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A natural experiment reveals impacts of built environment on suicide rate: Developing an environmental theory of suicide

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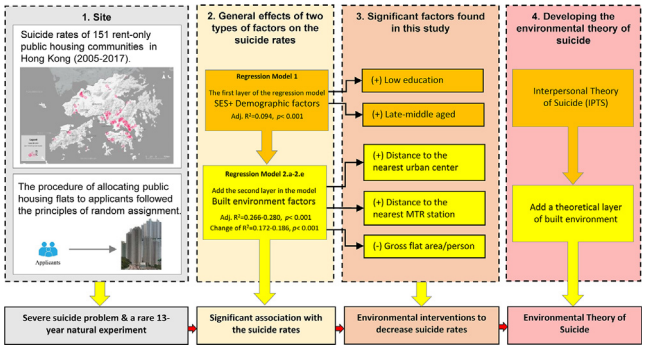
HIGHLIGHTS

- A study based on a 13-year natural experiment with minimal self-selection bias
- Examine 5841 suicides in 151 rent-only public housing communities
- Built environment has a significant & independent association with suicide rates.
- Three environmental factors have significant associations with suicide rates.
- Environmental Theory of Suicide based on the Interpersonal Theory of Suicide

GRAPHICAL ABSTRACT



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ABSTRACT

Background: Suicide is a global challenge. Although it is clear that socioeconomic and demographic factors influence suicide rates, we know little about the impacts of the built environment on suicide rates.
Methods: We investigated the relationship between characteristics of the built environment and suicide death rates over a 13-year period in 151 rent-only public housing communities in Hong Kong. The regulations of the public housing authority in Hong Kong constituted a natural experiment with minimal self-selection bias. We conducted hierarchical regression analyses and found that characteristics of the built environment were significantly associated with suicide rates after controlling for SES and demographic factors at the community level.
Results: Three significant environmental factors were identified distance to the nearest urban center, distance to the nearest Mass Transit Railway station, and gross flat area per person.
Conclusion: These findings demonstrate a significant association between features of the built environment and suicide rates. They also suggest possible interventions that might reduce suicide through design, or redesign, of the built environment. Lastly, we propose an environmental theory of suicide based on the Interpersonal Theory of Suicide.

1. Introduction

1.1. Background

Suicide is a global challenge of public health and well-being. According to the World Health Organization (WHO), there are approximately

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800,000 suicides annually worldwide. This accounts for 1.4% of all deaths and makes suicide the 18th leading cause of death (World Health Organization, 2019). Meanwhile, the percentage of people living in cities has risen rapidly from 33.6% to 55.3% in the last 60 years. Growing evidence suggests that people living in high-density cities are more vulnerable to suicide than those living in lower-density environments (Hsu et al., 2015; Murali and Oyebode, 2004; Ni et al., 2020).

It was well established that people with low socioeconomic status (SES) are more vulnerable to attempt suicide than individuals with higher SES (e.g., Phillips et al., 2002; Rehkopf and Buka, 2006; Zhang et al., 2010). In addition, suicide risk is associated with demographic factors, such as age, sex, marital status, and education attainment (e.g., Nock et al., 2008; Qin et al., 2003; Wong et al., 2008; Yip et al., 2005). It is surprising, however, that so little attention has been paid to the role of the built environment in suicide, as there is considerable evidence that built-environment conditions affect a wide range of precursors to suicide, such as depression, anxiety, and sense of helplessness (e.g., Bratman et al., 2019; Bratman et al., 2015; Hsu et al., 2015; Jiang et al., 2019). This gap in our understanding about the extent to which the built environment is associated with suicide prevents health care and public health officials, designers, planners, and municipal leaders from reducing suicide deaths by providing healthier living environment for citizens.

We explored this gap via a natural experiment conducted in 151 rent-only public housing communities in Hong Kong over a period of 2005 to 2017. There were 5841 suicides in these communities over these 13 years. Our overall research question was, 'After controlling for SES factors, demographic factors, and self-selection bias, to what extent are built environment factors in a high-density city associated with residents' suicide rates?'

1.2. A synthesis of theories of suicide: Interpersonal Theory of Suicide

The Interpersonal Theory of Suicide (IPTS) has been widely recognized as a comprehensive synthesis of previous theories of suicide (Van Orden et al., 2010). We employed IPTS as a theoretical foundation for this study rather than relying on various other theories of suicide for following reasons: IPTS is not "another" unilateral theory but grows from a synthesis of previous influential theories of suicide; Previous theories emphasized the importance of single constructs of suicide but IPTS proposed three distinct and interactive causes and pathways of suicide; Previous theories mixed suicidal ideations, suicidal attempts, and suicidal deaths as a unitary concept but IPTS clearly states the difference between suicide deaths from other concepts, which are lethal or near lethal suicide behaviors: This separation makes the analysis of suicide death much clearer than before; Many previous theories emphasized SES and demographic factors at the individual level while IPTS hints that environmental factors may contribute to deaths from suicide.

IPTS proposes three independent constructs that can interact to cause suicide: Belongingness (I am alone), perceived burdensomeness (I am a burden), and acquired capability for suicides (Van Orden et al., 2010). The first two constructs are related to a desire to commit suicidal while the third construct refers to an individual's capacity to commit suicide (Van Orden et al., 2010). IPTS summarizes the critical risk factors that could contribute to each of the three constructs, including social isolation, mental disorders, unemployment, previous suicide attempts, family conflicts, physical illness, and other factors.

1.3. Potential connections between built environments and risk factors for suicide

There is emerging evidence suggesting built environment may also contribute to suicide through influencing four factors of suicide summarized by IPTS. The four risk factors are social isolation, mental disorders, physical illness, and unemployment.

Social isolation is "arguably the strongest and most reliable predictor of suicidal ideation, attempts, and lethal suicidal behavior among samples varying in age, nationality, and clinical severity" (Van Orden et al., 2010). Social isolation has multiple facets, including loneliness, social withdrawal, having few social supports, living in non-intact families, losing a spouse through death or divorce, and living in an isolated prison cell (Van Orden et al., 2010). Impacts of built environment on social isolation have been demonstrated and summarized (Mazumdar et al., 2017). Among many influential environmental factors contributing to social isolation are proximity to urban centers with multiple social services (Chadwick and Collins, 2015), proximity to subway stations (Li et al., 2018) or general accessibility to public transport (Melis et al., 2015), walking friendly neighborhoods with mixed urban functions (Leyden, 2003), and density of neighborhood tree canopy (Holtan et al., 2014).

Mental disorder is another major risk factor that can lead to suicide (Van Orden et al., 2010). Many mental disorders can contribute to the development of suicide, the most important of which include depressive disorder, anxiety/agitation disorder, and impulse control deficit. In general, sustaining long-term positive mental states through maintaining social and family connections, having a decent job, and having physical health are critical to prevent suicide (Van Orden et al., 2010). Numerous environmental studies have found that vegetatively barren, crowded, geographically isolated, monotonous, and/or noisy built environments are associated with mental disorders, such as mental fatigue (Hartig and Staats, 2006), stress and anxiety (Jiang et al., 2019), aggression and impulsivity (Kuo and Sullivan, 2001; Poon et al., 2016), depression (Min et al., 2017; Sarkar et al., 2018), and a reduced sense of safety (Jiang et al., 2018). In contrast, green, spacious, and tranquil built environments can contribute to mental restoration and decrease risk of mental disorders (Jackson, 2003; Sullivan and Chang, 2011; Sullivan et al., 2014).

Physical illness is third major risk factor for suicide (Van Orden et al., 2010). Severe illness, especially an incurable or terminal illness (e.g., HIV/AIDS, certain types of cancer), increase the risk for suicide. The enormous cost of treating severe illness can induce in some individuals to feel a strong sense of self-blame (I am a burden). Moreover, individuals who have severe illnesses often suffer from distress and lowered self-esteem due to their reduced capacity to contribute at work and at home (I am useless). Finally, individuals who experience constant, significant pain caused by severe illness may develop an elevated physical pain tolerance, which is a significant component of acquired capability of committing suicide (Van Orden et al., 2010). The built environment can trigger or cause severe physical illness (Jackson, 2003). Exposure to environments that lack vegetation can degrade a person's immune functions while having contact with nature can promote immune functions (Kuo, 2015). Living in communities with low income and limited access to social resources are associated with higher rates of HIV/AIDS (Talman et al., 2013). Many studies have reported significant relationships between characteristics of the built environment and the most life-threatening illnesses in developed and developing countries. These illnesses include cardiovascular diseases (Koohsari et al., 2020; Seo et al., 2019), specific types of cancer (Gomez et al., 2015), and stroke (Xie et al., 2019).

Employment status is the fourth risk factor for suicide (Van Orden et al., 2010). The unemployment rate is the most widely used measure of employment status and it is an important indicator of SES (O'Farrell et al., 2016). Although the association between employment and suicide rates at the population level reported by studies are not fully consistent, a higher suicide rate is often associated with unemployment rate of vulnerable individuals. Another relevant line of evidence is that economic recessions with widespread unemployment and house foreclosures are often associated with increased suicide rate (Van Orden et al., 2010). Being unemployed may contribute to suicide because unemployed people have a higher vulnerability to psychological distress, self-blame and shame, low self-esteem, and drug addiction (Blakely et al., 2003). Being unemployed may also contribute to suicide because it can trigger

domestic violence, which is significant threat to the sense of reciprocal care (Anderberg et al., 2016). The relationship between characteristics of the built environment and unemployment has been largely neglected by previous studies. Nevertheless, some studies have found several characteristics of neighborhoods that have significant associations with higher unemployment rates. These characteristics include residential concentrations of low-skilled and/or low-educated adult population (Alves, 2012), areas dominated by a single land use (such as residential) that have a considerable mismatch between low supply of employment opportunities and a high demand for jobs (Alves, 2012), and residential areas with little or no connection to the public transportation services (Bastiaanssen et al., 2020; Thakuriah and Metaxatos, 2000). Although most studies focusing examining the unemployment rate as a convenient measure of unemployment, the relationship between employment status and suicide rate shall not only be influenced by the single factor but also many other factors, such as stability of employment, working condition, salary and employee benefits, and perceived respect and value in the workplace (Hussmanns, 2007).

It is important to note that the relationships among social isolation, mental disorders, physical illness, and unemployment are interactive and complex (Van Orden et al., 2010). Further, characteristics of the built environment might influence these risk factors simultaneously and interactively (Jiang et al., 2015; Ustun, 1999). The development of suicidal ideation and the decision to act on these ideas have complex and multifaceted antecedents including personality traits, family history and generics, life experiences, and so on. In this paper, we explore the possibility that specific environmental factors are related to suicide rates at the community scale. In this study, we do not aim to prove environmental factors are determinative but seek to explore the extent to which such factors are related to elevated probabilities of death by suicide.

1.4. Association between built environments and suicide

The few studies that have examined direct associations between characteristics of the built environment and suicide rates, have produced largely consistent findings. A nationwide study in Netherlands found the proportion of green space at the municipality level has a significant negative association with the suicide rates while measures of contact with landscapes that contained water were not related to suicide (Helbich et al., 2018). Similar suicide-risk buffering associations with green landscapes were reported by studies in Taiwan (Shen and Lung, 2018) and Korea (Min et al., 2017). A recent nationwide study in the Netherlands found that residents' exposure to green landscapes had a significant negative association with the suicide rate for models controlling for age, gender, and date of suicide but the association became non-significant after adding a control of individual and area factors (Helbich et al., 2020). Helbich and his co-authors suggest the environment-suicide relationship should be understood to operate through multiple social and psychological mechanisms besides the direct mental benefits of contact with nature. Similarly, a recent study conducted in Hong Kong found the association between greenery and suicide rate was non-significant but reported that measures of population density in the city had a positive association with suicide (Wang et al., 2020).

1.5. Residential self-selection bias: a significant challenge of environment-health research

Residential self-selection bias is a threat to the validity of research that examines the relationships among the built environment and public health, including suicide. Residential self-selection refers to when people choose their residential locations and environments because of their specific travel preference, neighborhood preference, attitudes, or other needs and capabilities in daily life (Boone-Heinonen et al., 2011; Boone-Heinonen et al., 2010; Zang et al., 2019). Self-selection bias can explain 30% to 50% of the association between the residential environment and residents' behavioral tendencies, even after controlling for the residents' SES and demographic conditions (Zang et al., 2019). To the best of our knowledge, most of environmental studies on residents' health and well-being examined hybrid residential environments (mixture of private and public housing estates). Thus, it is highly possible that their results were impacted by residential self-selection bias. Nevertheless, some studies have overcome this form of bias. A team of researchers adopted public housing environments in Chicago as research sites where low-income individuals and families on the waiting list were assigned to an available apartment, met the requirements of random assignment of individuals to the variations in the independent variable of interest (Kuo and Sullivan, 2001; Sullivan et al., 2004). This series of studies influenced the methodological and research design employed in this study.

1.6. Critical knowledge gaps

Based on the review of theories and empirical evidence, we argue there are three critical gaps in our knowledge regarding the extent to which features of the built environment might be associated with suicide.

First, although there are scattered hints of relationships between physical settings and suicide, few empirical studies have examined direct relationships between built environment factors and suicide. In addition, the theoretical connection between various features of the built environment and causes of suicide has not been clearly presented in theories of suicide.

Second, most studies that have reported associations between the built environment and various health precursors to suicide are subject to residential self-selection bias, because they typically studied communities that permit self-selection of residential units (Zang et al., 2019). Hence, the validity of the reported associations is open to question.

Last, to the best of our knowledge, few studies have examined the relationship between built environment factors and suicide rates in public housing communities. It is possible that the characteristics of the built environment in public housing developments have significant effects on public housing residents' suicide rates. If this is the case, environmental interventions might reduce the suicide rate in public housing neighborhoods.

1.7. Research questions

To address those critical gaps, we explored the extent to which built environment factors were associated with suicide death rates in 151 rent-only public housing communities in Hong Kong, over a 13-year period. We chose to investigate public housing communities with the aim of reducing self-selection bias. The allocation of public housing units to individuals and families in Hong Kong constituted a natural experiment with random assignment of people to characteristics of the built environment.

We examined two key questions:

(1) After controlling for SES and demographic factors, to what extent are built environmental factors in and near public housing communities associated with suicide rates?
(2) Which specific built environmental factors have significant associations with suicide rates in public housing communities?

2. Methods

2.1. Introduction of site city

Hong Kong is one of most densely populated cities in the world and it is also a global hub for international business, transportation, and culture communication, all of which makes it representative of many large high-density cities around the world.

Approximately half of Hong Kong residents live in public housing communities and most of these people have a lower SES and worse living conditions than the average Hong Kong resident (Hong Kong Housing Authority, 2019a). Suicide in public housing communities in Hong Kong has been a serious public health and social justice problem for decades in Hong Kong (Chan, 1993). According to the 2005–2017 suicide data collected by the Coroner's Court of Hong Kong, the suicide rate among Hong Kong's public-housing residents over this period was much higher than the suicide rate of the overall population of Hong Kong and that of China over similar periods (24.8 vs 12.0 vs 9.7, crude rate: number of suicide deaths/100,000 persons) (Centre for Suicide Research and Prevention, 2018) (Fig. 1). In addition, the suicide rate of Hong Kong's public housing residents during this time was much higher than that of the global rate (10.6), and that for Europe (15.4), Southeast Asia (13.2), the Americas (9.8), the Western Pacific region (10.2), Africa (7.4), and the Eastern Mediterranean region (3.9) (World Health Organization, 2018).

2.2. A natural experiment

Hong Kong has a well-established public housing system, which was initiated in the 1950s by the British colonial administration (Fig. 2). The system was designed and managed in a similar manner to public housing systems in other major cities in the West (Hong Kong Housing Authority, 2019b).

This study investigated 151 rent-only public housing communities in Hong Kong. There were a total of 243 public housing communities in Hong Kong in 2018 (Hong Kong Housing Authority, 2019a). Because the suicide data were collected from 2005 onward, we excluded any public housing communities built after 2005. We also excluded communities that offered full or partial home purchase (i.e. that allowed people from low-income households to buy public housing flats at a discounted price). Data from the remaining 151 rent-only public housing communities were employed in this study. The rent-only public housing residents' SES is remarkably homogenous, especially the income level, because only low-income individuals and families are eligible to apply for this type of housing. The SES homogeneity of the population under study increases the internal validity of the study design and increases the probability that any associations we uncover is due to build environment factors rather than differences endemic to the residents of any particular public housing development.

The rent-only public housing communities have three qualities of a naturally occurring experiment (Hong Kong Housing Authority, 2019b). First, governmental regulations randomly allocated public-housing flats to applicants, which substantially reduced the self-selection bias of this study. The rent-only applicants were assigned to flats according to availability and family size, not personal preference. Second, although applicants for public housing had three chances to be assigned, most of applicants accepted the first assigned apartment because they had to wait years to have the second and the third chance of being assigned. Third, urban environments in and nearby public housing communities are mostly administered by the government: public housing residents had little or no role in decision to shape the environments inside and outside the communities.

2.3. Dependent variable

The suicide rate was used as the dependent variable, and the individual public housing community was used as the unit of analysis. The suicide data during the period of January 2005 to December 2017 were

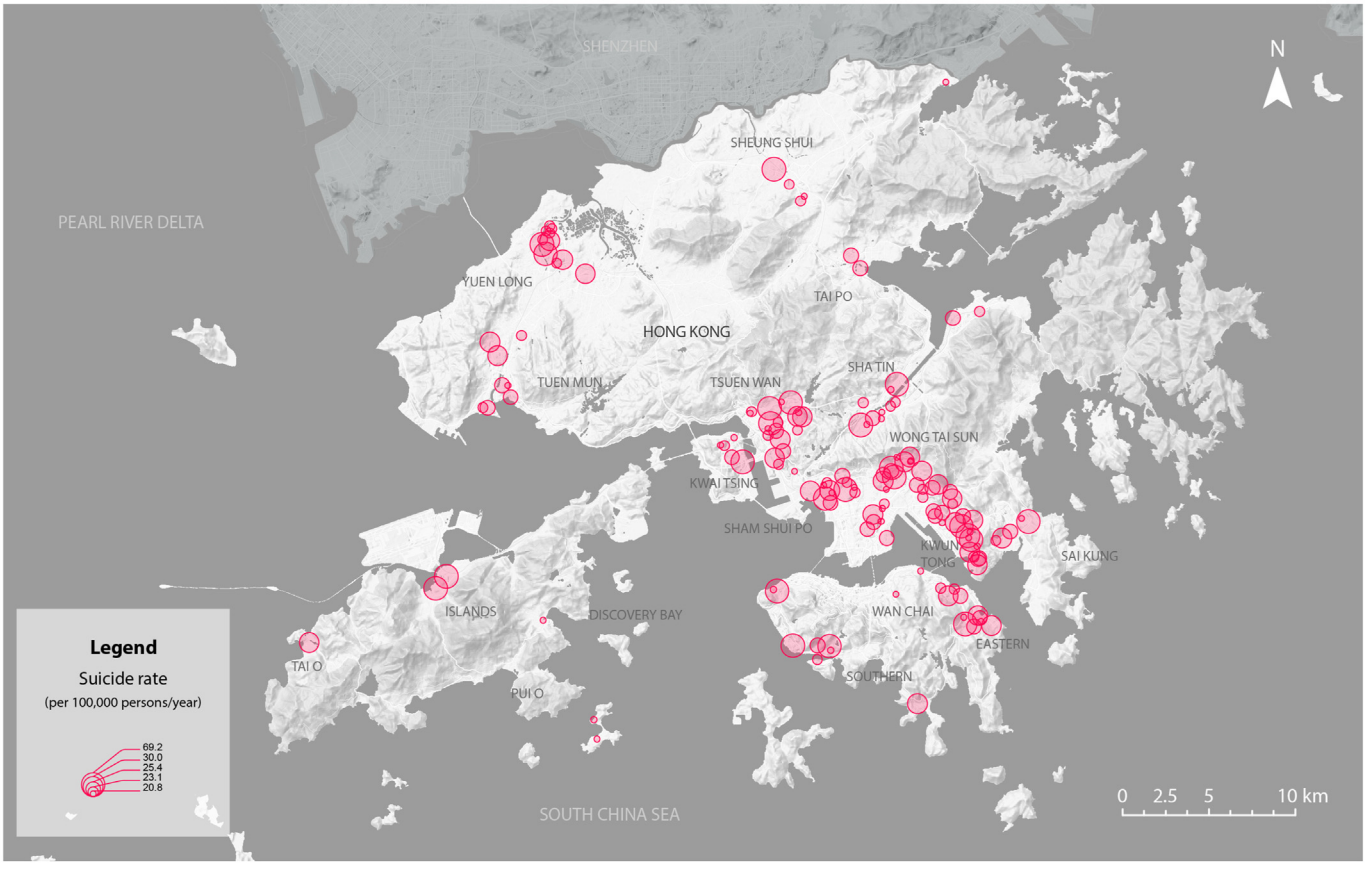

Fig. 1. The location and suicide rates of 151 rent-only public housing communities in Hong Kong. The pink circles represent different levels of suicide rate (per 100,000 persons/year).

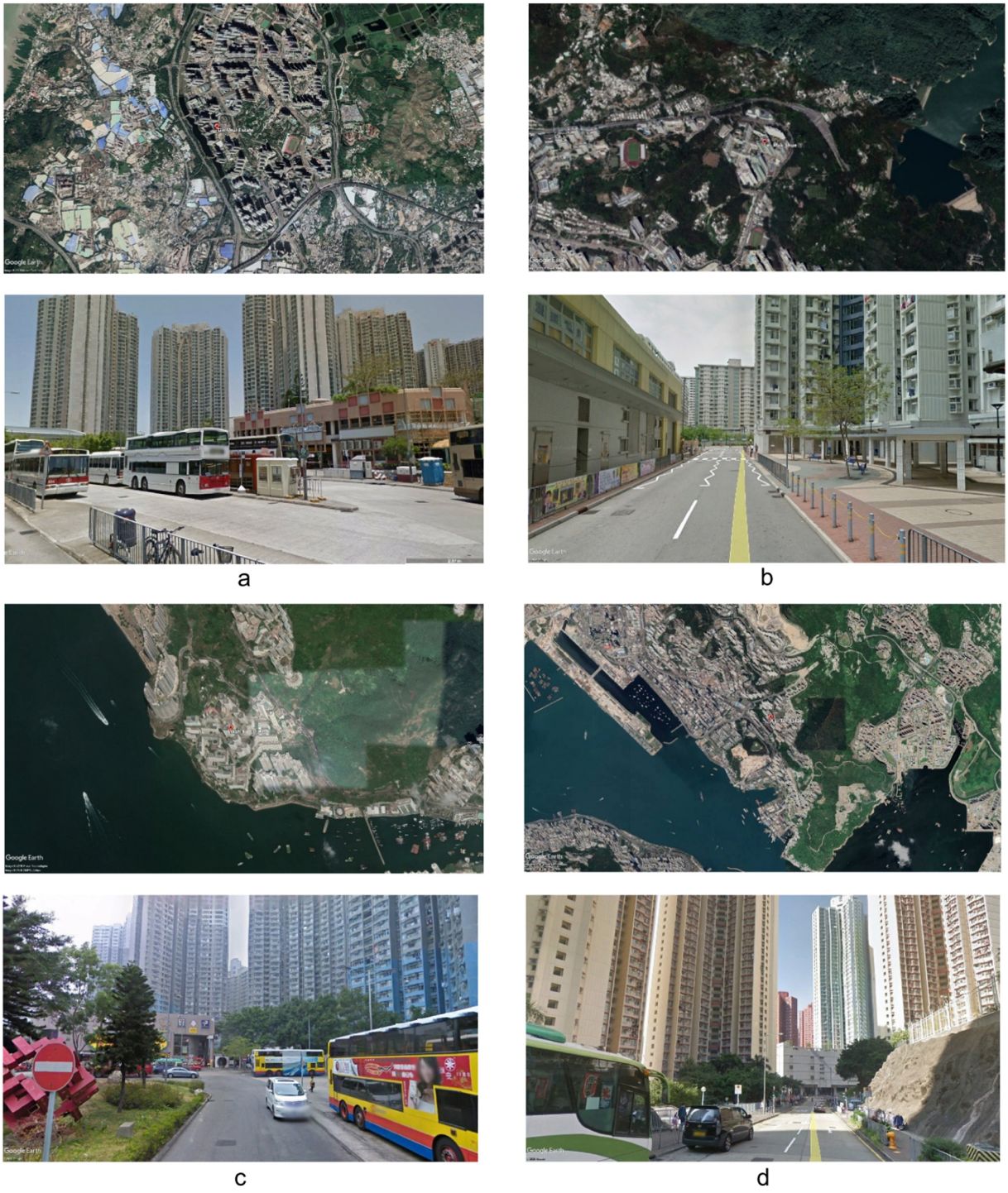

Fig. 2. Public housing residents in Hong Kong are living in highly dense environments while many communities were located in remote areas. The average s. Here are four sets of images of four public housing communities with high suicide rates. a Tin Shui Estate with an average suicide rate at 69 (per 100,000 persons/year, same hereafter); b Lei Muk Shue Estate with an average suicide rate at 62. c Wah Fu Estate with an average suicide rate at 59. d Kai Tin Estate with an average annual suicide rate at 40.
Image Source: Google Earth Pro.

collected from the Coroner's Court of Hong Kong, which conducts official inquiries into the causes and circumstances of all reportable deaths in Hong Kong, including suicide deaths. There were 5841 suicidal deaths recorded by the Court among residents of the 151 communities during the study period. The data comprised the dwelling locations of all persons who committed suicide, and these locations were geocoded into a map in ArcGIS 10.5. The suicide rate for each public housing community was calculated as the number of suicides per 100,000 residents per year.

2.4. Independent variables

A variety of built environment factors associated with each public housing community were measured using ArcGIS 10.5. Five spatial-buffer zones were defined for each public housing community and its surrounding neighborhood: the housing community site, and street-network buffers of 100 m, 200 m, 400 m, and 800 m away from the boundary of housing community site (Zang et al., 2019). The use of multiple buffer zones can mitigate the modifiable areal unit problem, which

is a statistical bias that causes the results of analyses to be influenced by the aggregation of geographic data (Tuson et al., 2018).

Based on our literature review, we examined the following three groups of built environment factors that may potentially influence suicide rates: 1) urban planning and architectural factors, 2) urban facilities factors, and 3) landscape factors. All built environment data between 2011 and 2015 were collected from the Planning Department of Hong Kong.

Urban planning and architectural factors included *distance to the nearest urban center*, *distance to the nearest MTR station* (*MTR stands for Mass Transit Railway, which is a citywide rapid transit railway network in Hong Kong*), *distance to the nearest coastline*, *land-use mix*, *population density*, *street-intersection density*, *number of street intersections*, *gross flat area per person*, and *floor-area ratio* (*FAR*). *Distance to the nearest urban center* was defined as the street network distance from a housing community to the nearest urban center, which are densely developed urban cores supported by essential infrastructure, commercial, and community facilities (Chadwick and Collins, 2015). This factor was log-transformed, as it was not normally distributed and was heavily skewed to the left. *Distance to the nearest MTR station* was defined as the street-network distance from a housing community to the closest MTR station, which revealed whether it is convenient for housing residents to use the MTR. *Distance to the nearest coastline* was defined as the distance from a housing community to the nearest coastline, which indicates the degree of accessibility to the coastline. *Land-use mix* was calculated using Eq. (1) to obtain the entropy score, as a measure of the level of diversity of land use, as follows:

$$Land\ use\ mix = (-1)\sum_i (p_i \ln(p_i))/\ln(n) \quad (1)$$

where p_i is the share of specific land-use type in total land area; and n is the number of land-use types. Three land-use types were considered: residential, retail, and office.

Population density was defined as the residential population per unit of land area. *Street intersection density* was measured as the number of street intersections (with three or more directions) per unit of land area. *Gross flat area per person* was defined as the ratio of total gross floor-area (residential and all community facilities) and the number of residents for each housing community. *FAR* was defined as the ratio of total floor area (gross floor area) to the site area in a public housing community.

Urban facilities in and around a public housing community were determined by a consensus of experts in urban planning and public health fields using the Delphi method. These facilities comprised hospitals, bus stops, cinemas, street markets and supermarkets, shopping malls, community centers, indoor stadiums, libraries, art venues, public swimming pools, sports grounds, playgrounds, public beaches, rest gardens, parks, and county parks. We calculated the number of community facilities within the community site and four buffer zones (100 m, 200 m, 400 m, and 800 m).

We measured a variety of landscape factors including urban greenness, park area, and sea area. Urban greenness within the community site and buffer zones was measured in two ways: overall greenery by NDVI and street greenery by Google Street View (GSV) images. The NDVI is derived from a 10-m resolution multispectral remote sense imagery dataset, by calculating the contrast between two bands (Matsushita et al., 2007): the chlorophyll pigment absorptions in the red band (red) and the high reflectivity of plant materials in the near-infrared (NIR) band. It formulated as Eq. (2), as follows:

$$NDVI = (NIR - Red)/(NIR + Red) \quad (2)$$

Street greenery was derived with GSV images, which were collected along all streets in a buffer with a spacing of 50 m, following previous studies (Lu, 2019; Lu et al., 2019). The level of greenery in GSV images, which is the ratio of greenery pixels to total pixels in a GSV image, were assessed via a deep learning technique with high accuracy ($r = 0.91$, $p < 0.01$ compared with manual extraction) (Zhao et al., 2017). Park area and sea area were calculated as the sum of the area of all parks and sea areas within the buffer zones.

The sociodemographic factors for each public housing community were extracted from the 2011 census data (Census and Statistics Department of Hong Kong, 2011). SES and demographic factors at the public housing community and district level were included. Hong Kong consists of 18 districts (large-scale administrative units). The demographic factors comprised the percentage of males/females in the population, the median age, the percentage of residents of different marital status, the percentage of residents in different age groups (<15 years, 15–24 years, 25–44 years, 45–64 years, ≥65 years), and the percentage of residents with different education levels (≤primary school, primary school to middle school, ≥secondary). SES factors were the median household income and the percentage of residents employed.

2.5. Statistical analysis

We used hierarchal linear regression models to examine the relationship between built environment factors and resident suicide rates, controlling for sociodemographic factors. All analyses were performed with the statistical software R v3.6.0.

A three-step analysis strategy was implemented. First, we examined the possibility that there was multi-collinearity between independent variables with Variance Inflation Factors (VIFs) using the *usdm* package in R (Naimi et al., 2014). To prevent multi-collinearity, all factors with VIF ≥4 were removed. Second, a basic model (Model 1) was developed that included only SES and demographic factors. Third, built environment factors were added to Model 2.a–2.e, at five spatial buffer zones: the housing community site, and 100 m, 200 m, 400 m, and 800 m from this site. All models were single-level linear regression models without any random slope or random intercepts. We tested whether the corresponding models improved after adding built environment indicators (i.e. by comparing Model 2.a–2.e to Model 1) using one-way analyses of variance and by comparing model-adjusted values of R^2.

3. Results

3.1. Descriptive statistics

Table 1 provides descriptive statistics of the suicide rates, built environment factors and SES and demographic factors of 151 public housing communities. In creating this table, we removed those variables that had high levels of multi-collinearity (i.e. if they had a Variance Inflation Factor (VIF) ≥4). The descriptive statistics of the excluded factors are shown in Table A in the Appendix.

During the 13-year period we examined, these 151 public housing communities had high suicide rates. Their average suicide rate was 24.8 per 100,000 people/year (standard deviation (SD) = 9.0). They were also, on average, far from urban centers (mean (M) = 4.1 km, SD = 3.8) or MTR stations (M = 1.2 km, SD = 1.9). The average population density in the surrounding areas of these communities was 33,357–42,925 persons/km^2 in various buffers (see Table 1), which was considerably greater than the overall population density in Hong Kong (6690 persons/km^2) (Census and Statistics Department of Hong Kong, 2015).

Public housing communities in Hong Kong also have older, poorer, and less educated residents compared to the overall Hong Kong population (Census and Statistics Department of Hong Kong, 2011). The average median age of residents in public housing communities was 45.3 years in 2011, compared to 41.7 years in the overall population. The average median household income of public housing estates was HK$13,383/month, approximately half the average household income of the overall population of Hong Kong (HK$23,500/month). Finally,

Table 1
Descriptive statistics of suicide rates, built environment factors, demographic and SES factors by five spatial zones for 151 public housing communities.

Variables (unit)	Community site	100 m buffer	200 m buffer	400 m buffer	800 m buffer
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Outcome					
Suicide rate (per 100,000 persons/year)	24.8 (9.0)	24.8 (9.0)	24.8 (9.0)	24.8 (9.0)	24.8 (9.0)
SES and demographic factors					
Community median age (year)	45.3 (7.5)	45.3 (7.5)	45.3 (7.5)	45.3 (7.5)	45.3 (7.5)
Community low education level (% ≤ primary school)	37.9 (6.2)	37.9 (6.2)	37.9 (6.2)	37.9 (6.2)	37.9 (6.2)
Community median household income (HK$/month)	13,383 (2907)	13,383 (2907)	13,383 (2907)	13,383 (2907)	13,383 (2907)
Community residents aged 45–64 (%)	31.3 (3.7)	31.3 (3.7)	31.3 (3.7)	31.3 (3.7)	31.3 (3.7)
Community residents aged ≥ 65 (%)	17.4 (7.2)	17.4 (7.2)	17.4 (7.2)	17.4 (7.2)	17.4 (7.2)
District median age (year)	42.0 (1.7)	42 (1.7)	42 (1.7)	42 (1.7)	42 (1.7)
District low education level (% ≤ primary school)	30.6 (3.2)	30.6 (3.2)	30.6 (3.2)	30.6 (3.2)	30.6 (3.2)
District median household income (HK$/month)	19,892 (4182)	19,892 (4182)	19,892 (4182)	19,892 (4182)	19,892 (4182)
Built environment factors					
Gross flat area/person (m^2/person)	21.5 (7.7)	21.5 (7.7)	21.5 (7.7)	21.5 (7.7)	21.5 (7.7)
Distance to the nearest urban center (m)	4129 (3799)	4129 (3799)	4129 (3799)	4129 (3799)	4129 (3799)
Distance to the nearest MTR station (m)	1196 (1877)	1196 (1877)	1196 (1877)	1196 (1877)	1196 (1877)
Land-use mix	N.A.	0.48 (0.21)	0.48 (0.20)	0.46 (0.18)	0.47 (0.16)
Population density (persons/km^2)	N.A.	42,925 (21764)	39,472 (19982)	36,220 (17354)	33,357 (15179)
Street intersection density (#/km^2)	N.A.	113.1 (44)	101.6 (37.1)	89.7 (31.2)	75.4 (28.1)
Number of parks	N.A.	0.2 (0.4)	0.4 (0.9)	1.0 (1.4)	2.7 (2.6)
Number of community centers	1.2 (1.2)	1.9 (1.5)	2.7 (1.9)	4.6 (2.6)	9.6 (5.0)
Number of sportsgrounds	1.2 (1.8)	3.6 (3.6)	7.1 (5.6)	15.3 (9.9)	34.5 (20.4)
Number of playgrounds	0.4 (0.9)	1.2 (1.4)	2.0 (1.9)	4.0 (3.0)	8.6 (5.1)
Number of markets	1.3 (1.1)	2.3 (1.3)	3.5 (1.9)	6.8 (3.5)	15.1 (7.2)
Number of malls	0.7 (0.7)	1.3 (1.2)	2.3 (1.8)	4.6 (3.1)	10.2 (5.7)
Urban greenness (NDVI)	0.14 (0.07)	0.19 (0.09)	0.21 (0.10)	0.22 (0.10)	0.23 (0.11)

Note: 100 HK dollars = 12.86 US dollars; 100 HK dollars = 11.51 Euro dollars in January 7th 2020 (The Hong Kong Association of Bank, 2020).

approximately 37.9% of public housing residents had completed only primary school education or less, higher than the rate for the overall population (26.3%).

3.2. Predicting suicide rates

The three key questions posed above were answered by performing multiple regression analysis, as presented in Table 2. First, we found that SES and demographic factors did explain the suicide rates. The adjusted coefficient of determination (R^2) of the basic model (model 1) was 0.094 ($p < 0.01$), indicating that 9.4% of the variation in the suicide rate of public housing communities was collectively due to SES and demographic factors. The proportion of residents with a lower education level (≤primary school) and of late middle-aged residents were also positively associated with the suicide rate.

Second, after controlling for the SES and demographic factors, we found that our measures of the built environment explained additional variance. That is, after adding built environment factors to the basic model, the adjusted R^2 of the full model (Model 2.a–2.e) increased to 0.266–0.280, indicating that 17.2–18.6% of the variation in suicide rate was explained by these built environment factors (Fig. 3). The built environment factors thus had greater explanatory power than the SES and demographic factors. The improvements from Model 1 to all submodels of Model 2 were significant ($p < 0.001$).

Third, Model 2 revealed that *distance to the nearest urban center* (Fig. 4b; d), *distance to the nearest MTR station* (Fig. 4a; d), and *gross flat area per person* (Fig. 4c) were factors that were significantly associated with suicide rates. *Distance to the nearest urban center* was positively associated with the suicide rate at four of five spatial scales, and on the edge of statistical significance at the 400-m buffer spatial scale. *Distance to the nearest MTR station* was positively associated with suicide rate at all five scales. Furthermore, *gross flat area per person* was negatively associated with the suicide rate at all the five scales. None of the other built environment factors were significantly associated with the suicide rate.

4. Discussion

This study produced several significant findings. First, we found that SES and demographic factors collectively have a significant association with suicide rates. This finding is consistent with and reinforces findings from a variety of studies (Wong et al., 2008; Yip et al., 2005; Zhang et al., 2010). Further, we found that the percentage of lower educated residents and percentage of late middle-aged residents had a significant positive association with the suicide rate, which is also consistent with many previous studies (e.g., Case and Deaton, 2015; Chen et al., 2012; Hsu et al., 2015; Lin et al., 2019; Van Orden et al., 2010; Yip et al., 2005; Zhang et al., 2010).

More importantly, we found that built environment factors collectively were significantly associated with the suicide rate. Further, we identified specific built-environment factors that were significantly associated with the suicide rate, including distance to the nearest urban center, distance to the nearest MTR (subway) station, and gross flat area per person.

Below, we interpret these findings through the lens of the environmental theory of suicide, which is based on understanding of the Interpersonal Theory of Suicide (IPTS), identify the contributions of the findings to the literature, and discuss limitations and promising areas for future research before concluding.

4.1. Interpretation of significant built environmental factors

4.1.1. Distance to the nearest urban center and/or MTR station

This study revealed that the distance from a public housing community to the nearest urban center/MTR station had a positive association with the suicide rate: the greater the distance to the nearest urban center/MTR station, the higher the suicide rate. The urban center is an area that contains a diversity of public goods and services, social opportunities for individuals and groups, and employment opportunities. Similarly, easy access to an MTR station allows public housing residents access to a wide variety of activities that require citywide transport,

Table 2
Results of multiple regression analysis on the relationship among suicide rate and SES and demographic factors and built environment factors, by five spatial zones for 151 public housing communities.

Model predictors	Model 1	Model 2.a (community site)	Model 2.b (100-m buffer)	Model 2.c (200-m buffer)	Model 2.d (400-m buffer)	Model 2.e (800-m buffer)
	β (SE), *p*-value	β (SE), *p*-value	β (SE), *p*-value	β (SE), *p*-value	β (SE), *p*-value	β (SE), *p*-value
Socio-demographic						
Community median age	−0.068 (0.107), 0.523	0.152 (0.117), 0.197	0.168 (0.119), 0.160	0.181 (0.118), 0.129	0.177 (0.118), 0.136	0.199 (0.120), 0.099
Community low education level (% ≤ primary school)	0.384 (0.101), <0.001***	0.308 (0.103), 0.003**	0.324 (0.103), 0.002**	0.345 (0.107), 0.002**	0.395 (0.106), <0.001***	0.388 (0.101), <0.001***
Community median household income	0.051 (0.094), 0.586	0.012 (0.087), 0.891	0.043 (0.089), 0.630	0.060 (0.090), 0.508	0.077 (0.089), 0.390	0.074 (0.089), 0.407
Community residents aged (45–64)	0.179 (0.084), 0.034*	0.229 (0.079), 0.004**	0.235 (0.079), 0.004**	0.220 (0.080), 0.007**	0.225 (0.082), 0.007**	0.243 (0.082), 0.004**
Community residents aged (≥ 65)	0.061 (0.119), 0.607	0.033 (0.116), 0.774	0.069 (0.124), 0.579	0.057 (0.124), 0.643	0.077 (0.123), 0.530	0.094 (0.125), 0.453
District median age	−0.106 (0.109), 0.330	0.085 (0.117), 0.469	0.089 (0.120), 0.457	0.094 (0.123), 0.442	0.024 (0.120), 0.842	0.015 (0.128), 0.905
District low education level (% ≤ primary school)	0.063 (0.226), 0.781	−0.217 (0.210), 0.302	−0.273 (0.220), 0.216	−0.241 (0.224), 0.284	−0.300 (0.235), 0.203	−0.316 (0.254), 0.216
District median household income	0.112 (0.219), 0.611	−0.261 (0.207), 0.209	−0.336 (0.221), 0.131	−0.329 (0.225), 0.147	−0.394 (0.234), 0.094	−0.383 (0.253), 0.132
Built environment						
Distance to the nearest urban center		0.234 (0.093), 0.013*	0.266 (0.096), 0.007**	0.212 (0.098), 0.033*	0.200 (0.103), 0.054	0.240 (0.101), 0.020*
Distance to the nearest MTR station		0.273 (0.106), 0.011*	0.244 (0.102), 0.018*	0.206 (0.102), 0.046*	0.228 (0.108), 0.036*	0.281 (0.117), 0.018*
Gross flat area/person		0.386 (0.076), <0.001***	0.404 (0.078), <0.001***	0.399 (0.080), <0.001***	0.405 (0.079), <0.001***	0.364 (0.078), <0.001***
Land-use mix		N.A.	−0.071 (0.083), 0.392	−0.047 (0.085), 0.577	0.062 (0.088), 0.480	0.057 (0.090), 0.527
Population density		N.A.	−0.099 (0.092), 0.281	−0.183 (0.100), 0.068	−0.110 (0.111), 0.324	0.075 (0.115), 0.518
Street intersection density		N.A.	0.061 (0.083), 0.466	−0.017 (0.084), 0.845	−0.067 (0.099), 0.500	−0.124 (0.128), 0.336
Number of parks		N.A.	−0.097 (0.075), 0.200	−0.052 (0.082), 0.528	−0.093 (0.090), 0.302	−0.078 (0.100), 0.439
Number of community centers		0.060 (0.089), 0.500	0.110 (0.095), 0.246	0.085 (0.097), 0.380	0.065 (0.095), 0.497	0.139 (0.125), 0.269
Number of sportsgrounds		0.024 (0.086), 0.782	0.074 (0.082), 0.367	−0.004 (0.088), 0.967	0.012 (0.099), 0.902	0.051 (0.122), 0.676
Number of playgrounds		0.023 (0.077), 0.770	0.010 (0.085), 0.906	0.025 (0.086), 0.771	−0.084 (0.089), 0.349	−0.003 (0.106), 0.977
Number of markets		0.158 (0.111), 0.157	0.029 (0.104), 0.780	0.097 (0.114), 0.397	0.228 (0.134), 0.092	−0.025 (0.192), 0.895
Number of malls		−0.044 (0.099), 0.655	0.007 (0.092), 0.936	−0.116 (0.102), 0.257	−0.147 (0.102), 0.153	−0.027 (0.123), 0.825
NDVI		−0.010 (0.084), 0.908	0.014 (0.103), 0.894	0.003 (0.108), 0.981	0.119 (0.114), 0.297	0.152 (0.105), 0.151
Model adjusted R^2	0.094**	0.280***	0.270***	0.266***	0.276***	0.267***
Model R2 improvement (vs. model 1)	N.A.	0.186***	0.176***	0.172***	0.182***	0.173***

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

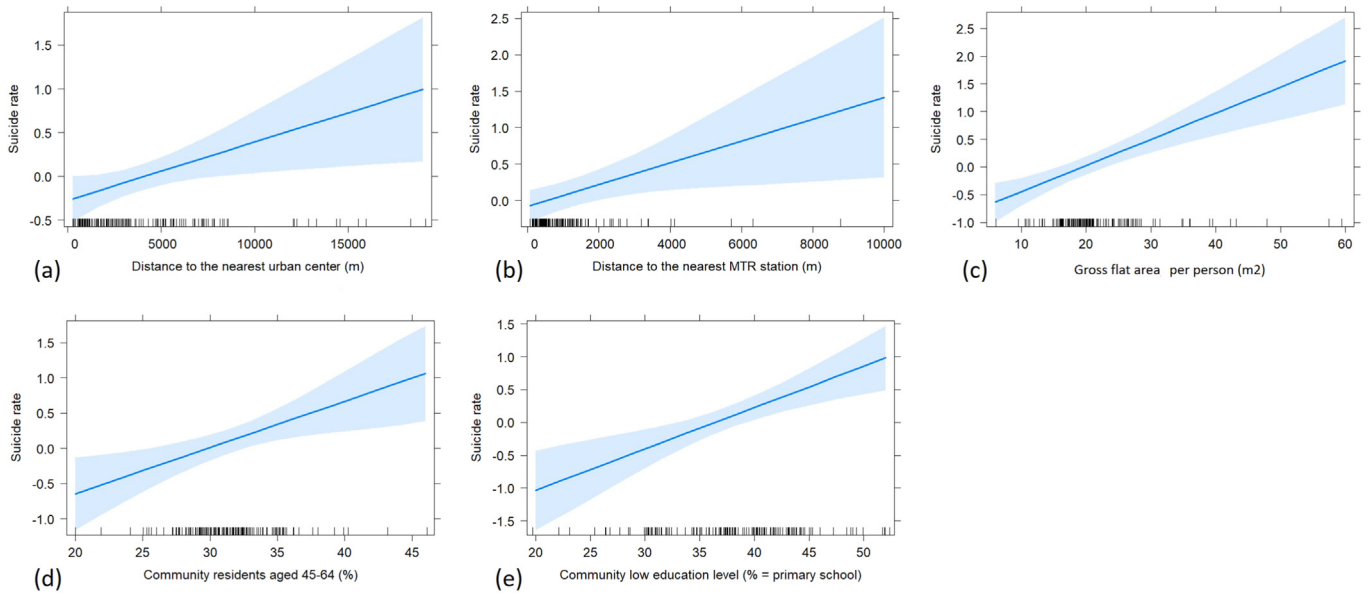

Fig. 3. The visualized effect of five significant predictors of suicide rate in Model 2.e. a. The effect of distance to the nearest urban center, while the other predictors are hold fixed. b. Distance to nearest MTR station. c. Gross flat area per person. d. Community residents aged 45–64. e. Community low education level. The shaded area represents the pointwise 95% confidence interval.

such as employment, recreation, entertainment, and medical treatment (Lu et al., 2018a). In so far as the distance to the nearest urban center is an indicator of how many public goods, services, and other resources residents can access within an urban district, the distance to the nearest MTR station is an indicator of how many public goods, services, and other resources residents can easily access across the city. Given that

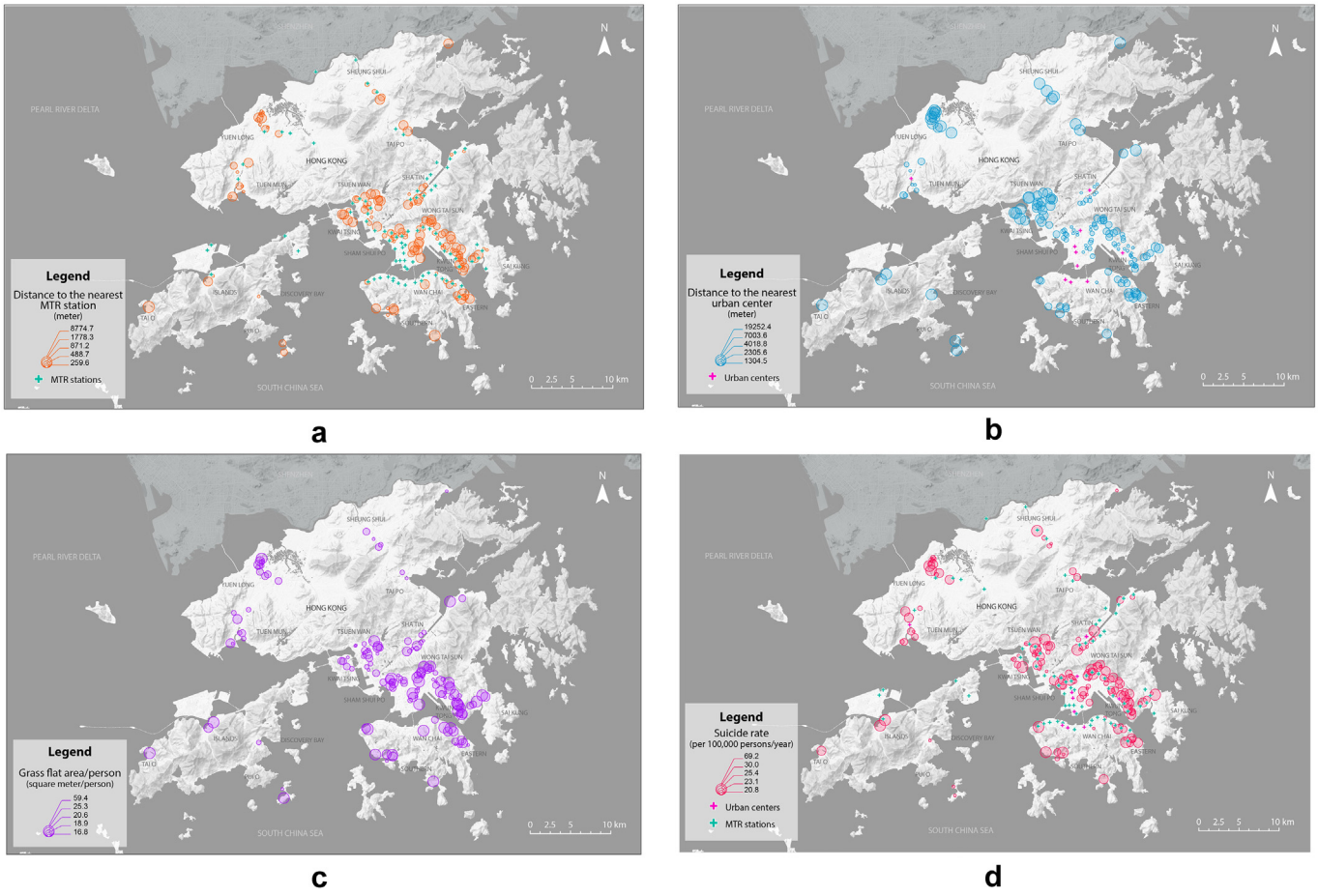

Fig. 4. The statistics of three significant built environment factors in 151 sampled public housing communities. a. The distribution and distance to the nearest MTR station of each sampled public housing community. b. The distribution and distance to the nearest urban center of each sampled public housing community. c. The distribution and grass flat area per person of each sampled public housing community. d. Suicide rate of each sampled public community with locations of MTR stations and urban centers.

these benefits are similar, we present one interpretation of these two factors to keep the discussion concise.

We argue that a greater distance to the urban center or MRT station is related to suicide rate by influences resident's levels of social isolation, mental health, and employment. We discuss each of these possibilities in turn below.

4.1.1.1. Social isolation. Social isolation can occur when individuals have limited opportunities for social engagement. A greater distance to the urban center or MRT station may result in an increased sense of social isolation through two pathways. The first pathway is by reducing access to social support. A greater distance to the urban center or MRT station may reduce the social support available to residents of public housing communities because the greater distance reduces opportunities of religious activities, recreation and entertainment activities, group exercise, group activities, and participation in social services or events (Chadwick and Collins, 2015; Lucas, 2012). Reduced social support, in turn, may contribute to a thwarted sense of belongingness or burdensomeness, increased levels of helplessness (Jiang et al., 2019), sense of loneliness (Joiner Jr. et al., 2002), and ultimately to higher suicide rates (Chadwick and Collins, 2015; Cheung et al., 2012; Judd et al., 2006; Lucas, 2012). Second, for public housing residents who have been relocated to remote settings, it is easy to imagine that they would feel unwelcomed or unneeded by society (I am unwanted), which might lead to a low-level self-esteem (I am a burden rather than a benefit for the society), self-blame or shame (I feel shame to be poor and incapable). These feelings surely do not prevent suicidal thoughts or actions.

4.1.1.2. Mental health. Keeping healthy reduces the likelihood of suicide because distress that grows from physical or mental illness can lead to a stronger sense of burdensomeness and thwarted belongingness (Van Orden et al., 2010). Many studies provide evidence for this statement: In general, living in remote or scattered communities can reduce residents' mental health (Chadwick and Collins, 2015; Frumkin, 2016; O'Farrell et al., 2016). A recent study in Hong Kong found the close proximity to the nearest urban center/MTR station might promote recreational walking thus promoting public health (Lu et al., 2018b). A study in Shanghai found a short distance to the subway station and adjacent central urban district was associated with residents' higher levels of happiness (Li et al., 2018). Similarly, a study in Turin found that close proximity to public transit stations and adjacent urban areas was beneficial to the general public and especially beneficial to reduce risk of depression for women and elderly by providing more opportunities to casual walking and increased social engagement (Melis et al., 2015).

4.1.1.3. Employment status. Last, a shorter distance to the nearest urban center/MTR station is likely beneficial for promoting residents' employment status by proving convenient access to a range of employment opportunities, such as jobs with better working conditions, a higher salary, or higher social status. By contrast, a greater distance to the urban center or MTR station suggests that public housing residents have less access to these positive employment opportunities. Since employment status was not a statistically significant factor in this study, we argue the quality of employment might have a greater effect on the suicide rate than the simple fact that a person is employed or not.

4.1.2. Gross flat area per person

We found that gross flat area per person was positively associated with the suicide rate – the greater the per person area, the greater the suicide rate. This relationship appears counter-intuitive at first, but upon further consideration a rationale becomes plausible. The Hong Kong Housing Authority stipulates four types of public housing unit sizes according to the number of residents per flat: 1 or 2 people (14.1 to 14.5 m^2); 2 or 3 people (21.4 to 22 m^2); 4 or more than 5 people (35 to 36.1 m^2) (Legislative Council of the Hong Kong, 2015). Therefore, if one person lives in a public housing flat, the gross area is greater than the gross area per person of two or more people per flat (Hong Kong Housing Authority, 2019c). This suggests that people with more personal living space are likely to be living alone. Previous research has found that living alone is a high-risk factor for suicide because it corresponds to social isolation (Schneider et al., 2014), and that those living alone are more vulnerable to stressful life events such as unemployment, poverty, and illness (Orford, 2008). Strong associations have also been found between the proportion of single-person households and suicide rates, especially for single residents in late middle-age (Wong et al., 2008). Nevertheless, more direct evidence needs to be generated in the future to fully confirm this possible interpretation.

4.2. A new layer for the interpersonal theory of suicide: the built environment

Findings of this study, combined with findings from previous studies suggest that theories of suicide, including IPTS, are missing an important factor that would lead to suicide: the conditions of the built environment (or physical environment). This study provides new empirical evidence demonstrating associations between conditions of the built environment and suicide. We propose that the conditions of the built environment influence suicide through their influence on social isolation, mental disorder, poor employment status, and physical illness. Thus, we suggest a possible addition to IPTS that includes conditions of the built environment. A new theoretical model of suicide including the layer of built environment factors is proposed as Fig. 5.

4.3. Other contributions and implications

In addition to the contribution of this study to the theory of suicide, we summarize four additional contributions and implications below.

First, for decades, investigations into suicide have been largely conducted by scholars of sociology, public health, or economics, and have explored SES and demographic factors (Qin et al., 2003; Van Orden et al., 2010; Zhang et al., 2010). Few studies, however, have examined potential impacts of built environment on the suicide rate (Hsu et al., 2015). The study reported here found the characteristics of the built environment can have significant associations to suicide rates. We call on governments, societies, public health professionals, and community leaders to recognize those significant associations and to do what they can to reduce social isolation that can grow from the design of the built environment.

Second, this study calls attention to the suicide problem in public housing communities in high-density cities, which has rarely been investigated. Worldwide, a high percentage of urban residents live in public housing communities, and they often suffer from SES and environmental disadvantages. The findings presented above provided evidence that it is not just the characteristics of the individuals who live in public housing communities that explains the higher than typical suicide rates seen in public housing communities. By holding constant the participants in this study – they were all residents of public housing communities, this study demonstrates that the conditions of the physical environment can explain in suicide rates above and beyond the SES and demographic characteristics of these communities.

Third, this study identified specific environmental factors that were significantly associated with public housing residents' suicide rate. Thus, it is not sufficient for policy makers, planners, and designers to understand that there is a general association between environmental factors and suicide rates: they must know which specific environmental factors are significant, to enable them to make pertinent environmental interventions. This is particularly important for cities in developing countries with limited human and monetary capital. Based on our interpretation of the significant environmental factors, we propose a series of interventions that might contribute to reduce suicide deaths (Table 3).

Finally, we hope our findings lead to future reformation of urban development and design that reduce environmental inequality in cities. Environmental resources are often disproportionately allocated to

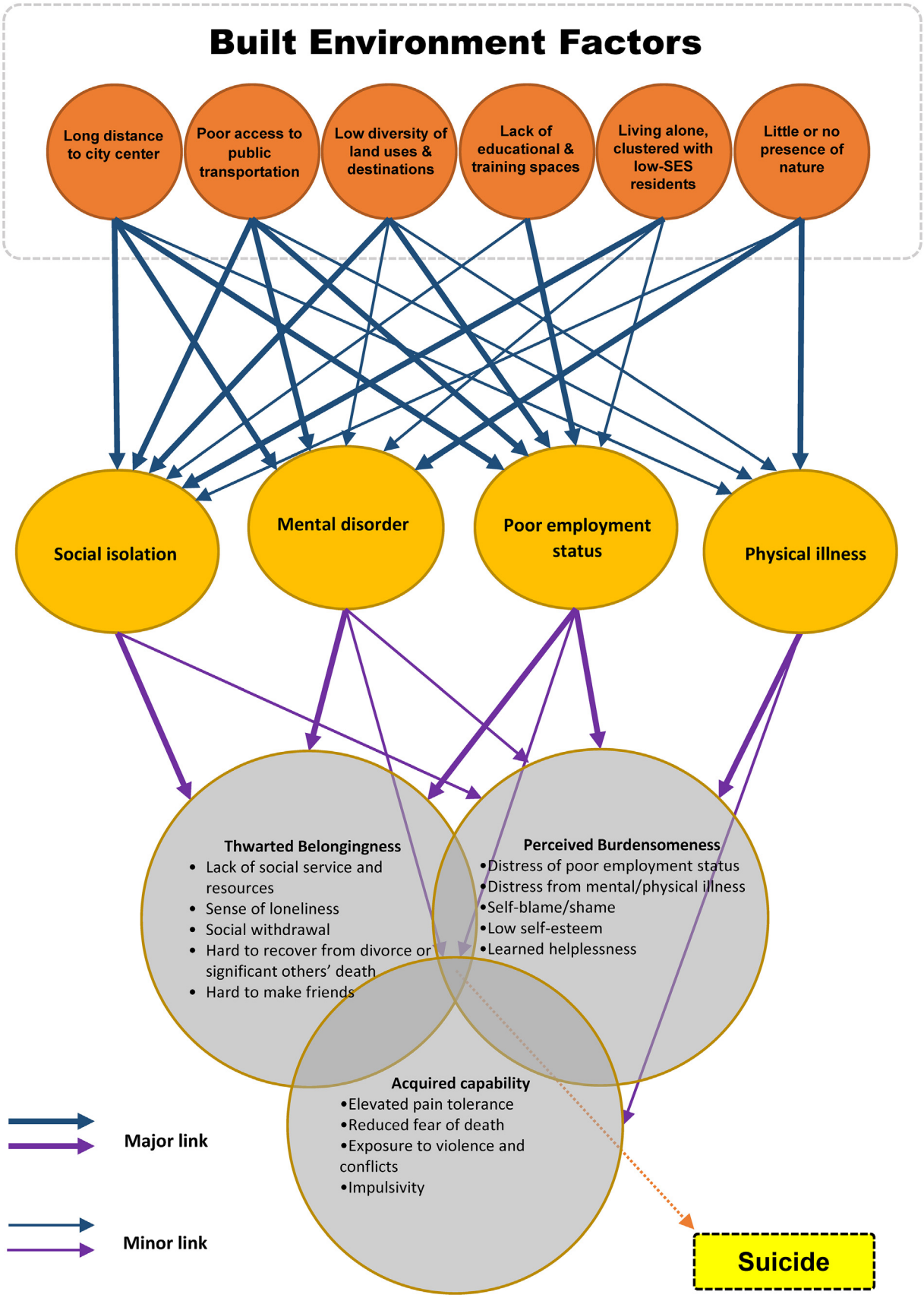

Fig. 5. A theoretical model of suicide including the layer of built environment factors based on IPTS. This study proposes that the conditions of the built environment influence suicide through their influence on social isolation, mental disorder, poor employment status, and physical illness.

Table 3
Suggestions of planning and design strategies for reducing suicide rates in public housing communities.

Type of factors	Significant factors	Planning and design strategies
Built environment factors	Distance to the nearest urban center	• Locate the community in proximity to an urban center so residents can have a better access to public service, social engagement, job opportunities, and recreation/entertainment opportunities. • Provide low-cost, safe, comfortable, and convenient walking, biking, or public transport connections between the community and urban center. • Provide special shuttle bus services for seniors, children, pregnant women, and disabled/injured/ill residents upon appointment or emergency calls; Developing more urban centers across the city with a decent level of spatial equality to provide residents more vital urban life and job opportunities in proximity. • Give priority to applicants who have been diagnosed with severe mental disorders or physical illness or a record of previous suicide attempts to live in communities near the urban center.
	Distance to the nearest MTR station	• Locate the community within a walkable distance to a subway station. • Provide a weather-free, safe, comfortable, and convenient walking connection between the community and the station. • Provide low-cost, high-frequency, and comfortable shuttle bus service between the community and the station if the distance is too long to walk. Provide shuttle bus service for seniors, children, pregnant women, and disabled/injured/ill residents upon requests. • Prioritize applicants who have been diagnosed with severe mental disorders or physical illness or who have a record of previous suicide attempts to live in communities near the station.
	Gross flat area per person	• Provide inviting public spaces for single residents for diverse and benign social activities. Provide social spaces for single residents to establish new marriages or partnerships. It is essential to avoid a large cluster of single-resident apartments in a community.
Socio-economic & demographic factors	Education (low educational level)	• Provide spaces to support residents' formal and informal educational programs, especially for middle-aged and senior residents who received limited education when they were young.
	Age (late middle-aged)	• Provide public spaces for late-middle-aged residents to have a decent social engagement level, family cohesion, knowledge and skill learning and exchange, and employment opportunities.

different income groups in cities and this inequality can lead to a deterioration of public health and wellbeing (Orton et al., 2013). Allocating critical environmental resources more equitably to communities may lessen the negative effects of SES inequality (Mitchell and Popham, 2008; O'Farrell et al., 2016). The findings and recommendations of this study could help to make public housing communities better living environments, encouraging more positive and healthy lifestyles among their residents.

4.4. Limitations and future research opportunities

As an initial exploration of the relationship between built environment and suicide rates, this study has limitations, which suggest six opportunities to expand our understanding of this important topic through future research.

First, although we argue that the allocation of public housing units to applicants largely followed rules of random assignment, the government has some policies to take care people who need special cares. The government allows individuals who are mentally or physically disabled or who need long-term medical support or who are above 60 years to submit an application for choosing a special district and/or type of housing unit. The application was reviewed by the government on a case-by-case basis. The number of approved cases was not reported but it is a reasonable estimate that number would not be large due to the significant gap between the low number of available apartments and huge number of applicants in the waiting list. Nevertheless, those special applications would have certain interferences to the natural experiment and they might need to be more restrictively controlled in statistical analysis in future studies (Hong Kong Housing Authority, 2020a, 2020b, 2020c).

Second, we conducted this study in a high-density city where people use the subway system as their main mode of transportation. Therefore, the effect of the subway system in this study is likely more profound than that of other modes of transportation, such as private vehicle, bus, and bicycle. It will be necessary to duplicate this study in other cities and societies to understand how different transportation modes affect the association between transportation availability and suicide rate.

Third, in this study, we found that vegetation and water landscapes did not significantly relate to suicide rates – a finding that is at odds with results from a few previous studies of built environment and suicide (e.g., Helbich et al., 2020; Shen and Lung, 2018). We believe the reason for this disparity in findings is due to the high level of exposure to both vegetation and water in Hong Kong, a coastal city dominated by sea and mountain landscapes. Future research should examine the association between varying levels of exposure to green and blue landscapes in cities that provide such variation.

Fourth, four age-related variables were presented in the regression model after the VIF test, which may have presented an over-adjustment to the VIF problem. We included multiple measures of age based on its importance from previous suicide research findings. In these studies, age was a major factor associated with suicide (Cukrowicz et al., 2011; Zhang et al., 2010). Previous studies across the world show the late-middle age and older individuals are especially vulnerable to suicide (e.g., Case and Deaton, 2015; Hsu et al., 2015). Though some age variables were kept while many other SES and demographic factors were removed by the VIF test (Appendix Table), future research should measure and categorize residents age in such a way that it addresses this over-adjustment problem.

Fifth, due to protection of residents' privacy, the courts in Hong Kong would not provide access to detailed SES data of individuals who died by suicide or information about the specific causes of each death, which presented us with a common obstacle for this type of research. Lack of these details prevented us from measuring the effect of personal factors on suicide rates and thus may cause an over-statement of environmental factors' effects. If we had more information about variables such as personality, childhood experience, financial condition, and family relationship (Wang et al., 2020). We may have found that these variables explained a large portion of the variance and that in doing so, the characteristics of the physical environment may not have reached significance. Research in the future should seek to remove this obstacle by finding a way to aggregate individual-level data without sacrificing residents' privacy.

Lastly, previous studies suggest that some other factors might have impacts on the suicide rate, such as immigration and ethnic minority (Forte et al., 2018) and high attitude of apartment (Reno et al., 2017). We did not examine these factors in this article for three reasons: Public housing communities in Hong Kong only provide service for permanent citizens but not for new immigrants or non-permanent residents (Hong Kong Housing Authority, 2019b); Hong Kong society is an ethnically homogenous society, with approximately 92% of its residents being Han Chinese (The Demographics: Ethnic Groups, 2018); All public housing buildings examined by this study are high-rise buildings with similar altitude. Nevertheless, researchers might need to measure their impacts

for some studies with particular social, demographic, and environmental conditions of research site and population.

5. Conclusions

The study reported here was a 13-year natural experiment that examined the relationship between built environment factors and the suicide rates of public housing communities in Hong Kong. After controlling for SES and demographic factors, we found that built environmental factors were significantly associated with public housing community residents' suicide rates. These findings suggest that environmental interventions might reduce suicide rates and promote the health and wellbeing of urban dwellers across the world. Lastly, we propose the Environmental Theory of Suicide based on the theory of Interpersonal Theory of Suicide.

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CRediT authorship contribution statement

Bin Jiang: Conceptualization, Methodology, Formal analysis, Design of theoretical Model, Writing-original draft, Writing-review and editing, Graphic design; **Ke Shen**: Conceptualization, Data collection and treatment, Formal analysis; **William C. Sullivan**: Revision of theoretical model, Writing-review and editing; **Yiyang Yang**: Data collection and treatment; Formal analysis; **Xueming Liu**: Writing-review and editing, Graphic design; **Yi Lu**: Conceptualization, Methodology, Formal analysis, Writing-original draft, Writing-review and editing

Declaration of competing interest

The authors declare no competing interests. The manuscript is approved by all authors for publication. The work described is original research and it has not been published or under consideration for publication elsewhere.

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