequality of green space accessibility at the community-level, respectively. Using the central city of Shanghai as a case, we aimed to identify (1) the spatial pattern of green space accessibility and (2) environmental inequality of green space accessibility. In this paper, green spaces were defined as urban parks, public green land, and natural reserves that were freely allowed to access for the public. The paper proceeds as follows. The following section explains the analytic and modeling framework of environmental inequities in access to green space. Sections 3 and 4 introduce the study area, data source, and methods. Section 5 presents the results. Section 6 and 7 outline the discussion and conclusions, respectively.

2. Analytic and modeling framework

The crucial theoretical issue to the paper is: how to comprehend the environmental inequality of accessibility to green space? The theory of distributional justice improved by Rawls (1971) and (Young, 1990) provides the theoretical basis to interpret the environmental inequality of green space distribution among different users (Nesbitt, Meitner, Sheppard, & Girling, 2018) (Fig. 1). Rawls (1971) reflects on how resources should be distributed. As defined by Rawls' *A Theory of Justice*, justice is a standard whereby the distributive aspects of the basic structure of society are to be assessed (Nesbitt et al., 2018; Rawls, 1971). Equality is a foundation for distributional justice, which underlines the collective well-being of society. To pursue the distributional justice, freedom (another foundation for distributional justice) to consume resources should be partially given up to guarantee collective well-being. Particularly, social equality should be placed as a priority over freedom in the context of places wherein specific resources are limited. Therefore, distributional justice is focused on the fair distribution of resources. Young (1990) focuses on the factors that affect inequitable distribution. Young's literature *Justice and the Politics of Difference* is focused on the role of social determinants in the process of resource distribution. In her claim, inequitable resource distribution often arises from oppression, such as marginalization, exploitation, and cultural imperialism. Furthermore, such oppressions are rooted in social and institutional factors. In this regard, social structure, cultural belief, and institutional context may be the determinants of distributional injustice (Schlosberg, 2007; Young, 1990).

In light of the distributional justice theory, urban green space is a kind of limited public goods (Anguelovski, Connolly, Garcia-Lamarca, Cole, & Pearsall, 2018) that should be equitably distributed. However, different social groups have different degrees of freedom to possess green spaces. In this regard, environmental equality is analogous to equal opportunity of all regions and users to acquire green spaces, regardless of their socioeconomic status, cultural beliefs, and institutional context (Nicholls, 2001). Therefore, the phenomenon that access to green spaces among different social groups is uneven indicates an environmental inequality.

Existing literature focuses on exploring the relationship between green spaces and different social groups to describe environmental inequality. The modeling in existing literature can be decomposed into three components, namely, place of origin, destination, and distance (La Rosa, 2014). Place of origin refers to the location where users have the potential to enjoy green spaces. The attributes of the residence or user (e.g., housing price, income, ethnic group) can be proxies to reveal the social determinants mentioned by Young (1990). For example, Wu et al. (2018) used gated communities to characterize users' socioeconomic status in the distribution of green space. Destination refers to

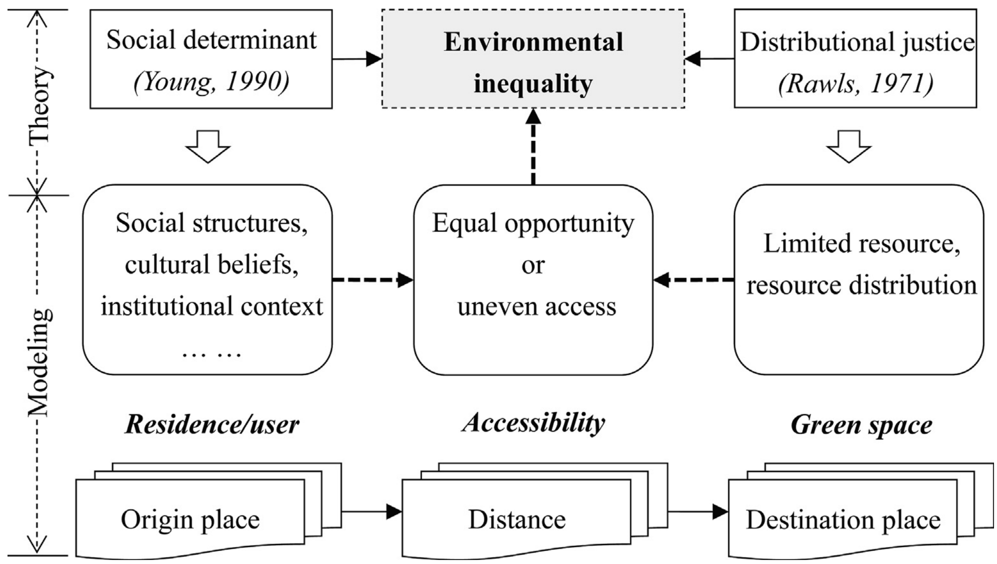

Fig. 1. Analytic and modeling framework for environment inequality in green space accessibility.

green space that can provide ecological service to users. Geometric polygons, entrances, and centroids of green spaces are generally applied to represent urban green spaces (La Rosa, 2014). Distance refers to the measurement of accessibility from users' locations to green spaces, such as Euclidean distance, network distance, and cost time. The distance is the criterion that identifies environmental inequality by examining whether users or residences have equal opportunities to acquire green spaces.

3. Study area and data

3.1. Study area

Shanghai, located in the middle of China's coastline and the Yangtze estuary, is the hub of China's economy, finance, trade, and shipping, with 24.19 million inhabitants (Fig. 2). Shanghai acquired 3.79% of China's GDP in 2016, with 1.75% of the nation's population. According to the roster of world cities proposed by Beaverstock, Smith, and Taylor (1999), Shanghai is categorized as an Alpha plus world city. Shanghai's central proper refers to the domain within the outer ring road, with an area of 662 km^2, which consists of eight districts: Huangpu, Xuhui, Changning, Jingan, Putuo, Hongkou, Yangpu, and Pudong. Given that nearly half of the city's population is clustered in the central proper (Shen et al., 2017), the city's population density is notably higher than any other megacities across the world (Hoole, Hincks, & Rae, 2019; You, 2016b).

Shanghai is putting great attention on green planning as the city embraces the concept of an ecological and low-carbon city. Public green spaces are witnessing unprecedented rapid growth, with the amount per capita increasing from 0.7 m^2 in 1990 to 7.8 m^2 in 2016. However, the indicator still falls behind the World Health Organization's criterion of a minimum of 9 m^2. Meanwhile, Shanghai is increasingly experiencing a "class transformation" that displaces low-income residents in old urban areas with the emerging middle class (He, 2007, 2010), which induces housing and socioeconomic inequalities. Under - such circumstances, the disadvantaged groups and low-income households are likely to live in deprived neighborhoods (Li & Wu, 2008; Wu, He, & Webster, 2010), with inadequate infrastructures and an absence of green spaces.

3.2. Data preparing

We used multiple-source data to explore the environmental inequality of green space accessibility. Firstly, green spaces were extracted from Amap (https://ditu.amap.com/), one of China's well-known navigation maps. The location-based service (LBS) on the Amap provides a full-scale classification of areas of interest (AOI), such as parks, shopping malls, residential zones. We selected AOI, including public parks, greenbelts, urban forests, plazas, and playgrounds and obtained these data by linking the Amap LBS using the Python code. 198 green spaces were extracted on April 3, 2017, as shown in Fig. 2. Fee-paying green spaces, such as zoos, botanical gardens, and golf courses, were excluded. Secondly, the data of the residential community was extracted from the website of Lianjia (http://www.lianjia.com/). Lianjia is one of China's web-based housing deal platforms that can provide services for real estate and rental deals. Lianjia documents complete attributes of residential communities, including locations, coordinates, prices, and building ages. We extracted the attributes of residential communities from the sectors of real estate in Lianjia website using the Python code on April 26, 2017. The data contains 8079 residential communities within the central city of Shanghai. In China, a residential community refers to a neighborhood with a mass of buildings developed by a property developer. Thirdly, the administrative map and industrial land maps were obtained from the Shanghai Bureau of Planning and Natural Resource.

4. Methods

4.1. Amap-based accessibility measurement

Four common methods are used to measure green space accessibility in existing literature (Dai, 2011; La Rosa, 2014): indicator (container, coverage, and composite index), minimum distance, travel cost (network analysis), and gravity-based model (Gaussian-based 2SFCA method). However, these approaches have a common drawback that fail to recognize the individual's preferred routes to green spaces (Nicholls, 2001) and the specifical built environments from communities to green spaces (e.g., river segregation and traffic signal).

Enlightened by the methodological gap, we developed a real-time navigation route approach based on Amap API to measure green space accessibility. Amap is a web-based navigation map that includes fine-scale road networks and entire urban fabrics, whose geographical features are more accurate than other data. The navigation route on Amap is similar to Google navigation (F. Wang & Xu, 2011; Zhou & Kim, 2013), which can provide optional routes and travel times according to real-time traffic conditions, road network, and travel mode when

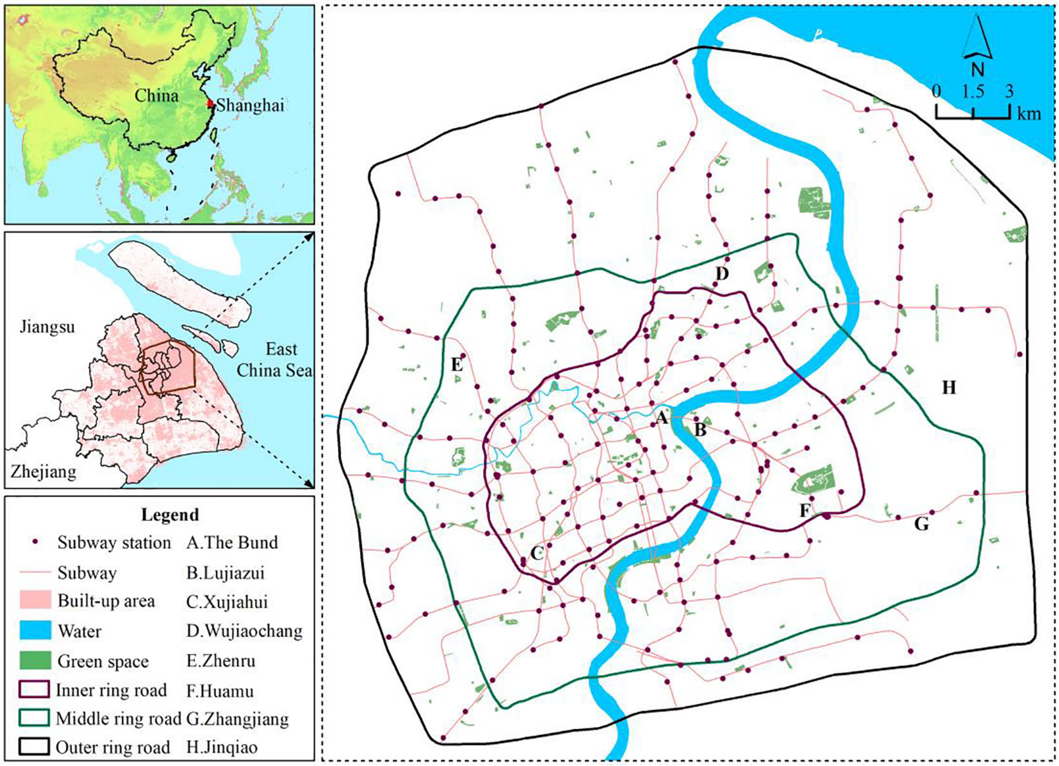

Fig. 2. Location of study area and distribution of green space. Notes: In this study, Shanghai is divided into three domains by the inner and middle ring road.

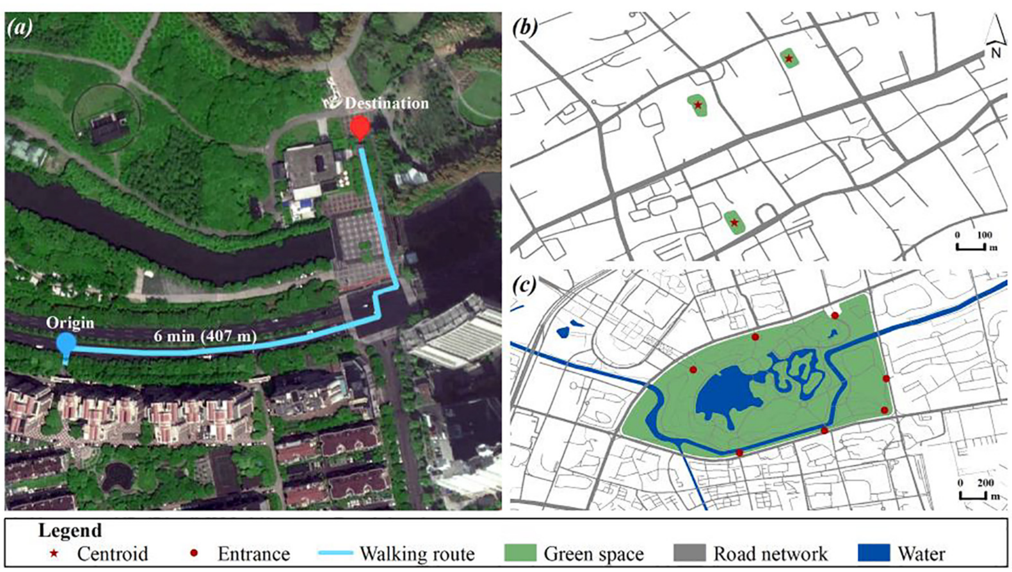

Fig. 3. Origins and destinations in the Amap navigation route. (a) Origin, destination, and travel time in a case. (b) Destinations of urban green spaces at community-level. (c) Destinations of urban green spaces at municipal-level.

origins and destinations are defined (Fig. 3a). In this study, a Python program was developed to obtain accessible data from the Amap Route Planning API (https://lbs.amap.com/api/webservice/guide/api/batchrequest). By using the program, we sent batch requests for navigation routes to the Amap API server to calculate the travel time from origins to a nearby green space. The accessibility data from Amap API was obtained in May 2017, and concrete steps were summarized as follows.

The first step is defining the foundational components for modeling the accessibility, including travel mode, place of origin, and destination. Firstly, we chose walking as the travel mode, given that inhabitants prefer to walk from residential communities to the nearest green spaces. Secondly, we defined 100 m*100 m sampling points covering the study area, regarding each point as an origin. The travel time of the optimum route from each sampling point to the nearest green space will be calculated in the Amap-based accessibility measurement (Fig. 3a). In terms of destination, we defined the centroid and entrances of green spaces as destinations (Higgs, Fry, & Langford, 2012; Nicholls, 2001) according to the level of green spaces. The centroids and entrances were defined as the destinations of community-level (area < 1 ha) and municipal-level (area ≥ 1 ha) green spaces, respectively (Fig. 3b and c).

In the second step, three defined variables were programmed in Python. We defined each sampling point as an origin to calculate the accessibility to the nearby destination by iterative algorithm. The travel time (min) of optimum routes from all origins to destinations were calculated by invoking the Amap API. To depict the coverage of green space accessibility, we used Kriging interpolation to transform origin points into a polygon that covered the study area. Moreover, the green space accessibility of 8079 communities was derived by overlaying the points of communities with the polygon of green space accessibility. In the present work, green space accessibility was measured in the unit of min.

4.2. Spatial correlation analysis

Global bivariate Moran's I and local bivariate Moran's I were employed to examine the spatial correlation between housing price and green space accessibility. These analyses were used to quantify the spatial correlations across the study area and within different communities, respectively (Anselin & Rey, 2014). In this study, time consumption from a community to the nearest green space was used to indicate green space accessibility; the less the time consumption, the better green accessibility. Housing price was used to indicate dwellers' socioeconomic attributes in the context of the booming housing market. Due to the high housing price in Shanghai that may require purchasers to spend decades of income on the house, housing price can be a proxy for reflecting residents' income, socioeconomic status, and purchasing/spending power (Guo et al., 2019; Wu et al., 2018). The spatial correlations between housing price and green space accessibility can be calculated by given equations:

$$I_{P,A} = \frac{N\sum_i^N \sum_{j\neq i}^N W_{ij} Z_i^P Z_j^A}{(N-1)\sum_i^N \sum_{j\neq i}^N W_{ij}} \tag{1}$$

$$I'_{P,A} = Z_i^P \sum_{j=1}^N W_{ij} Z_j^A \tag{2}$$

where $I_{P,A}$ and $I'_{P,A}$ refer to the global and local bivariate Moran's I, respectively, N refers to the total number of residential communities, Z_i^P refers to the standardized value of housing price for the i^{th} community, Z_j^A refers to the standardized value of green space accessibility for the j^{th} community. W_{ij} refers to the N-by-N spatial weight matrix for calculating the spatial correlation between i^{th} and j^{th} community, which was derived from the Euclidean distance weight. In the present work, we calculated bivariate Moran's I by using GeoDa 1.14. We used 999 permutations to assess the statistical significance of bivariate Moran's I; the significance values were defined at < 0.01.

The values of bivariate Moran's I range from −1 to 1. For statistically significant bivariate Moran's I, the positive values and negative values indicate spatial clustering (positive spatial correlation) and spatial dispersion (negative spatial correlation), respectively (Zhang et al., 2018). A larger absolute value of bivariate Moran's I indicates a stronger spatial correlation between housing price and green space accessibility. The cluster map derived from local bivariate Moran's I can be used to identify four kinds of spatial correlations at the community-level: High-High type indicates high housing price surrounded by high time consumption; Low-Low type indicates low housing price surrounded by low time consumption; High-Low type indicates high housing price surrounded by low time consumption; Low-High type indicates low housing price surrounded by high time consumption.

4.3. Regression analysis

In this study, we hypothesized that environmental inequality would appear when wealthier communities enjoyed better accessibility to green spaces. To explain environmental inequality, we used multiple regression models to examine whether green spaces accessibility is equitable across communities with different price levels (Wüstemann et al., 2017; Wu et al., 2018). Given the spatial autocorrelation in green space accessibility (Moran's I > 0.3 within the inner, middle, and outer ring roads, $p < 0.01$), we further used the spatial lag regression to address spatial dependency in dependent variables (Dai, 2011). The multiple regression and the spatial lag regression are expressed as Eqs. (3) and (4), respectively.

$$Y = \alpha + \sum_{k=1}^{N} \beta_k X_i + \varepsilon \tag{3}$$

$$Y = \alpha + pWY + \sum_{k=1}^{n} \beta_k X_i + \varepsilon \tag{4}$$

where Y is green space accessibility (min), X_i is mean price of i community, β_k is the coefficient of independent variables k, N is the total number of independent variables, ε is random error term, p iscoefficient of spatial lag term, α is the constant, W is an N-by-N spatial weight matrix.

In regression analyses, 8079 samples were classified into five groups (≤40,000 Yuan/m^2, 40,000–55,000 Yuan/m^2, 55,000–70,000 Yuan/m^2, 70,000–85,000 Yuan/m^2, and > 85,000 Yuan/m^2), which guaranteed each group to have approximate amount of community. The lowest price group (≤40,000 Yuan/m^2) and the other four groups were defined as the reference group and experimental groups, respectively. The original values of four experimental groups were defined as dummy variables (1 and 0); for example, in the experimental group > 85,000 Yuan/m^2, the values of communities > 85,000 Yuan/m^2 and other communities were defined as 1 and 0, respectively. In regression results, the coefficients of the reference groups are 0, which can be compared with those of dummy variables. The coefficient of the dummy variable would be statistically significant if that experimental group differed from the reference group (Wu et al., 2018). A positive coefficient indicates that a group with a higher housing price is likely to spend more time to green space than the reference group, while a negative coefficient indicates that a group with a higher housing price is likely to spend less time than the reference group.

5. Results

5.1. Accessibility to green spaces

5.1.1. Coverage of accessibility to green spaces

Fig. 4 and Table 1 show the spatial distribution and coverage of green space accessibility, respectively. The results show a declining trend of green space accessibility from the central urban area to the *peri*-urban area. The coverage of accessibility < 15 min within the inner ring road is 85.86%; the same coverages within the middle and outer ring roads are 52.32% and 30.83%, respectively. Meanwhile, the coverage of poor accessibility tends to cluster in the *peri*-urban area. As shown in Table 2, only 14.14% of the coverage is more than 15 min to green spaces within the inner ring road. Although the area within the middle ring road is dominated by good accessibility, 13.75% of the area distributed in its south requires 30 min at least to arrive at a green space. Within the outer ring road, 38.68% of its coverage takes > 30 min to arrive at a green space, which is distributed as six clusters along the outer ring road (Fig. 4).

5.1.2. Accessibility of residential community to green space

Table 2 and Fig. 5 show the amount and distribution of residential communities' access to green spaces in Shanghai, respectively. The spatial pattern is consistent with the coverage of green space accessibility that the number of communities with good accessibility declines from the area within the inner ring road to the city periphery, with poor-accessibility communities mainly located along the outer ring road. The proportions of the community within 15 min to green space

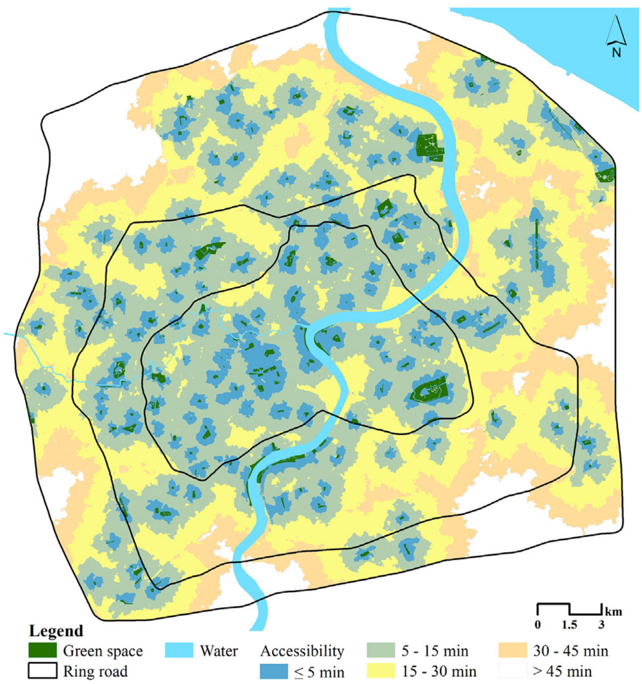

Fig. 4. Spatial distribution of accessibility to green space.

are 88.65%, 73.8%, and 54.4% within the inner, middle, and outer ring roads, respectively. Most communities (83.41%) that require more than 30 min of walking to green spaces are scattered along the outer ring road.

5.2. Spatial mismatch between green space accessibility and housing price

The result of global bivariate Moran's I is −0.212 ($p < 0.01$), revealing a negative spatial correlation between housing price and time consumption. That is, a community with a higher housing pricegenerally costs less time to green space. The cluster map of local bivariate Moran's I in Fig. 6 further displays the spatial mismatch at the community level, especially in High-Low type and Low-High type. High-Low types (high housing price and low time consumption) are comprised of 2463 communities concentrated mainly within the inner ring road, including the old urban area, Hongkou, and Pudong. The mean housing price (> 90,000 Yuan/m^2) of all communities in High-Low type is the highest among four types, while the mean green space accessibility is the best (8.3 min). Low-High types (low housing price and high time consumption), comprised of 907 communities, are mainly distributed along the north outer ring road and south middle ring road. Interestingly, Low-High types show a similar spatial pattern to the poorest green accessibility in Fig. 5. The low housing price and the poorest green accessibility of Low-High type indicate that disadvantaged communities in the city periphery are subjected to undersupply of green spaces. Low-Low types (low housing price and low time consumption) are comprised of 2281 communities, which match their relatively low housing price and low time consumption. These types are centered in north Shanghai and the region between the inner and middle ring road. High-High types (high housing price and high time-consumption) are only comprised of 221 communities scattered across the region. This result indicates that wealthy communities are rarely accompanied by poor green space accessibility in Shanghai.

5.3. Environmental inequality of accessibility to green space

The results of multiple regression and spatial lag regression are shown in Table 3. The results of multiple regression and spatial lag regression (R^2 ranges from 0.50 to 0.88) show that the coefficients are significantly negative from the group 55,000-70,000 Yuan/m^2 to the group > 85,000 Yuan/m^2 within the inner and middle ring roads. This indicates that housing price is negatively correlated with travel time to green space. Furthermore, these coefficients show a decreasing trend from middle price group to high price group, indicating that communities with higher prices can spend less time to green spaces, compared to the communities in reference group ≤ 40,000 Yuan/m^2. These results indicate an environmental inequality in green space accessibility, which confirms our hypothesis. However, this phenomenon cannot be observed within the outer ring road. Within the outer ring road, the coefficients are significantly negative and increase from middle price communities to higher price communities. These results reveal that the middle price communities can cost less travel time to green spaces than high price communities.

6. Discussion

6.1. Impacts of urban spatial reconstructing

Our findings for Shanghai show that residential communities in central urban areas benefit more from green space accessibility than those in the *peri*-urban areas. The difference can be partly attributed to Shanghai's spatial reconstructing by means of industrial suburbanization and provision of green infrastructure.

First, the peripheral industrial parks, including Gaoqiao-Gaohang (port district), Zhangjiang-Beicai (high-tech industry), Wusong (steel base), Jinqiao (export goods processing), Kangqiao (information technology and automotive industry), and Taopu (intelligent technology), appear to overlap with poor green accessibility along the outer ring road, indicating the influence of industrial suburbanization on green coverage and accessibility (Fig. 7). Since the 1990s, a large number of manufacturing industries were relocated from the central urban areas to the peripheral industrial parks (Fan et al., 2020; Yue, Fan, & Qi, 2014; Yue, Fan, Wei, & Qi, 2014). However, suburban industrial parks expanded at the cost of consuming green land and forest. As reported by Yin et al. (2011), green lands located 8-14 km from the urban center (areas between the middle and outer ring road) decreased rapidly from 1990 to 2009. For achieving intensive industrial development, green coverage was likely to be restricted in the peripheral industrial parks. According to the *Controlling index of construction land for industrial projects* published by the Ministry of Land and Resources in 2008, green spaces should be prohibited to distribute within an industrial project or

Table 1
Coverage of accessibility to green space.

Time consumption (min)	Inner ring road		Middle ring road		Outer ring road		Total coverage	
	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)	Area (km^2)	(%)
≤ 5	30.66	26.79	25.26	12.58	22.69	6.53	78.61	11.86
5–15	67.6	59.07	81.8	40.74	84.4	24.3	233.8	35.29
15–30	15.97	13.95	66.13	32.93	105.88	30.49	187.98	28.37
30–45	0.22	0.19	21.54	10.73	68.07	19.6	89.83	13.56
> 45	0	0	6.05	3.02	66.25	19.08	72.3	10.92

Table 2
Accessibility of residential community to green space.

Time consumption (min)	Inner ring road		Middle ring road		Outer ring road		Total communities	
	Number	(%)	Number	(%)	Number	(%)	Number	(%)
≤ 5	791	22.17	402	16.08	188	9.35	1381	17.09
5–15	2372	66.48	1443	57.72	906	45.05	4721	58.44
15–30	405	11.35	581	23.24	545	27.10	1531	18.95
30–45	0	0	69	2.76	208	10.34	277	3.43
> 45	0	0	5	0.20	164	8.16	169	2.09

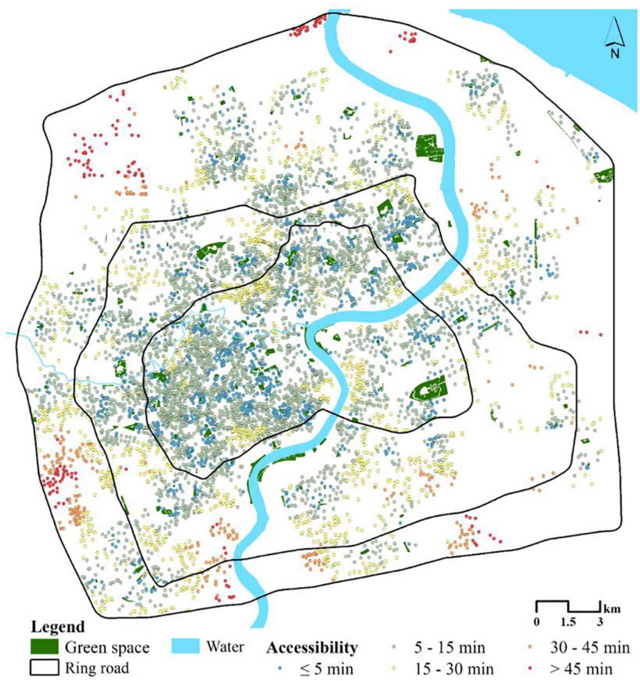

Fig. 5. Spatial pattern of green space accessibility from the community to green space.

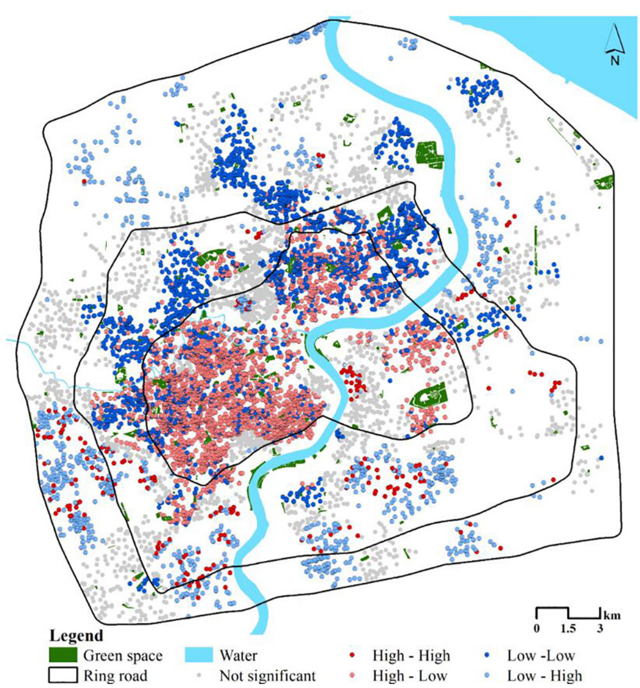

Fig. 6. Spatial correlation between accessibility and community price.

distributed < 20% for exceptional industrial projects. Consequently, the continuous industrial-oriented growth led to the shrinking of green spaces and a subsequent weakening in green space accessibility along the outer ring road.

Secondly, good provisioning of green infrastructure in the central urban area contributes to good accessibility. Accompanied by industrial suburbanization, green infrastructure construction took off as Shanghai placed the tertiary sector as the priority for central city development. For example, Shanghai Master Plan (1999-2020) proposed green planning goals that developed green spaces along the Huangpu River between the Nanpu and Huangpu Bridges. Prior to the Shanghai World Expo, Shanghai converted industrial lands along the Huangpu River in the central urban areas to waterfront parks and green belts (Fan et al., 2017). Under these circumstances, the provisioning of urban parks for the area within inner ring road is far better than that for the *peri*-urban areas. As recorded in Shanghai Park List (http://lhsr.sh.gov.cn/sites/lhsr/yuyindaohang.aspx?ctgId), 104 and 70 of 158 urban parks were built within Shanghai's central city and the inner ring road, respectively. Besides, since 1990, the central city had 45 newly built parks, and the amount within the inner ring road reached 34.

6.2. Green gentrification and environmental inequality

Our findings agree with previous studies, which have found that more affluent neighborhoods tend to enjoy better access to green space than disadvantaged neighborhoods (Astell-Burt et al., 2014; Barbosa et al., 2007; Guo et al., 2019; Wu et al., 2018). Interestingly, environmental inequality of green space accessibility in Shanghai seems to be associated with green gentrification described by Gould and Lewis (2012), Wolch et al. (2014), and Haase et al. (2017). Green gentrification refers to the phenomenon in which an undesirable place is evolved into a prime location in the housing market for middle- or high-income buyers because of the implementation of greening strategies (Anguelovski, Connolly, Masip, & Pearsall, 2017). As a result, the place is developed into high price communities, and low-income urban dwellers are ineluctably excluded.

Green gentrification is particularly evident within the inner ring road, which stimulates environmental inequality in access to green space. In the 1970s and 1980s, old communities in the central urban area suffered from poor infrastructures due to limited investment (Wu, 1999). However, since 1990, the central urban area has been endowed with a livable environment by building or redeveloping massive urban parks (e.g., Century Park and Lujiazui Central Green Space). Such greening efforts provided better green space accessibility for old communities and further raised property values. Within the inner ring road, the percentage of residential communities within 15 min to green spaces is 88.3%. Interestingly, the inner ring road also has a high housing price of 81,071 Yuan/m^2, being 45.72% and 24.07% above those within the outer ring road and middle ring road, respectively. The Century Park in Pudong District is a good example that illustrates the influence of green gentrification on environmental inequality of green space accessibility. The park was built in 1994 on the realm of former villages covering 140.3 ha. In the rural area featured by low-rise buildings and cultivated land over past decades, the park has so far

Table 3
Regression results of housing price and green space accessibility.

Housing price (Yuan/m^2)	Multiple regression			Spatial lag regression		
	Inner ring road	Middle ring road	Outer ring road	Inner ring road	Middle ring road	Outer ring road
Reference group ≤ 40,000 Yuan/m^2						
40,000–55,000	0.319	−0.904	−7.746**	0.364	−0.324	−1.039*
55,000–70,000	−2.544**	−2.518**	−9.366**	−0.644*	−0.627*	−2.062**
70,000–85,000	−2.951**	−2.748**	−8.438**	−0.934**	−0.858**	−1.591**
> 85,000	−4.405**	−3.122**	−5.466*	−1.329**	−1.272**	−0.901
p				0.90	0.89	0.97

Note: * and ** represent the significance level of 0.05 and 0.01, respectively. The total numbers of communities within the inner, middle, and outer ring roads are 3568, 2500, and 2011, respectively.

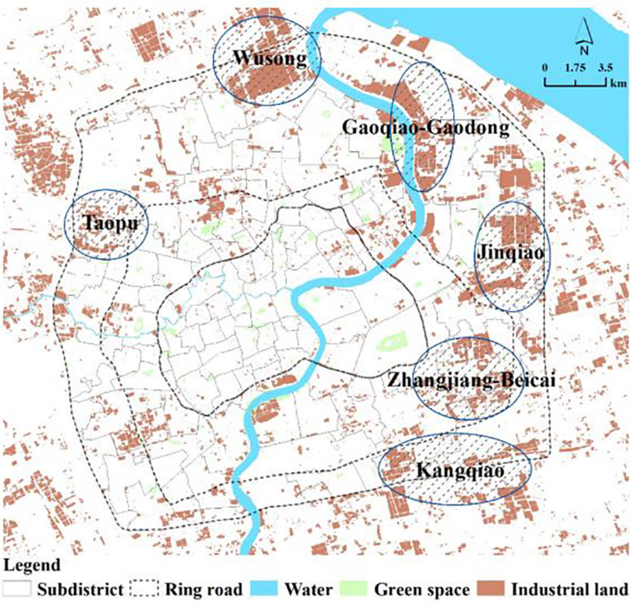

Fig. 7. Distribution of peripheral industrial parks.

evolved into the largest ecological park within the inner ring road. As a result, the high-quality environment and improved infrastructures have significantly driven up housing prices around the park. At present, the mean price of residential communities within 5-min accessibility to the park is 88,936 Yuan/m^2, being the highest price in Shanghai.

However, the *peri*-urban area does not show green gentrification trends. Greening strategies conducted along the outer ring road are not as large in scale as in the central urban areas (Fan, Xu, Yue, & Chen, 2017). Only a few communities such as the public housings built in the 1980s-1990s in Pengpuxincun, Linfenlu, and Jiangwan in northern Shanghai are benefiting from greening strategies. These communities are equipped with parks (e.g., Lingnan Park and Pengpu Park), which may result in the less travel times to green space than other regions. Nevertheless, these communities are undesirable for home buyers because of old-fashion buildings, high-density population, and public ownerships. This may explain why some communities within the outer ring road are characterized by low/middle housing prices but good green accessibility (Fig. 6 and Table 3). In contrast, affluent communities rarely benefit from public greening spending due to their decent private environmental amenities. The most affluent communities are distributed around the Xijiao Hotel along the southwest outer ring road, which is well-known for the villa district since the 1930s. These villas and low-density housings possess high greening ratios and club green space (e.g., Hongqiao Golf Club) but also are in short supply of public green spaces (Fig. 4). This phenomenon is consistent with the substitution effect of privately-supplied green space on public parks (Xiao, Li, & Webster, 2016), which explains the poorer green accessibility of affluent communities than that of low/middle price communities within the outer ring road.

6.3. Policy implications and potential limitations

The spatial inequality in green space accessibility in Shanghai can support municipal authorities and planners to identify where additional effort should be put to improve green space accessibility. In Shanghai, the greening strategy that all dwellers should live within 15 min to the nearest green spaces has been set as the priority for green planning. The Shanghai Master Plan (2017-2035) further proposed that 90% of Shanghai's communities are required to walk 5 min at the most to arrive at green spaces (> 400 m^2). The present work has found a gap that 17.09% of communities satisfied the proposed target from the Shanghai Mater Plan, and only 75.53% of communities were distributed within a 15-min walking distance. Fortunately, we marked six clusters that have the poorest green accessibility along the outer ring road for further improvement. Thus, building new green spaces should be the preferential goal of infrastructure construction in the *peri*-urban areas.

The spatial mismatch between housing prices and green space accessibility can be useful for implementing an appropriate greening strategy. Planning efforts should finance green spaces around communities of Low-High type in the *peri*-urban areas to meet the low-income dwellers' demands for green infrastructure. Governors can also learn what the first goal of policy intervention in communities of High-Low type is improving the green quality. Further improvement is necessary to enrich the category of amenities, green types, interior structures, and overall appearance in existing green spaces to attract more users.

Governors and planners should be sensitive to environmental inequality in access to green space and raise greater awareness of the matter (Lucy, 1981). Green spaces cannot be merely built around the central urban areas, affluent communities, and wherever a prime location due to the common-pool attribute of green spaces. Besides, the demands for accessibility of different social groups should be a crucial indicator of green planning (La Rosa, Takatori, Shimizu, & Privitera, 2018). Social groups living in disadvantaged communities should be endowed with additional provisions of green spaces to guarantee equal opportunities. Such lessons are also applicable in other cities, such as Beijing (Wu et al., 2018), Delhi (Gupta et al., 2016), and Santa Cruz (Wright Wendel, Zarger, & Mihelcic, 2012), wherein a certain number of disadvantaged groups are experiencing the inequity of access to green spaces.

The study has some limitations to be further improved. First, we used housing price to reflect residents' socioeconomic status, and we did not account for related factors, including location, environment, and transportation. Lianjia and other similar housing agent platform include rich information about all communities, such as traffic condition, external and inner environment, and facility. These factors can be incorporated to reflect variability in socioeconomic status in the future work. Meanwhile, given that communities' green accessibility may be influenced by specific environmental factors in Shanghai, the specific factors, such as distance to CBD, are necessary to be defined as control variables. Second, green space types were not subdivided when analyzing the environmental inequality of green space accessibility among communities. Green spaces that vary in size, amenity, and attractiveness may pose different impacts on housing prices. The measurement for environmental inequality of green space accessibility would be more precise if green attributes were considered. Third, when analyzing environmental inequality of communities' access to green space, the total amount of households and dwellers in these communities was not calculated due to the unavailability of data. It is necessary to count the number of households and dwellers varying in social groups to gain a deeper insight into environmental inequality in access to green space.

7. Conclusion

The fair distribution for green space is increasingly considered as an environmental inequality issue that is an emergent problem in China. In this study, we put forward the interpretive framework for environmental inequality in access to green space. Taking Shanghai as a case, we explored environmental inequality from the perspective of communities' access to green spaces using multi-source big data. A real-time navigation route measurement based on Amap API and housing price were employed to measure green space accessibility and dwellers' socioeconomic status, respectively. Furthermore, bivariate Moran's I, multiple regression, and spatial lag regression were used to examine the environmental inequality in green space accessibility. The results show a spatial inequality pattern in which residential communities in the central urban areas enjoy better green space accessibility than those in the *peri*-urban areas. Besides, a negative spatial correlation between housing price and green space accessibility is identified. The results of multiple regression and spatial lag regression show that wealthier communities enjoy better green space accessibility than disadvantaged communities within the inner and middle ring roads, indicating an environmental inequality of green space accessibility. However, such a phenomenon fails to appear within the outer ring road, where middle price communities enjoy the best green space accessibility.

The present work illustrates that the gap of green space accessibility between the central urban areas and *peri*-urban areas may be associated with Shanghai's spatial reconstructing. First, industrial suburbanization leads the process of industrial land development in the city periphery, which occupies the room for green space. Second, Shanghai primarily focuses on the provision of green infrastructure in central urban areas. Furthermore, green gentrification may contribute to environmental inequality of accessibility to green space. Within the inner ring road, the implementation of greening strategies improves green space accessibility. The process drives up housing prices in that area, which results in the tendency of wealthier communities to enjoy better green space accessibility than other communities. In contrast, the *peri*-urban area does not show green gentrification and environmental inequality of green space accessibility. For future planning, three policy implications were highlighted: (i) building new green spaces in the *peri*-urban areas, (ii) implementing appropriate greening strategies according to different type communities, and (iii) gaining awareness to prevent environmental inequality.

CRediT authorship contribution statement

Yang Chen: Methodology, Software, Investigation, Validation, Writing - original draft. **Wenze Yue:** Conceptualization, Formal analysis, Writing - review & editing, Supervision, Funding acquisition. **Daniele La Rosa:** Resources, 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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