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Effects of housing environments on COVID-19 transmission and mental health revealed by COVID-19 Participant Experience data from the All of Us Research Program in the USA: a case–control study

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ABSTRACT

Objectives To examine the association between housing types and COVID-19 infection (or mental health) during the early stages of the pandemic by using the large-scale individual-level *All of Us* Research Program COVID-19 Participant Experience (COPE) survey data. We hypothesise that housing types with a shared component are associated with elevated COVID-19 infection and subsequent mental health conditions.

Design A retrospective case–control study.

Setting Secondary analysis of online surveys conducted in the USA.

Participants 62 664 participant responses to COPE from May to July 2020.

Primary and secondary outcome measures Primary outcome measure is the self-reported COVID-19 status, and the secondary outcome measures are anxiety or stress. Both measures were applied for matched cases and controls of the same race, sex, age group and survey version.

Results A multiple logistic regression analysis revealed that housing types with a shared component are significantly associated with COVID-19 infection (OR=1.19, 95% CI 1.1 to 1.3; $p=2\times10^{-4}$), anxiety (OR=1.26, 95% CI 1.1 to 1.4; $p=1.1\times10^{-6}$) and stress (OR=1.29, 95% CI 1.2 to 1.4; $p=4.3\times10^{-10}$) as compared with free-standing houses, after adjusting for confounding factors. Further, frequent optional shopping or outing trips, another indicator of the built environment, are also associated with COVID-19 infection (OR=1.36, 95% CI 1.1 to 1.8; p=0.02), but not associated with elevated mental health conditions. Confounding factors are controlled in the analysis such as ethnicity, age, social distancing behaviour and house occupancy.

Conclusion Our study demonstrates that houses with a shared component tend to have an increased risk of COVID-19 transmission, which consequently leads to high levels of anxiety and stress for their dwellers. The study also suggests the necessity to improve the quality of the built environment such as residential housing and its surroundings through planning, design and management, ensuring a more resilient society that can cope with future pandemics.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ We used a large number of individual-level housing type and COVID-19 data in the study.
- ⇒ We matched cases and controls while accounting for many confounding factors.
- ⇒ COVID-19 status was self-reported.
- ⇒ Socioeconomic factors were not controlled for.
- ⇒ Spatial crowding and population densities were not accounted for due to unavailability.

INTRODUCTION

Since the start of the COVID-19 pandemic in December 2019, over 6 million deaths have been reported. The SARS-CoV-2 virus is transmitted within the particles and droplets of the respiratory fluids from infected persons.[1] The virus can also be transmitted from aerosols of circulated air[2] if the ventilation rate is insufficient[3] or if the air is highly recycled in a closed setting, such as a plane or a cruise ship, as seen on the Diamond Princess Cruise Ship.[4] Further, the virus can remain on the surface of objects, such as doorknobs, stairs and elevator panel buttons, for hours or even days.[5] Thus, one can get infected by touching the mucous membranes of their body (eg, nose) with soiled hands after touching the surface of objects contaminated by the virus. In the last two situations, the SARS-CoV-2 virus is transmitted through the built environment, which refers to the human-made space where people live, work and recreate on a daily basis.[6] Therefore, the built environment plays a critical role in curbing viral

transmission. To respond effectively, the early phase of a pandemic is particularly important because knowledge of the virus transmission and how to approach it is very limited.

A handful of studies have reported the connections between various types of built environments and COVID-19 transmission, and key findings are summarised in a recent review study.[7] These studies scanned different types of built environments with various characteristics of cities from multiple countries, such as trains in and between cities in Hubei Province (eg, Wuhan),[8] restaurants and public markets in Hong Kong,[9 10] transportation infrastructure in Huangzhou,[11] air ducts of apartments in Seoul,[12] house quality (eg, house size and crowding ratio) in Washington, DC,[13] assessed values, number of residential units, occupancy (persons per household) and crowding (persons per room) of buildings in New York City[14] and interventions on the built environment in cities in Turkey.[15] Many studies found that housing quality and living conditions are strong predictors for the ward-level COVID-19 death count, such as in Washington, DC.[13] Other studies have corroborated the results. A study in King County, Washington, demonstrated that built environment density (eg, building density) is positively associated with COVID-19 incidence rates.[16] Although mitigation measures such as regulating air delivery systems can theoretically reduce viral transmission, studies that examine the relationships between the built environment and COVID-19 transmission are still limited due to small sample sizes,[14] lack of good quality and high-precision first-hand data, as most come from census surveys at county,[17] city,[8] zip code,[16] census tract/ward[13 18] and community/neighbourhood scales.[13] Studies about the association between the individual-level data of the built environment and the COVID-19 status are still lacking in prior studies, most likely due to the high cost of acquiring individual-level data and the difficulty of controlling confounding factors, such as social activities, which played a detrimental role in transmitting the virus.[16] Due to people's tendency to stay at home rather than in the working environment at the early stage of the pandemic due to quarantine policies and self-protection,[19 20] in the current study, we focus on housing environments (specifically housing types), which refer to social, economic, functional and aesthetic aspects of housing, interiors and other environments,[21] one of the most critical built environmental variables during the pandemic.

Recent advances in data-driven projects include the All of US Research Program (AllofUsRP),[22] the largest biobank project in the USA. AllofUsRP thus provides a unique opportunity to investigate the impact of the built environment on COVID-19 transmission. AllofUsRP has conducted six rounds of large-scale, comprehensive surveys for the COVID-19 Participant Experience (COPE) in 2020 and 2021.[23] The first three rounds of COPE collected residential housing type information in May, June and July 2020, respectively, which were in the early phase of the pandemic. These rounds involved a large number of participants with individual-level household building type information, ranging from free-standing houses to various types of apartments and studios. More importantly, COPE also collected the mental health information of the participants, as quarantine measures are well known for their negative impact on mental health.[24 25] In addition, COPE has gathered information on participants' social distancing behaviours during 2020–2021, providing further opportunities to examine the impact of the housing conditions on the stress that dwellers experienced.

The study objective is to examine the relationship between housing types and COVID-19 infection rate (or mental health) during the early stages of the pandemic by using the AllofUsRP COPE survey data. We hypothesise that housing types with a shared component (eg, a shared wall or interior communal space) are associated with an elevated risk of COVID-19 infection and subsequently higher levels of mental health conditions compared with free-standing houses. We perform a series of multivariable logistic regression analyses to examine the associations between the built environment variables (housing conditions) and the outcome variables (eg, COVID-19 infection status), while controlling for potential confounding factors. To our best knowledge, this is one of the first large-scale case–control studies using individual-level data to examine the impact of the built environment on virus transmission during the early stage of the pandemic.

METHODS

COPE survey data in AllofUsRP and preprocessing

We chose the AllofUsRP data set because it contains a large cohort of diverse populations and the availability of housing type data in the COPE survey. AllofUsRP aims to recruit adults (18 years and older) who live in the USA from all backgrounds. To date, the programme has enrolled over 300 000 participants, who present from diverse backgrounds (eg, ethnicities, social behaviours, geographic locations, medical conditions) and are representative of the demographics of their communities in research studies.[26] The transparency, diversity and inclusion of the AllofUsRP provide researchers with a unique opportunity to investigate the roles that the built environment can play on mental and physical health.[27] AllofUsRP shares the data sets collected from the participants in a common cloud environment, the All of Us Researcher Workbench.[26] Approved researchers can access and analyse its deidentified individual-level data sets through interactive, web-based, cloud computing environments.[22] Access to the data of the registered or controlled tier requires corresponding training, which has been fulfilled by authors directly analysing the data (at least for the registered tier).

The AllofUsRP COPE online survey began in May 2020 and ended in February 2021, which aims to better understand how COVID-19 affects participants' daily lives and

health conditions, especially their mental health.[28] The survey takes around 20–30 min to complete and covers topics like social distancing experiences, self-reported COVID-19 status, well-being, basic participant's information, mental health, COVID-19-induced socioeconomic changes (eg, work and financial changes) and physical activity, among many others.[23] The survey questions have six versions thus far. Participants are asked to use the most recent version, which enables researchers to examine the effects of COVID-19 over time. In our analysis, we took advantage of the first three versions (May, June and July 2020) of the COPE data, consisting of 62 664 participants in version 4 of the AllofUsRP data set, where housing type information becomes available. Our analysis focused on the responses on anxiety, stress, housing types, social distancing behaviours and participants' COVID-19 infection conditions. We used the Structural Query Language to extract data guided by the concept IDs of the variables (outcomes and covariates; details shown below) relevant to the interest of our study.

Patient and public involvement

No patients were directly involved in the secondary analysis of the COPE data in this study.

Construction of the study cohorts

Based on the participants' responses to COPE, we conducted a retrospective case–control study that started by identifying all positive and negative responses for each outcome, specifically COVID-19, anxiety and stress status. COVID-19 status was self-reported in the answers to the survey question: 'Do you think you have had COVID-19?'. The status was considered as the binary outcome variable ('Yes': positive; 'No': negative); for convenience, we removed the participants who were not sure about their COVID-19 status with a 'Maybe' response. We used the most relevant question of anxiety to measure the secondary outcome of anxiety: 'In the past 2 weeks, how often have you been bothered by the following problem? Feeling nervous, anxious, or on edge'; we treated 'more than half of days' and 'nearly every day' as positive anxiety cases and 'not at all' as negative controls. We removed missing responses and the responses of 'several days' due to the challenge of determining the status as positive or negative cases. Similarly, for the most relevant question of stress: 'In the last month, how often have you felt nervous and "stressed"?', we treated 'fairly often' and 'very often' as positive stress cases versus 'never' and 'almost never' as negative controls and excluded 'sometimes' from the analysis.

We matched each positive case with a control while building the cohort to study an outcome variable by selecting the control that has the same demographic factors as the case, such as race, sex, age group (in 10-year brackets) and survey version with the case, as used in our previous COVID-19 study.[29] This study approach ensures inclusion of factors that are related to social behaviours, which directly influence COVID-19 transmission. First, we divided the available cases and controls of an outcome (eg, COVID-19 status) in COPE into strata of the same race, sex, age group and survey version. Second, we randomly sampled without replacement from every stratum for control individuals with a targeted sample size equal to the number of cases in the stratum. Third, for a few scenarios that do not have enough controls, we relaxed the matched field in the order of survey version, race, sex and age group. Cases in the strata without any matched controls (including partial matches) were excluded from the analysis. When the confounding factors are fully matched, they will not be expected to be significant in the statistical analysis even if they are significant before matching.

Statistical analysis

We fitted a multiple logistic regression model with the COPE survey data to determine the relationship between housing types and each of the influenced outcomes, COVID-19 infection, anxiety or stress during the early stages of the COVID-19 pandemic. We controlled various types of confounding factors, while studying the interwoven factors, taking advantage of the rich information collected by the survey. Three models were tested with potential confounding factors adjusted for the association between our studied covariates and outcome variables as described below.

These models are: (1) Model A (see section: *Associations between housing type and COVID-19 status*) used COVID-19 status as the outcome and housing types as the major explanatory variable (covariate), which was adjusted for other confounding covariates such as household occupancy (the number of occupants in a household), race/ethnicity, sex, age, social distancing, social habits (eg, shopping trips or outings that were 'just for fun' in the last 5 days, referred to as optional shopping or outing trips hereafter) and mental health (anxiety and stress). (2) Models B and C (see section: *Associations between housing type and mental health during COVID-19 pandemic*) used mental health (anxiety and stress) as the outcome to study the contribution of housing types, which is adjusted for the other covariates, like model A.

For households, we examined individual types (eg, free-standing houses and apartments with different numbers of bedrooms). We also combined housing types with a shared component for a summarised analysis, which specifically included the townhouses; three-bedroom (or more), two-bedroom and one-bedroom apartments; studios; and nursing homes or rehabilitation facilities. We included the household occupancy as a confounding covariate in all models because it may relate to COVID-19 transmission[30] and mental health. For social distancing behaviour, we included the number of days with the following behaviours in the last 5 days: staying at home, working or volunteering outside the home, attending social gatherings outside with more than 10 people and having close contact with somebody from a risk group. We also included hygiene practices in the analysis. We

treated each variable as numerical (eg, age) or categorical data, particularly for those with missing responses (as a special level). Full details of the survey questions and multichoice response options can be found on the AllofUsRP website.[28]

ORs of the outcome by the covariates of interest were calculated from the contrasts to the conventionally selected reference groups (ie, the free-standing house for housing types; none of the days (0 day) of optional shopping or outing trips) for daily behaviour in all models. Covariates that were irrelevant after analysis of variance (p>0.25 with χ^2 test) were excluded in the final logistic regression model. All statistical tests were two sided, and a p value <0.05 was considered statistically significant. Analyses were implemented in the AllofUs Researcher Workbench with R.

RESULTS

Associations between housing type and COVID-19 status

We first investigated to what extent housing type (eg, apartment) impacted COVID-19 transmission using the matched cases and controls (see the Methods section: *Construction of the study cohorts*). Of the 62 664 participants in the COPE survey, 4870 COVID-19 cases were reported from 3700 participants (some participants responded multiple times in different versions of the survey during May, June and July 2020). We thus matched 4870 negative controls with the same race, sex, age group (in 10-year brackets) and survey version (month) as the cases (four failed to match survey version and nine failed to match survey version and race). The majority of participants lived in the free-standing house (single-family house): 59.3% (2886 out of 4870) of the self-reported cases (COVID-19=1), which is close to the national average. The characteristics of the cases and matched controls are summarised in table 1. Since free-standing houses are assumed to be less risky for COVID-19 infection, we used it as the reference level to compute the ORs of infection for participants living in other housing types. Using a multiple logistic regression model, we examined the association between housing type and COVID-19 status, controlling for ethnicity, birth year, social distancing behaviour, household occupancy and anxiety and stress status.

Figure 1 shows the distribution of housing types conditioned on COVID-19 status, visualising the probability of each housing type given a COVID-19 status. The figure demonstrates that participants who became infected had a lower probability of living in a free-standing house as compared with the non-infected. Participants with positive cases were more likely to live in housing types with shared components (see the reverse trend in figure 1 for apartments). A multiple logistic regression analysis further confirms the trend. Participants living in housing types with a shared component (eg, townhouse and apartment) had a statistically significant increased association with infection (OR=1.19, 95% CI 1.1 to 1.3; p=0.0002) as compared with those living in a free-standing house. Among all the housing types with a shared component, the OR of contracting COVID-19 for participants who live in a nursing home or rehabilitation facility was more than sevenfold greater than participants who live in free-standing houses (OR=7.13, 95% CI 1.5 to 33.7; p=0.01). Other significantly higher ORs appear among the respondents who live in three-bedroom (or more) apartments (OR=1.37, 95% CI 1.1 to 1.7; p=0.001). This result was not confounded by age which had a different level of infection risk, likely due to distinct social behaviours. Even when controlled by age group (using both cases and controls within the same age group), the trends of ORs were similar (data not shown). Some housing types lacked significance, such as those depleted due to age group (eg, nursing home facilities for ages 40 and below). In addition, race, sex, age, ethnicity, survey version and household occupancy were not associated with COVID-19 infection in the matched cohort, but social distancing behaviour (eg, number of days staying at home, gatherings with over 10 people, shopping, etc) and mental health (anxiety and stress) were (discussed in the next sections).

Table 1 Characteristics of COVID-19 matched cohort from AllofUsRP COPE data collected in May, June and July 2020

	COVID-19 status (n)	
Characteristic	Positive	Negative
Age		
18–29	480	476
30–39	851	847
40–49	835	837
50–59	1113	1115
60 and over	1591	1595
Sex at birth		
Female	3459	3465
Male	1382	1381
Others	29	24
Race and ethnicity		
White	3833	3843
Asian	105	102
Black/African American	316	316
More than one population	112	112
Others*	466	465
Skip, prefer not to say or no answer	38	32

*Including another single population, none of these, none indicated and no matching concept.
AllofUsRP, All of Us Research Program; COPE, COVID-19 Participant Experience.

Figure 1 Distribution of housing type conditioned on COVID-19 status. A free-standing house has a less conditional probability of infection than non-infection, but the housing types with shared components have a larger conditional probability of infection than non-infection. ORs and p values of COVID-19 infection for the housing types compared with free-standing houses are shown above the probability bar graphs of the corresponding housing type.

Associations between housing type and mental health during COVID-19 pandemic

Next, we examined the impact of housing type on mental health, specifically anxiety and stress. We hypothesised that COVID-19 status and infection risk may affect participants' mental health by varying degrees. Thus, the housing type may affect a person's mental health even though they are not infected. We modelled the mental health outcome of anxiety or stress statuses using a multiple logistic regression model to evaluate the relationship between the two conditions and housing type while controlling for various confounding factors. The models included race, ethnicity, sex at birth, birth year, hygiene, social distancing behaviour (eg, shopping and outing behaviours), COVID-19 status, survey versions and the other mental health conditions (eg, stress to anxiety or vice versa) (see the Methods section). A large number of positive anxiety and stress cases were reported, consisting of 19 918 anxiety cases from 14 818 (23.6% of 62 664) participants and 21 821 stress cases from 15 810 (25.2% of 62 664) participants. We made a non-anxiety control cohort of 14 818 (896 partial matches) and a non-stress control cohort of 17 276 (933 partial matches) with matched race, sex at birth, age group and survey versions (partially matched controls are still in the same age groups as the cases).

The conditional probability of housing type with respect to anxiety and stress is shown in figure 2. Housing type was associated with anxiety and stress similar to COVID-19 infection: participants living in a free-standing house comprised a smaller proportion among mental health cases as compared with mental health controls, while larger proportions of mental health cases were found in housing types with a shared component. Participants who lived in housing types with a shared component were associated with an increased risk of anxiety (OR=1.26, 95% CI 1.1 to 1.4; $p=1.1\times10^{-6}$) and stress (OR=1.29, 95% CI 1.2 to 1.4; $p=4.3\times10^{-10}$). For instance, participants in one-bedroom apartments were correlated with a significantly elevated risk of mental health conditions compared with participants who lived in free-standing houses (anxiety: OR=1.48, 95% CI 1.3 to 1.7, $p=1.4\times10^{-6}$; stress: OR=1.46, 95% CI 1.3 to 1.7, $p=4.2\times10^{-8}$); homeless had the highest OR of anxiety (OR=4.13, 95% CI 1.5 to 11.7; p=0.008), particularly for those above their 50s. Race, sex and age were confounding factors for the association between housing type and mental health (eg, stress) as all the factors were significantly ($p<0.01$) associated with mental health in the matched models. COVID-19 status, household occupancy, hygiene and social distancing habits (close contact, days at home and at work) were associated with both anxiety and stress ($p<0.05$). Last, stratification studies of sex and age group led to similar trends (data not shown), and anxiety and stress were correlated.

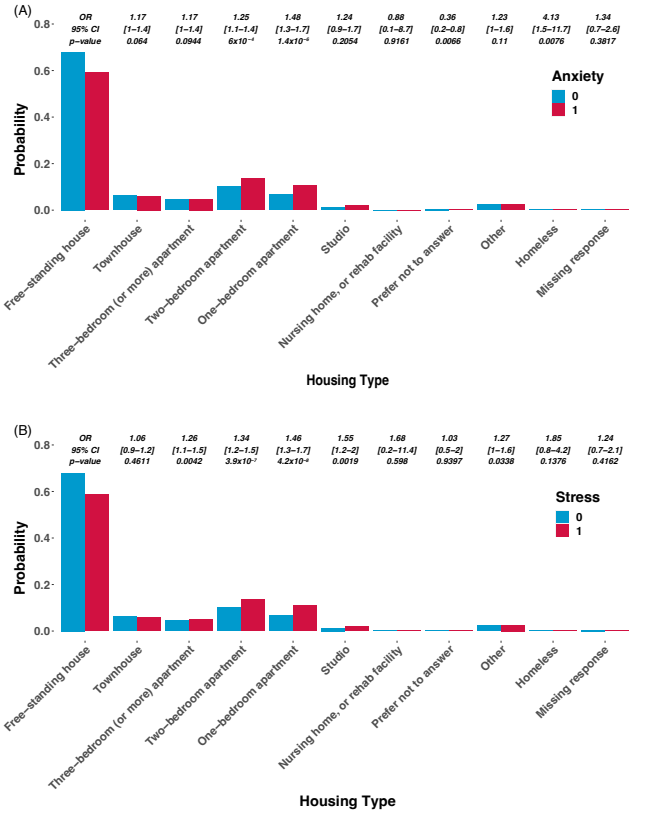

Figure 2 Distribution of housing type conditioned on anxiety or stress status. Participants with anxiety (A) or stress (B) are less likely to live in a free-standing house and more likely to live in a housing type with shared components compared with those without anxiety. ORs and p values of anxiety or stress for each of the housing types as compared with free-standing houses are shown above the probability bar graphs for their corresponding type.

Impact of shopping behaviour on COVID-19 status and mental health

Finally, we examined the association between COVID-19 status and optional shopping or outing trips using the same analysis in section *Associations between housing type*

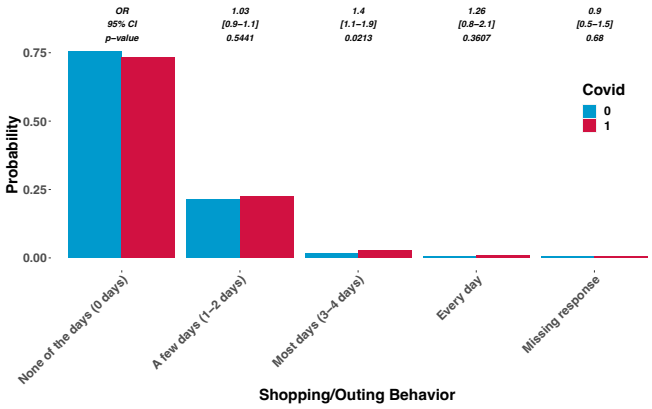

Figure 3 Distribution of optional shopping or outing behaviours in the last 5 days conditioned on COVID-19 status.

and COVID-19 status and section *Associations between housing type and mental health during COVID-19 pandemic.* Most shopping in the USA was done indoors, and therefore is an issue also related to the built environment. Figure 3 shows the distribution of optional shopping and outing behaviours with respect to COVID-19 status, which suggests that partaking more in optional shopping or outing trips was associated with an elevated risk of COVID-19 infection. During the early stages of the pandemic, most participants tended to eliminate optional trips. More than 70% of the participants reported none of the days in the last 5 days. Therefore, we set this shopping type as the reference level. The multiple logistic regression analysis showed that participants who went on optional trips more often were correlated with a higher risk of infection. Participants who went out by choice most days (more than 3 days within the last 5 days) yielded nearly 36% more risk compared with the participants who answered none of the days (OR=1.36, 95% CI 1.1 to 1.8; p=0.02). Of note, participants with frequent optional trips were not significantly associated with more anxiety or stress (see the Discussion section). Overall, the results suggest that commercial land use or public areas of the built environments, such as shopping malls, were likely to be related to COVID-19 transmission in the early stage of the pandemic. However, a more precise measurement of the built environment types (such as separating survey questions of shopping and outing behaviours) is needed to draw a more robust conclusion.

DISCUSSION

In this study, we applied multiple logistic regression analyses using the COPE survey data and found that housing type was associated with COVID-19 infection and mental health (eg, anxiety) during the early stages of the COVID-19 pandemic. Our analysis also revealed that individuals with more frequent optional shopping trips or non-essential outings (eg, socialising outings) were associated with higher rates of COVID-19 infection. Figure 4 illustrates the summarised findings among the housing type, COVID-19 infection, mental health and optional shopping or outing trips. While previous studies have suggested the associations between built environments and COVID-19 infection based on summarised data (eg, population density or house density,[31] COVID-19 transmission rate at the zip code scale[16]), the current study employed large-scale individualised data with stringent control of various confounding factors, such as sex, age and social behaviours. Thus, associations between the housing environment and COVID-19 transmission are supported by stronger scientific evidence, demonstrating the significance and the novelty of the study.

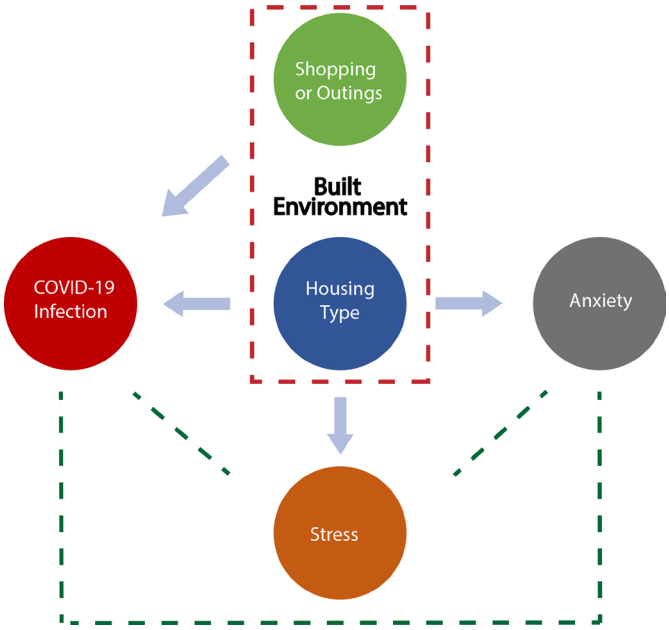

Figure 4 Relationships among the housing type, COVID-19 infection, mental health and optional shopping or outing trips. Arrows indicate associations between the built environment and its impact outcomes, while dotted lines show the confounding associations among the outcomes.

The robustness of results from secondary studies is often a concern. Our results indicated that people who lived in nursing homes or rehabilitation facilities were associated with a much higher possibility of becoming infected with COVID-19 compared with those who lived in free-standing houses. This was true even with stratification analyses using the same age group (although they lacked power). For instance, we found an OR=3.96, 95% CI 0.7 to 23.2, p=0.13 for those over the age of 60. Many research reports suggested that household overcrowding is a risky factor for infection and mortality,[32] particularly in nursing homes. In addition, apartment dwellers (ie, three-bedroom (or more) apartments) showed a higher correlation for contracting COVID-19, even when considering the confounding factor of the number of occupants in the house (data not shown). Meanwhile, two-bedroom or one-bedroom apartments showed inconsistent and underpowered results in some age groups likely due to lower household occupancy. Although contributions from confounding factors that were not modelled may

play a role (eg, population density[17] or spatial crowding[31] at aggregated scales or interactions with visitors and workers[17]), the possibility of association with the built environment is high due to the stringent controls and reproducibility of the results in the stratified analyses. Concerning mental health, people who are homeless and participants who lived in apartments with shared living spaces were at a higher rate of reporting anxiety than inhabitants in free-standing homes. This corroborates prior reports and is associated with the congregate living conditions.[33] All the results indicated that built environments with shared components played a role in the transmission of SARS-CoV-2 and imposed mental burdens on dwellers during the COVID-19 pandemic.

Considering the association between social behaviours and COVID-19 infection, such as optional trips and COVID-19 infection, there is an increasing trend of positive cases with more frequent optional shopping or outing behaviours (three or more days in the last 5 days) as compared with individuals who opted for none of the days. As shown in figure 4, shopping and outing behaviours could relate to the built environment due to a large group of shoppers mixing indoors throughout the pandemic, providing common areas for COVID-19 viral transmission.[34]

The relationship between our investigated outcome variables can be interwoven. Further, previous studies have shown that people with pre-existing mental health conditions may even have a higher tendency of being infected due to medical visits and emotional responses to the COVID-19 pandemic, thereby placing them at an increased level of risk of COVID-19 infection compared with those without mental health conditions.[35] Conversely, another study has pointed out that individuals with mental health disorders are likely to have greater barriers in obtaining timely medical services, exacerbating mental health issues.[36] Although our results corroborated previous findings (figure 4), we could not distinguish the order of mental disease and COVID-19 infection due to the lack of longitudinal information in the survey. Also, in the early stages of the pandemic, except for the built environment, many other factors may contribute to the widespread and increased psychological problems[25 27 37 38] in an age-specific manner.[39] These factors affect a person's well-being and daily life through COVID-19 infections, increasing trends of COVID-19-positive cases and deaths, growing financial difficulties, quarantine measures and strict social distancing regulations,[40] a lack of knowledge of the virus and spread of misinformation, panic emotion induced by social media[41] and reduced usage of green and blue spaces.[42]

Even with abundant studies on mental health during the COVID-19 pandemic, the relationship between optional trips and mental health has been rarely studied. Our studies did not observe any robustly significant association between more frequent non-essential trips and mental conditions (anxiety or stress). In addition, previous studies have not identified significant associations between stress levels and the use of community parks or engagement in outdoor activities, which may partially corroborate our findings. Although it is beyond the scope of our current study to investigate these factors, other latent connections exist between those trips and anxiety and stress. Previous studies have reported that moderate shopping could provide both psychological and therapeutic value.[43 44] Additionally, experiments about the effectiveness of diversion buying for stress release showed that a certain amount of spending was necessary to release stress.[45] Therefore, having more optional trips may be related to anxiety and stress in a positive manner. For example, our study associated a reduction in stress (OR=0.07, p<0.0001) with frequent shoppers (every day) in their youth (20s age group).

The study results should be interpreted with caution due to several limitations: (1) The associations identified in the study may not indicate causal relationships, particularly because of the secondary use of existing COPE data. (2) COVID-19 status was based on self-reporting in lieu of PCR-tested results, which were limited at the early stages of the pandemic. (3) COVID-19 infection is highly related to social behaviours, which vary significantly among age groups. Some of the stratification analyses in particular age groups may be underpowered. (4) As the shopping status is combined with outings, the association with the commercially built environment needs further examination. (5) COVID-19, anxiety and stress present interwoven relationships. Therefore, the order of the phenotypes can hardly be determined. Socioeconomic status (eg, employment status, financial difficulties and other COVID-19-related impacts) might also confound the study but was not included in the current study due to the option for multiple answers rather than the multiple-choice survey in COPE, which might cause power issues and multicollinearity in regression. (6) We could not include spatial crowding (eg, number of apartments in a building or number of houses within a region) or population density in the analyses because the data are not available.

In conclusion, the study demonstrated that housing environments with a shared component are associated with an increase in COVID-19 transmission while their dwellers experienced an increase in self-reported anxiety and stress levels. These findings will provide guidance on mitigation strategies for COVID-19 transmission with respect to different housing types and will suggest the necessity of providing adaptive and resilient design solutions focusing on the built environment to respond to potential airborne and contagious viruses in the future.[46] It is thus crucial to improve the quality of the built environment through planning, design and management, pursuing a more resilient society that is able to cope with future pandemics. Prospective endeavours include enhancing the ventilation systems and design standards for residential housing,[40] improving the plumbing system designs[40] and prompting more contactless access technologies[47] (eg, using intelligent cards and facial recognition)

for shared facilities in apartment buildings (eg, entry doors and elevators).

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