Built Environment Characteristics and SARS-CoV-2

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According to the socioecological framework, SARS-CoV-2 infection risk is affected by multilevel factors, such as individual (e.g., sex, age, and attitudes), behavioural (e.g., mobility and social interaction), social environment (e.g., family and friends), built environment, natural environment (air pollution, humid, and temperature), community (e.g., norms of wearing masks), and public policy (e.g., social distancing measures) factors. These multilevel factors may interact with each other and make the impact of the built environment on infection risk more complex. Therefore, it is necessary to control such covariates or to investigate the interactions between the built environment and the social environment in future studies.

Keywords: SARS-CoV-2 ; COVID-19 ; built environment

1. Introduction

The three major transmission mechanisms of severe acute respiratory syndrome coronavirus 2(SARS-CoV-2)are large droplet transmission, aerosol transmission, and fomite transmission [1][2].Although many social distancing measures, such as limiting large group gathering and mandatory mask-wearing requirement have been enforced and several vaccines have been developed, there is no effective treatment to cure infected individuals.COVID-19 has significantly changed daily life and challenged the global public health system and social economic development [3][4].

Built environment can be defined as human-made surroundings, which provide space and place for human activity [5].As a key sphere of socioecological framework, built environment factors significantly affect long-term health outcomes, and such effects have been identified across different social and urban contexts [6][7].Evidence also supports that a well-designed built environment can improve human health via several major pathways, e.g., promoting physical activity, reducing stress, increasing social contacts, and reducing pernicious environmental exposures (e.g., air pollution, sanitation, and noise) [8][9][10].Several built environment factors that influence health have been identified in previous reviews [8][11][12][13].These factors can be summarized in a five-dimensional (5D) model framework including density, diversity, design, destination accessibility, and distance to transit [11].

Circumstantial evidence supports that built environment characteristics may be related to the transmission of coronavirus infection.In previous existing literature, a large number of studies have revealed the relationship between built environment and the transmission mechanism and infection risk of SARS-CoV-2 because the built environment affects how people move around and the human-to-human contact in outdoor and indoor environments [14][15][16].For example, a higher density of service facilities (e.g., commercial facilities, schools, hospitals) may increase the risk of close contact, thus leading to the person-to-person SARS-CoV-2 transmission.In addition, public transit passengers may have high infection risk due to prolonged virus exposure within the enclosed carriages.However, evidence related to the effect of special built environment characteristics on the SARS-CoV-2 infection risk is inconclusive.For instance, people who lived in high-density areas may have more social contacts in their daily lives and thus a high risk of infection [14].Whereas cities and nations with a higher population density were found to implement stricter regulations, which effectively alleviated the spread of the virus [17].No review has summarized the role of the built environment in the COVID-19 pandemic.This gap in knowledge about built environment characteristics and to what extent they affect SARS-CoV-2 infection should be addressed, as a lack of knowledge may prevent government officials and urban planners from creating effective guidelines and urban environments to contain SARS-CoV-2 infections and face future pandemic challenges.

Given the research gaps discussed inSection 1.2, this review aimed at summarizing the existing evidence and providing an overview of the effect of built environment on SARS-CoV-2 infection during the COVID-19 pandemic.First, we identified the critical built environment factors that affect SARS-CoV-2 infection by comprehensively reviewing empirical studies on this topic.Second, we explored the potential mechanisms by which the built environment characteristics affect SARS-CoV-

2 infection.Our study may help to identify high-risk urban areas and thus develop effective strategies to reduce SARS-CoV-2 infection via targeted interventions.Our study may also contribute to providing urban planning guidelines to cope with future pandemics.

2. Major Findings

2.1. Commercial Facility Density

In this review, the strongest evidence was found for the association between commercial facilities and SARS-CoV-2 infection risk. Eleven out of 13 studies (84.6%) reported positive associations. One plausible explanation is that people who lived in neighbourhoods with more commercial destinations and services are more likely to use these facilities [10][18][19], therefore their risk of exposure to the virus increased [20][21]. Besides, in some recreation and service facilities, such as restaurants, hotels, and bars, people tend to take off their masks to talk, drink, and dine [21]. Furthermore, a large number of the commercial locations are designed as indoor spaces with inadequate ventilation, which can easily become high-risk places because the spread of the virus is intensified in confined spaces [22]. Hence, urban areas with intensive commercial facilities may be confronted with a higher virus infection risk. Some social distancing measures, for example, closure of unnecessary commercial destinations and/or controlling the number of people in such destinations, are needed.

2.2. School Density

Three studies investigated the association between school density (e.g., schools of different categories (elementary and middle schools)) and infected cases. Two studies in China showed a positive association [21][23], whereas one study in the U.S. revealed an insignificant association [24]. The potential mechanism linking school density and infection risk is that many teachers and students gather in classrooms and frequently interact with each other at a short distance in class and in after-class activities. In this setting, long and intimate contact in a closed environment may significantly increase virus transmission [25].

Given that many schools have been conducting online teaching rather than face-to-face teaching, the teaching mode may have also modified the observed results. Thus, more studies are needed to explore the relationship between school density, teaching mode, and infection risk. School density may also be a proxy for other constructs. For instance, the number of schools may be a measure of population density or socioeconomic status (SES) of an area because public schools are funded by local tax revenues in some countries, e.g., China and U.S. [24]. Although the infection risk is more pronounced in areas with a high school density, the causal relationship is still uncertain. Therefore, the potential influence of school density needs to be further investigated.

2.3. Road Density

Two out of four studies showed that road density is positively associated with virus infection [26][23]. A neighbourhood with a higher road density may have higher mobility and pedestrian activities [27] and consequently a higher risk of virus exposure and transmission. However, the results of two studies conducted in Bangladesh and China showed that road density had no significant effect on SARS-CoV-2 incidence [22][28]. This might have been due to the local social restrictions established to contain the rapid spread of COVID-19. For example, Wuhan, China, implemented a total lockdown policy during the data collection period, which sharply decreased the traffic flow and pedestrian activities [22].

2.4. Accessibility to Public Transit

Three out of six studies showed positive associations between accessibility to public transit and virus infection [29][21][30]. Public transit conveys many passengers for daily commuting or other activities in confined and often crowded settings. Given the potential for virus exposure among public transit passengers, the risk of virus transmission is substantial [31].

However, one study revealed a more complex relationship and found that the impact of public transit on the prevalence of COVID-19 was significant only when social distancing measures were relaxed [32]. People may mitigate the potential virus infection risk associated with public transit by using private vehicles, staying home, or wearing masks. The demand for public transit significantly decreased during the pandemic [33]. Furthermore, many cities implemented compulsory measures for public transit passengers (e.g., wearing masks and maintaining social distancing) [34]. Thus, the influence of accessibility to public transit may vary according to different pandemic stages, social distancing measures, and social contexts.

2.5. Availability of Green Space

Four out of seven studies showed the negative association between the availability of green space and COVID-19 incidence [30][35][36][37]. There are two possible explanations for this result. First, it is widely recognized that green space can promote long-term physical and mental health [37][38] by supporting physical activity and providing stress relief, which may help to boost the immune system against the virus. Second, air pollution may exacerbate the SARS-CoV-2 infection risk [39], yet green space can reduce exposure to air pollution, thereby decreasing the virus infection risk [37]. Other studies also found that green space usage increased during the pandemic [40], and the availability of green space decreases racial disparity in virus infection rates [41]. However, two studies suggested a positive association between green space and virus infection risk [42][43]. Some researchers believe that green spaces may promote close contact and increase infection risk, although the outdoor infection risk is low. People may also be infected when using public fitness facilities and public toilets in green spaces, which involve physical touch. Overall, with adequate precautions (e.g., controlling the number of users in green spaces, social distancing, and hygiene), the provision of green space may be an effective urban design strategy to face the challenge from the COVID-19 pandemic and future pandemic crises.

2.6. Urban Density

Urban density, which was often assessed by population density, building density, or residential density, was the most intensively investigated factor when discovering the relationship between built environment characteristics and COVID-19 incidence. One of the potential explanations is that urban density is commonly positively associated with the rates of infection during pandemics, and population-related data are easier to obtain [44].

The evidence for urban density is not conclusive. Only eight out of 24 (33.3%) studies found that urban density was positively associated with COVID-19 incidence. This may account for that in high-density areas, e.g., large cities or urban centres, people may have more social contacts, which may lead to a higher infection risk compared with that in low-density areas. However, five studies reported a negative association and 11 reported an insignificant association. Such mixed results may be explained by three reasons. First, some affluent and high-density cities, especially those in developed countries, have high-quality and accessible health care systems [44][45]. Second, the social distancing policies in high-density areas may be taken more seriously and managed strictly by the government and urban residents, thereby leading to a lower infection rate in these areas [17]. Third, the modifiable areal unit problem [45], i.e., using different spatial scales of analytical units, such as a community, town, county, or census tract, when calculating the area-based urban density or infection rate, may lead to different results in different studies [45].

Therefore, although urban density is arguably the most important built environment characteristic and planning parameter, little is known about its effect on SARS-CoV-2 infection. More studies with rigorous research designs are needed on this topic.

2.7. Hospital Density

The hospital density results were inconsistent. Three out of eight studies reported positive associations between hospital density and COVID-19 incidence [21][22][23]. Hospitals may be a hot spot for virus transmission because of close person-to-person contact and crowded indoor environments [46]. Many people, including patients, visitors, and healthcare staff, were infected in hospitals due to a lack of understanding about SARS-CoV-2 infection and a lack of appropriate protection during the initial COVID-19 outbreak in China [22]. However, one study in China showed inverse associations between hospital density and COVID-19 incidence [42]. The authors argued that patients can be scattered when there are more hospitals in one area, which may reduce the risk of transmission. Four studies found no significant relationship between hospital density and COVID-19 incidence [20][32][47]. Overall, the inconsistent evidence from these studies indicated that the effect of hospital density on COVID-19 is confounded by other factors, such as the health conditions of residents. Hospital density may also be a proxy for other latent constructs, such as the SES of an area or medical care conditions.

3. Recommendations for Future Studies

Future studies should address the following four limitations identified in this review.

First, all studies covered in this review, except for one, used a cross-sectional study design, which prevented us from establishing any causality. A major issue in cross-sectional research design is the residential self-selection bias [8][48]. This means that people who have a predisposition for physical activity and a healthy lifestyle may prefer to choose neighbourhoods with space or facilities supporting physical activity and healthy lifestyles [8]. With such bias, observed built environment–health associations may be explained by potential individual attitudes and preferences for physical activity and healthy lifestyles and failed to infer a true causal relationship. Thus, the impact of built environment characteristics on health outcomes, including SARS-CoV-2 infection risk, can be overrated in cross-sectional studies design as well. More controlled and longitudinal studies are needed to determine robust and long-term associations between built environment characteristics and COVID-19 incidence [49][50]. The availability of a suitable control group in a prospective longitudinal study will help us to establish a natural experiment by ruling out the self-selection bias [50].

Second, owing to the limited COVID-19 pandemic information released, the incidence and infection data were often offered as aggregated at the county or city level. All of the selected studies in this review also measured built environment characteristics at the county or city level. Such aggregated data are subject to ecological fallacy, which means that we cannot infer the outcome of individuals based on group information [51]. In addition, there are notable variations in built environment exposure for people living in the same county or city [19]. In future research, measuring of individual infection risk and corresponding individual-level built environment exposure is warranted to address this limitation.

Third, besides the built environment, social, cultural, and behavioural factors may also influence the spread of COVID-19, such as social norms, social distancing policies, individual mobility, and behaviours [35][36][37]. Such factors were often neglected in recent studies of built environment–infection associations. According to the socioecological framework, SARS-CoV-2 infection risk is affected by multilevel factors, such as individual (e.g., sex, age, and attitudes), behavioural (e.g., mobility and social interaction), social environment (e.g., family and friends), built environment, natural environment (air pollution, humid, and temperature), community (e.g., norms of wearing masks), and public policy (e.g., social distancing measures) factors. These multilevel factors may interact with each other and make the impact of the built environment on infection risk more complex. Therefore, it is necessary to control such covariates or to investigate the interactions between the built environment and the social environment in future studies.

Fourth, except for one multinational study, the remain studies selected in the current review were conducted in only five countries. Given the impact of the COVID-19 pandemic in almost all countries and the significant variations among the social and built environments across countries, additional studies covering more countries are required to allow cross-country comparisons. Research covering multiple countries in a single study is strongly recommended. The observation of homogeneous built environment–infection associations in different geographic settings can strengthen the generalizability and causality of the results.

4. Conclusions

This review summarizes recent evidence regarding the associations between various built environment factors and SARS-CoV-2 infection risk. Areas with higher infection risks often feature dense commercial facilities, schools, and street networks, fewer green spaces, and accessible public transit. The evidence for some important built environment characteristics (e.g., urban density, green space, and land-use mixture) remains mixed. Understanding how built environment affects SARS-CoV-2 infection risk is critical to control the COVID-19 pandemic. This review provides valuable recommendations for policymakers and urban planners in post-pandemic planning and future urban planning practices. To address the barriers and limitations in the literature, future studies should use a longitudinal research design, focus on long-term effects, accurately measure both infection risk and built environment exposure, and cover diverse regions.

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