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COVID-19 and the compact city: Implications for well-being and sustainable urban planning

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HIGHLIGHTS
• New evidence on compact urban environments and health/well-being under COVID-19
• High density linked to lower life satisfaction and happiness during COVID-19
• Small dwellings linked to lower life satisfaction and happiness during COVID-19
• Public transport reliance linked to an increase in anxiety during COVID-19
• Access to local facilities linked to better health and well-being during COVID-19

ABSTRACT
This paper provides new evidence on the role of city planning, urban form, and built environment characteristics in health and well-being during the coronavirus disease (COVID-19) pandemic. Based on survey and geographic information systems (GIS) data from Oslo and Viken in Norway, the paper investigates changes in health and well-being due to COVID-19 and how the compact city and its characteristics relate to these changes. Findings indicate that self-reported measures of health and well-being worsened due to COVID-19. The most substantial changes were reported for life satisfaction, anxiety, and satisfaction with leisure, personal relationships, and vacations. General health, happiness, and satisfaction with income also declined during COVID-19 in comparison with pre-COVID-19 times. Overall, residents of compact neighborhoods reported lower well-being during COVID-19 compared to residents of lower-density neighborhoods. Important compact city characteristics – higher neighborhood density, reliance on public transport, smaller dwellings, and less green space – were negatively associated with well-being and health outcomes during COVID-19. In contrast, another compact city attribute, the presence of numerous local facilities, was positively linked to well-being and health during COVID-19. Based on these findings, the paper presents possible implications for sustainable urban planning and compact cities.

1. Introduction
The coronavirus disease (COVID-19) pandemic has caused numerous deaths worldwide but has also indirectly affected physical and mental health, and most, if not all, domains of life (Brooks et al., 2020; Fiorillo and Gorwood, 2020; Li et al., 2020; Moreno et al., 2020; Patrick et al., 2020; White and Van Der Boor, 2020). This indirect impact of COVID-19 on health and well-being can be attributed to measures that were implemented to slow down infection rates: lockdowns, quarantines, social distancing measures, travel restrictions, and closing of businesses and facilities. The risk of infection together with these unforeseen measures contributed to stress and fear of infection, unemployment, loss of income, economic instability, insecurity for the future, lack of social connectedness, feelings of isolation, problems in social relationships, lack of participation

http://dx.doi.org/10.1016/j.scitotenv.2021.152332
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in favorite activities, limited options for doing sports and physical exercise, and inability to travel for leisure.

The role of cities, city planning, and built environment characteristics in the changes in health and well-being occurring due to COVID-19 has not been sufficiently investigated yet. Urban form and built environment characteristics can contribute to health and well-being in several ways (Hamidi et al., 2018; Litman, 2020b; Mouratidis, 2021b; Stevenson et al., 2016). But more knowledge is needed on how compact versus sprawled urban forms and their characteristics might have contributed to health and well-being during the COVID-19 times. The compact city is a type of urban form and public policy that offers multiple environmental, societal, and economic benefits compared to urban sprawl (Dye, 2008; Glaeser, 2011; Meyer, 2013; Mouratidis, 2018b), and is therefore widely considered the preferred model in the quest for sustainable urban planning and policy (Bibri et al., 2020; OECD, 2018). Studying the links between urban form compactness (and its characteristics) and health and well-being during COVID-19 times in diverse contexts can shed light on a timely, critical issue for sustainable urban planning and offer evidence-based knowledge for possible policy recommendations for compact cities in times of pandemic crises.

This study provides new evidence on changes in self-reported health and well-being due to COVID-19 and investigates how the compact city relates to these changes. It is one of the first studies to combine survey data with geographic information systems (GIS) data on the built environment in order to examine links between compact city planning and health/well-being changes due to COVID-19. Two research questions are addressed: (1) How did self-reported health and well-being change before versus during COVID-19? (2) How do compact city characteristics relate to health and well-being before and during COVID-19? The study focuses on the region of Oslo and Viken in Norway. This region includes both compact and low-density urban environments with diverse spatial characteristics, thus offering a useful case for exploring the research questions of the study.

2. Literature review

2.1. Compact city planning and well-being

The links between compact city characteristics and health and well-being have been widely studied in the period before COVID-19 (e.g. Alamanita et al., 2018; Cao, 2016; Ettema and Scheekerman, 2016; Howley et al., 2009; Ibleak et al., 2021; Kytä et al., 2016; Markevych et al., 2017; Mouratidis, 2018a, 2019a; Mouratidis, 2019b; Wang and Wang, 2016). Compact cities—cities of short distances allowed by higher densities—offer both advantages and disadvantages in relation to health and well-being. They provide greater access to destinations, enable the use of efficient public transport systems, provide walkable access to a wider range of facilities, and provide access to the public realm. Thereby, they have been linked to increased walking, lower obesity, higher life expectancy, increased overall social activity, increased travel satisfaction, and higher residential satisfaction (Cosby et al., 2019; Dye, 2008; Hamidi et al., 2018; Litman, 2020b; Melis et al., 2015; Mouratidis, 2018a, 2018b; Mouratidis et al., 2019; Saelens and Handy, 2008; Stevenson et al., 2016). Increased overall social activity in compact cities not only contributes to social capital and well-being but also to resilience during adverse events such as pandemics (Sharifi, 2019). On the other hand, compact urban forms have some considerable disadvantages. They cannot provide the benefits that low-density suburbs can offer, as they typically lack ample green space and private gardens, while they tend to be noisier and to have higher air pollution at a local level (Howley et al., 2009; Tao et al., 2020). Dwellings in compact urban forms are also typically smaller than the ones found in suburban detached housing, with possible negative implications for well-being. Furthermore, although compact urban form enables social activity at a city level, social relationships at a neighborhood level tend to be weaker than those in low-density suburban areas (French et al., 2014; Mouratidis and Poortinga, 2020). Disadvantages of compact cities might be responsible for some negative mental health outcomes reported in the literature, although causality should be further examined (Gruebner et al., 2017; Litman, 2020b).

2.2. Compact cities and well-being under COVID-19

Human health, including physical and mental health, and human well-being, including quality of life domains and overall subjective well-being, declined due to COVID-19 in several, if not most, parts of the world (e.g. Brooks et al., 2020; Fiorillo and Gorwood, 2020; Moreno et al., 2020). Although early evidence suggests that health and well-being declined due to COVID-19, little empirical knowledge exists on how this change is linked to city planning and the compact city model in specific. Several studies have already discussed issues around city planning and COVID-19 (Barak et al., 2021; Connolly et al., 2020; Florida et al., 2021; Hamidi et al., 2020; Honey-Rosés et al., 2020; Litman, 2020a; Mouratidis, 2021a; Sharifi and Khavarian-Garmsir, 2020; Trasberg and Cheshire, 2021), but empirical evidence on how compact urban form relates to changes in health and well-being due to COVID-19 is limited (McFarlane, 2021). A synthesis of existing knowledge of how compact city characteristics could contribute to health and well-being during COVID-19 is presented in Table A1 (Appendix A).

Based on what is known about how and where the virus SARS-CoV-2 typically spreads, we could reasonably expect that some of the established benefits of compact urban form might have attenuated during the pandemic. Indeed, early evidence suggests that denser neighborhoods were associated with lower well-being outcomes during COVID-19 (Mouratidis and Yiannakou, 2021). Quarantines, social distancing, risk of infection, the closing of facilities and businesses, and travel restrictions might have substantially reduced some compact city benefits such as the use of lively public spaces, walking activity, use of public transport, socializing in cafes and restaurants, and easy access to other parts of the city or the airport (Bucsky, 2020; de Haas et al., 2020; Gössling et al., 2021; Honey-Rosés et al., 2020).

Although some compact city benefits might have attenuated during COVID-19, the high accessibility to local facilities (typical for compact urban forms) that remained open during the pandemic could still prove to be important to perform certain activities (Litman, 2020a). For example, good access to high-quality healthcare facilities and services have provided health benefits during the pandemic and has been linked to lower mortality from COVID-19 (Hamidi et al., 2020; Lieberman-Gribbin et al., 2020; Peto, 2020). Other potential compact city benefits during COVID-19 could be the possibly better internet access which was crucial during the pandemic, better access to food deliveries and other forms of online shopping (Mouratidis and Papagiannakis, 2021), and the access to public spaces when restrictions allowed (Honey-Rosés et al., 2020). Compact cities and compact neighborhoods, that are typically more noisy and more polluted than low density areas, might have benefited more from the reduced noise and air pollution (Sharifi and Khavarian-Garmsir, 2020) due to reduced urban mobility during COVID-19 (Politis et al., 2021; Shakhbaei et al., 2021). Nevertheless, poor air quality, found in certain compact cities, might have increased the risk of infection, mortality, and fatality due to COVID-19 (Mondal et al., 2022; Sarkodie and Owusu, 2021).

The importance of certain advantages of low-density development might have increased during COVID-19. Lockdowns, quarantines, and social distancing measures have forced large parts of the population to spend most of the time at home. Thus, living in a larger dwelling, typically found in the suburbs, facilitated daily life activities and possibly provided well-being and mental health benefits (Ahmad et al., 2020; Amerio et al., 2020; Mouratidis and Yiannakou, 2021; Tilson and Clair, 2020). In addition, private gardens attached to dwellings typically found in low-density sprawled development and large green spaces found in low-density areas (but also in some compact areas) seem to be particularly important during COVID-19 as they provide space for performing activities with a low risk of infection (Poortinga et al., 2021; Pouso et al., 2021; Shoari et al., 2020; Slater et al., 2020; Ugolini et al., 2020; Venter et al., 2020; Xie et al., 2020). Another attribute of suburban living that has been strengthened.
The first aim was to observe the differences in built environment characteristics examined in the study. These characteristics are all related to urban form compactness. The geospatial analysis for the following built environment characteristics was performed with GIS. Survey participants filled in their residential addresses when completing the survey. The residential addresses were georeferenced and then built environment characteristics were measured in GIS for each residential location individually: distance to city center, neighborhood density, public transport, local facilities, and green space. Distance to city center was calculated in kilometers along the walking network. This measure was used to assess the location of each participant’s dwelling in relation to the city center of Oslo. Neighborhood density was assessed as the population density within a 1000 m buffer from each participant’s dwelling. It was measured in persons per hectare based on the 2019 population dataset for statistical grids (250 m × 250 m) from Statistics Norway. Public transport accessibility was calculated as the number of bus, tram, metro, and train stops within a 1000 m buffer from each participant’s dwelling. This analysis was based on OpenStreetMap data. Local facilities were assessed as the number of facilities within a 1000 m buffer from each participant’s dwelling. This analysis was based on “amenity” OpenStreetMap data. The analysis included all types of facilities in the dataset such as: restaurants, cafés, cinemas, theaters, post offices, schools, libraries, hospitals, and banks. Green space was measured as the percentage of green space area within a 1000 m buffer from each participant’s dwelling, based on 2019 data by Hansen et al. (2013). Two additional characteristics of the built environment were captured via the survey. These are attributes of the dwelling of each participant. The survey included a question on the type of dwelling that the participant lives in. This item was later coded as 1 = apartment and 0 = other (e.g. detached house, duplex). The second dwelling attribute obtained via the survey is the size of each participant’s dwelling, measured in square meters. This question was optional, for privacy reasons, so the sample size is smaller for this variable due to missing data. Table A4 in Appendix A presents a correlation matrix showing bivariate correlations between built environment characteristics. Health and well-being variables and individual sociodemographic characteristics were obtained via the survey. Descriptive statistics for health and well-being data are presented in Table A5 in Appendix A. The survey questions are presented in detail in Appendix B. For the questions on health and well-being, survey participants were asked to consider their “life during the lockdown (the period with the most restrictions) due to the coronavirus
pandemic (COVID-19)” and their “life right before the COVID-19 pandemic”. The questions on health and well-being are based on questions from the European Social Survey (2012) and OECD (2013). Participants responded to the question “How satisfied are/were you with your...?” for different items: “life as a whole”, “health status”, “leisure activities”, “vacations”, “personal income”, and “personal relationships”. The scale used ranged from “extremely dissatisfied” (0) to “extremely satisfied” (10). To evaluate their general health (self-reported health) participants were asked “How would you describe your health in general?”. The scale ranged from “extremely poor” (0) to “extremely good” (10). Participants were also asked “Please tell us how much of the time you felt...” for the items: “happiness”, “anxiety”, “headache”, and “back pain”. The scale used ranged from “very rarely or never” (1) to “very often or always” (5). All health and well-being variables were evaluated for both “before COVID-19” and “during COVID-19”.

3.3. Analytical methods

For the analysis addressing the first research question – how health and well-being changed before and during COVID-19 – paired t-tests and Wilcoxon signed-rank tests were performed. This analysis tested for significant differences in each health/well-being measure before versus during COVID-19. The paired t-test and the Wilcoxon signed-rank test are used to examine the difference between two variables for the same subject. Since health and well-being were measured at two different times, before and during COVID-19, for the same individuals, with a “natural intervention” (i.e. COVID-19) occurring between the two, these two tests are suitable for detecting significant differences.

For the second research question – how compact city characteristics relate to health and well-being before and during COVID-19 – multiple linear regression was used. Built environment and sociodemographic characteristics were the independent variables. Since built environment and sociodemographic characteristics and health and well-being were all measured at the individual level, there was no need for multilevel modeling approaches. Health and well-being variables were examined as dependent variables, each one with a different regression model. These variables were: life satisfaction, personal relationships satisfaction, leisure satisfaction, general health, happiness, and anxiety. The other health and well-being variables in the dataset were excluded from this analysis to reduce complexity and keep the study more focused on basic health and well-being indicators. Based on previous theoretical models on the built environment in monocentric areas such as the one of Oslo and Viken (Mouratidis and Poortinga, 2020; Næss, 2019), a two-step approach was followed for the inclusion of built environment characteristics in the models. The first step examines the variables neighborhood density and distance to city center, while the second step additionally examines variables influenced by density and distance to city center: local facilities, green space, public transport, and dwelling characteristics. All models include individual sociodemographic variables as covariates: age, gender, unemployment, cohabitation status, citizenship, income, education level, presence of children in household, religiosity, and disability. Models on life satisfaction and happiness additionally include a “age squared” variable to capture their U-shaped relationship with age. Finally, to understand the relationships between compact city characteristics, bivariate correlation analyses were conducted (Table A4, Appendix A).

4. Results

4.1. Health and well-being before versus during COVID-19

The first part of the analysis compares health and well-being before and during COVID-19. The distributions of health and well-being variables are presented in Figs. A3 and A4 (Appendix A). The means of health and well-being variables before and during COVID-19 and comparisons with paired t-tests and Wilcoxon signed-rank tests are presented in Figs. 1 and 2. Results show that all health and well-being variables significantly worsened during COVID-19 compared to before COVID-19. Differences are all statistically significant at the p < 0.001 level. The most substantial changes are reported for well-being measures: life satisfaction (16% decrease), anxiety (25% increase), personal relationships satisfaction (18% decrease), leisure satisfaction (32% decrease), and satisfaction with vacations (49% decrease). The changes in general health (4% decrease), satisfaction with health (5% decrease), headache (3% increase), back pain (6% increase), happiness (9% decrease), and satisfaction with income (5% decrease) are smaller in size, but still statistically significant.

Next, the relationships between individual characteristics and the changes in health and well-being before during COVID-19 were examined with multiple linear regression models that include all sociodemographic variables shown in Table A2 (Appendix A) as independent variables and the change for each health and well-being variable before-during COVID-19.

Fig. 1. Health and well-being (mean values) before and during COVID-19 in Oslo and Viken (1/2). Notes: *p < 0.001: significant differences based on paired t-tests as well as Wilcoxon signed-rank tests. Variables are measured on a scale from 0 to 10.
increase in the frequency of back pain. Individuals with higher household incomes had a larger decrease in satisfaction with vacations. Religious individuals had a larger decrease in general health and a larger increase in anxiety. Individuals with serious health problems or a disability had a smaller decrease in life satisfaction.

4.2. Compact city, health, and well-being before-during COVID-19

The second part of the analysis investigates how the compact city and its characteristics relate to health and well-being. Tables 1–6 present the results of linear regression models. Each table examines a different health or well-being measure as the dependent variable. The analysis was performed for health and well-being: before COVID-19, during COVID-19, and for the change before-during COVID-19. The analysis for before COVID-19 examines associations between compact city characteristics and health/well-being for the pre-COVID-19 period, the analysis for during COVID-19 examines these associations for the COVID-19 period, the analysis for the change before-during COVID-19 investigates whether and how compact city characteristics relate to the increase or decrease of a health/well-being variable due to COVID-19. Each table consists of Models 1 and 2 (columns 1 and 2) corresponding to the two steps explained in Section 3.3. All the analyses include individual sociodemographic characteristics as covariates. Their coefficients are not presented here to reduce the size of the tables.

Table 1 presents regression models on life satisfaction. Results show that neighborhood density is negatively associated with life satisfaction during COVID-19. It is also observed that neighborhood density is associated with a larger change (decrease) in life satisfaction before-during COVID-19. These results indicate that residents of denser neighborhoods experienced a larger decline in life satisfaction during the pandemic. Dwelling size is positively associated with life satisfaction during COVID-19 and is associated with a smaller change (decrease) in life satisfaction before-during COVID-19. These results indicate that residents living in smaller dwellings experienced a larger decline in life satisfaction during the pandemic. Green space is found to be negatively associated with life satisfaction.

Table 2 presents regression models on personal relationships satisfaction. The main finding from this analysis is that local facilities are

Table 1
Regression models of life satisfaction before and during COVID-19.

| Variables | Life satisfaction | Before COVID-19 | During COVID-19 | Change (Before − During COVID-19) |
|-----------|------------------|----------------|----------------|----------------------------------|
|           |                  | 1 (β, SE) | 2 (β, SE) | 1 (β, SE) | 2 (β, SE) | 1 (β, SE) | 2 (β, SE) |
| Built environment |                  |           |           |           |           |           |           |
| Distance to city center | 0.042 (0.0024, 0.0015) | 0.045 (0.0025, 0.0016) | 0.099 (0.0007, 0.0020) | −0.013 (−0.0009, 0.0022) | 0.025 (0.0017, 0.0019) | 0.051 (0.0033, 0.0021) |
| Neighborhood density | −0.028 (−0.0008, 0.0008) | −0.071 (−0.0021, 0.0016) | −0.085** (−0.0033, 0.0011) | −0.098 (−0.0038, 0.0022) | 0.069* (0.0025, 0.0011) | 0.047 (0.0017, 0.0021) |
| Public transport | 0.010 (0.0003, 0.0015) | 0.035 (0.0006, 0.0020) | 0.065 (0.0004, 0.0004) | −0.035 (−0.0016, 0.0020) | −0.102 (−0.0006, 0.0003) | −0.051 (−0.0065, 0.0043) |
| Local facilities | −0.039 (−0.0002, 0.0003) | −0.064* (−0.0069, 0.0034) | 0.002 (0.0003, 0.0046) | 0.002 (0.0003, 0.0046) | 0.037 (0.1382, 0.1301) | 0.1382 (0.1301) |
| Green space | −0.040 (0.1229, 0.1027) | −0.004 (−0.0153, 0.1374) | 0.073* (0.0021, 0.0010) | 0.105 (0.0065, 0.0043) | 0.1382 (0.1301) | 0.1382 (0.1301) |
| Apartment | 0.010 (0.0002, 0.0007) | 0.078 (0.0021, 0.0010) | 0.078 (0.0021, 0.0010) | 0.037 (0.0002, 0.0007) | 0.042 (0.0019, 0.0009) |

Notes: Coefficients out of the parenthesis are standardized beta coefficients. The parenthesis includes the unstandardized coefficient and the standard error of the estimate. The models include individual sociodemographic variables as covariates (coefficients not shown here to reduce complexity): age, age squared, gender, unemployment, cohabitation status, citizenship, income, education level, presence of children in household, religiosity, and disability.

* p < 0.05.

** p < 0.01.
associated with higher personal relationships satisfaction during COVID-19 and are also associated with a smaller change (decrease) in personal relationships satisfaction before-during COVID-19. These results indicate that residents living in proximity to many local facilities experienced a smaller decline in personal relationships satisfaction during the pandemic.

Table 3 displays regression models on leisure satisfaction. Results indicate a negative association between neighborhood density and leisure satisfaction during COVID-19. Neighborhood density is also associated with a larger change (decrease) in leisure satisfaction before-during COVID-19. These results indicate that residents living in denser neighborhoods experienced a larger decline in leisure satisfaction during the pandemic. Green space is associated with a smaller change (decrease) in leisure satisfaction before-during COVID-19, indicating that residents with access to more green space experienced a smaller decline in leisure satisfaction during the pandemic.

Table 4 displays regression models on general health. The most significant and substantial finding is that local facilities are associated with a smaller change (decrease) in general health before-during COVID-19. This finding indicates that those living in proximity to numerous local facilities...
Regression models of happiness before and during COVID-19.

Table 4

| Variables | General health before COVID-19 | During COVID-19 | Change (Before − During COVID-19) |
|-----------|-------------------------------|----------------|---------------------------------|
|           | Before COVID-19 | During COVID-19 |                                 |
| Built environment | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) |
| Distance to city center | 0.011 (0.0007, 0.0016) | 0.011 (0.0007, 0.0017) | 0.032 (0.0023, 0.0018) | 0.015 (0.0011, 0.0020) | $-0.040$ ($-0.0016, 0.0011$) | $-0.010$ ($-0.0004, 0.0012$) |
| Neighborhood density | $-0.016$ ($-0.0005, 0.0009$) | $-0.039$ ($-0.0013, 0.0017$) | $-0.014$ ($-0.0005, 0.0010$) | $-0.047$ ($-0.0018, 0.0020$) | $-0.000$ | 0.022 |
| Public transport | 0.024 ($0.0009, 0.0016$) | $-0.003$ | ($-0.0014, 0.0018$) | 0.094* ($0.0023, 0.0011$) | $-0.149^{**}$ |
| Local facilities | 0.017 ($0.0001, 0.0003$) | 0.099 ($0.0006, 0.0003$) | 0.030 ($0.0040, 0.0041$) | 0.014 ($-0.0005, 0.0002$) | $-0.040$ ($-0.0030, 0.0026$) |
| Green space | 0.008 ($0.0010, 0.0035$) | 0.061 ($0.0004, 0.0018$) | 0.030 ($0.0040, 0.0041$) | 0.014 ($-0.0005, 0.0002$) | $-0.040$ ($-0.0030, 0.0026$) |
| Apartment | 0.007 ($0.0253, 0.1057$) | $-0.001$ ($-0.0040, 0.1228$) | 0.030 ($0.0008, 0.0009$) | 0.014 ($-0.0005, 0.0002$) | $-0.040$ ($-0.0030, 0.0026$) |
| Dwelling size | 0.008 ($0.0002, 0.0007$) | 0.030 ($0.0008, 0.0009$) | 0.030 ($0.0008, 0.0009$) | 0.014 ($-0.0005, 0.0002$) | $-0.040$ ($-0.0030, 0.0026$) |

Summary statistics

| Variables | Before COVID-19 | During COVID-19 | Change (Before − During COVID-19) |
|-----------|----------------|----------------|---------------------------------|
| N | 1796 | 1760 | 1796 | 1760 | 1796 | 1760 |
| Adjusted R-squared | 0.248 | 0.244 | 0.208 | 0.208 | 0.009 | 0.015 |

Notes: Coefficients shown out of the parenthesis are standardized beta coefficients. The parenthesis includes the unstandardized coefficient and the standard error of the estimate. The models include individual sociodemographic variables as covariates (coefficients not shown here to reduce complexity): age, gender, unemployment, cohabitation status, citizenship, income, education level, presence of children in household, religiosity, and disability.

* $p < 0.05$.

** $p < 0.01$.

experienced a smaller decline in general health during the pandemic. On the other hand, public transport is associated with a larger change (decrease) in general health before-during COVID-19, indicating that residents living in transit-oriented neighborhoods experienced a larger decline in general health during the pandemic.

Table 5 presents regression models on happiness. Neighborhood density is found to be negatively associated with happiness, while it is also associated with a larger change (decrease) in happiness before-during COVID-19. These results indicate that residents of denser neighborhoods experienced a larger decline in happiness during the pandemic. Local facilities are positively associated with happiness both before COVID-19 and during COVID-19. Living in an apartment is positively associated with happiness both before COVID-19 and during COVID-19. A larger dwelling size is associated with higher happiness during COVID-19.

Table 6 presents regression models on anxiety. The main finding is that higher public transport accessibility is associated with higher anxiety.

Table 5

Regression models of happiness before and during COVID-19.

| Variables | Happiness | Before COVID-19 | During COVID-19 | Change (Before − During COVID-19) |
|-----------|-----------|----------------|----------------|---------------------------------|
|           |           | 1 | 2 | 1 | 2 | 1 | 2 |
| Built environment | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) | $\beta$ (B, SE) |
| Distance to city center | 0.022 (0.0006, 0.0008) | 0.020 (0.0006, 0.0008) | 0.021 (0.0007, 0.0009) | 0.006 (0.0002, 0.0010) | $-0.002$ (0.0001, 0.0008) | 0.013 (0.0004, 0.0008) |
| Neighborhood density | $-0.003$ ($-0.0000, 0.0004$) | $-0.082$ ($-0.0012, 0.0008$) | $-0.077^{**}$ ($-0.0013, 0.0005$) | $-0.177^{**}$ ($-0.0031, 0.0010$) | $0.089^{**}$ ($0.0013, 0.0004$) | $0.128^{*}$ ($0.0019, 0.0008$) |
| Public transport | $-0.060$ ($-0.0010, 0.0008$) | $-0.074$ ($-0.0015, 0.0009$) | $-0.074$ ($-0.0015, 0.0009$) | $-0.074$ ($-0.0015, 0.0009$) | $0.028$ ($0.0005, 0.0008$) |
| Local facilities | 0.121* ($0.0003, 0.0001$) | 0.154** ($0.0004, 0.0002$) | 0.020 ($0.0001, 0.0002$) | 0.020 ($0.0001, 0.0002$) | 0.014 ($0.0007, 0.0018$) |
| Green space | 0.016 ($0.0008, 0.0017$) | 0.002 ($0.0001, 0.0017$) | 0.002 ($0.0001, 0.0017$) | 0.002 ($0.0001, 0.0017$) | 0.014 ($0.0007, 0.0018$) |
| Apartment | 0.075* ($0.1176, 0.0522$) | 0.075* ($0.1366, 0.0616$) | $-0.011$ ($-0.0160, 0.0529$) | $-0.011$ ($-0.0160, 0.0529$) | $-0.056$ ($-0.0006, 0.0004$) |
| Dwelling size | 0.032 ($0.0004, 0.0004$) | 0.074* ($0.0009, 0.0004$) | $-0.056$ ($-0.0006, 0.0004$) | $-0.056$ ($-0.0006, 0.0004$) |

Summary statistics

| Variables | Before COVID-19 | During COVID-19 | Change (Before − During COVID-19) |
|-----------|----------------|----------------|---------------------------------|
| N | 1796 | 1760 | 1796 | 1760 | 1796 | 1760 |
| Adjusted R-squared | 0.078 | 0.078 | 0.067 | 0.069 | 0.021 | 0.020 |

Notes: Coefficients shown out of the parenthesis are standardized beta coefficients. The parenthesis includes the unstandardized coefficient and the standard error of the estimate. The models include individual sociodemographic variables as covariates (coefficients not shown here to reduce complexity): age, age squared, gender, unemployment, cohabitation status, citizenship, income, education level, presence of children in household, religiosity, and disability.

* $p < 0.05$.

** $p < 0.01$. 


5. Discussion and conclusions

5.1. Discussion of results

The analysis addressing the first research question of the paper compared health and well-being before versus during COVID-19 (Section 4.1). Findings suggest that health and well-being worsened during COVID-19 compared to the before COVID-19 period. The worsening of health and well-being due to COVID-19 is in line with previous findings from other contexts (Li et al., 2020; Moreno et al., 2020; Mouratidis and Yiannakou, 2021; Patrick et al., 2020; White and Van Der Boor, 2020). Factors that have contributed to the decline of health and well-being due to COVID-19 could have been the COVID-19 health-related risks, quarantine, social distancing, isolation at home, travel restrictions, loss of economic activity, unemployment, and closing or lack of access to various types of facilities. The decline in health and well-being due to COVID-19 was also analyzed for its relationship with individual characteristics (Section 4.1). The most notable findings were that health and well-being before during COVID-19 worsened considerably more for females, for individuals who do not have higher education, and for individuals who live alone.

The second research question of the paper was examined with regression models on how the compact city and its characteristics relate to health and well-being outcomes during COVID-19. Public transport accessibility is also associated with a larger increase (increase) in anxiety before-during COVID-19. These results indicate that residents of transit-oriented neighborhoods experienced a more substantial increase in anxiety during the pandemic.

during COVID-19. Public transport accessibility is also associated with a larger change (increase) in anxiety before-during COVID-19. These results indicate that residents of transit-oriented neighborhoods experienced a more substantial increase in anxiety during the pandemic.

Table 6
Regression models of anxiety before and during COVID-19.

| Variables         | Anxiety           | Before COVID-19 | During COVID-19 | Change (During – Before COVID-19) |
|-------------------|-------------------|-----------------|-----------------|-----------------------------------|
|                   |                   | 1               | 2               | 1                              | 2               | 1                              | 2               |
| Built environment |                   | β                | β               | β                              | β               | β                              | β               |
|                   |                   | (B, SE)          | (B, SE)         | (B, SE)                        | (B, SE)         | (B, SE)                        | (B, SE)         |
| Distance to city center | −0.005           | (−0.0002, 0.0009) | 0.020           | 0.041                          | 0.028           | 0.053                          |
| Neighborhood density | 0.028            | (0.0005, 0.0005) | 0.037           | 0.060                          | 0.015           | 0.054                          |
| Public transport  | 0.047             | (0.0010, 0.0009) | 0.123**         | 0.097*                         | 0.012           | −0.102                         |
| Local facilities  | 0.012             | (0.0000, 0.0002) | −0.077          | (−0.0003, 0.0002)              | (−0.0003, 0.0002) | 0.041                          |
| Green space       | 0.023             | (0.0015, 0.0021) | 0.055           | 0.0041                         | 0.0026          | 0.022                          |
| Apartment         | −0.036            | (−0.0661, 0.0628) | −0.019          | (−0.0025, 0.0727)              | (−0.0025, 0.0727) | 0.007                          |
| Dwelling size     | −0.028            | (−0.0004, 0.0004) | (−0.0003, 0.0005) | 0.012                          | (−0.0003, 0.0005) | 0.011                          |
| Summary statistics |                  |                 |                 |                                 |                 |                                 |
| N                 | 1796              | 1760            | 1796            | 1760                           | 1796            | 1760                           |
| Adjusted R-squared | 0.111            | 0.108           | 0.094           | 0.094                          | 0.094           | 0.012                          |

Notes: Coefficients shown out of the parenthesis are standardized beta coefficients. The parenthesis includes the unstandardized coefficient and the standard error of the estimate. The models include individual sociodemographic variables as covariates (coefficients not shown here to reduce complexity): age, gender, unemployment, cohabitation status, citizenship, income, education level, presence of children in household, religiosity, and disability.

⁎ p < 0.05.

⁎⁎ p < 0.01.

Higher neighborhood density was found to be associated with lower life satisfaction, lower happiness, and lower leisure satisfaction during COVID-19. Residents of denser neighborhoods typically live in smaller dwellings, rely more on public transport, have lower access to green space, and have access to a greater number of local facilities (see correlation analyses in Table A4, Appendix A). Since smaller dwellings, public transport reliance, and lack of access to green space seem to have negative implications for health and well-being during COVID-19, neighborhood density may contribute, overall, to negative health and well-being outcomes during COVID-19. The seemingly positive implications of local facilities for health and well-being found in the study do not completely counterbalance the possible negative implications of smaller dwellings, public transport reliance, and less green space. Moreover, it was difficult for residents of denser neighborhoods to avoid urban stressors during the pandemic, which might have additionally contributed to lower well-being. Travel restrictions, lockdowns, and quarantines made it difficult to visit nature and rural areas or travel abroad for leisure (Gissling et al., 2021). The finding of denser neighborhoods being associated with lower well-being during COVID-19 is in line with earlier evidence from a study in Greek cities (Mouratidis and Yiannakou, 2021).

Public transport accessibility was found to be associated with a larger increase in anxiety and with a larger decline in general health before-during COVID-19. Public transport exposed passengers to a high risk of infection during the pandemic and therefore its use greatly declined compared to other transport modes (Bucsky, 2020; Hadjidemetriou et al., 2020; Jenelius and Cebecauer, 2020; Teixeira and Lopes, 2020). However, some residents living in transit-oriented neighborhoods who had to travel during COVID-19 did not have the option to use travel modes other than public transport. These residents might have been infected to a larger extent but might have also experienced stress from the fear of infection during travel by public transport. The high risk of infection associated with public transport is also likely to have decreased the mobility of residents of
compact, transit-oriented neighborhoods, compared to residents of low-density neighborhoods who could have used their private car to access destinations and participate in activities. All these considerations may explain the negative association between public transport and health and well-being outcomes.

**Living in a smaller dwelling** was associated with lower life satisfaction and lower happiness during COVID-19. The importance of the dwelling dramatically increased during COVID-19 since residents had to spend more time and perform more, if not most, of their activities at home. Numerous teleactivities replaced out-of-home activities during COVID-19 (de Haas et al., 2020; Pierce et al., 2021; Shamshiripour et al., 2020; Wijesooriya et al., 2020). For that purpose, larger dwellings were likely to be more pleasant, less stressful, and more functional, since they were more likely to allow members of the same household to perform different activities at home. This finding is in line with the link between poor housing and increased risk of depression during COVID-19 found by Amerio et al. (2020) and with the link between smaller dwellings and increased anxiety found by Mouratidis and Yiannakou (2021).

**Living in an apartment** (versus living in a detached/semi-detached house or row house) was not adversely linked to health and well-being during COVID-19, when dwelling size and the amount of green space were included in the statistical models. On the contrary, living in an apartment was associated with greater happiness before and during COVID-19. These findings may suggest that it was the size of the dwelling and the surrounding green space that mattered for health and well-being during COVID-19, and not the type of dwelling per se. However, since apartments tend to be generally smaller and to lack outdoor green space, residents living in apartments likely experienced more negative health and well-being impacts during the pandemic.

**Access to numerous local facilities** was associated with higher happiness and higher personal relationships satisfaction during COVID-19. A higher number of local facilities was also associated with a smaller decrease in general health before-during COVID-19. The presence of numerous facilities within walkable distance is likely to have allowed residents to participate in certain activities by using facilities that remained open during COVID-19. In Norway, several facilities were open during the COVID-19 period. In areas with many facilities, it is possible that the sheer number and variety of existing facilities made it more likely that at least some facilities were open and accessible, while in other areas with fewer facilities almost everything was shut down besides grocery stores. The presence of numerous local facilities might have also reduced the risk of infection and the fear of infection associated with using public transport to access facilities that are not within walkable distance. Good access to high-quality healthcare facilities could have also provided health-related benefits and might be linked to lower mortality from COVID-19 as suggested by Hamidi et al. (2020).

Green space was found to have some possibly positive well-being implications as it was associated with a smaller reduction in leisure satisfaction before-during COVID-19. In other words, the leisure satisfaction of residents of areas with more green space in close proximity decreased to a smaller extent during the pandemic than the leisure satisfaction of residents of areas with less green space in close proximity. This finding suggests that access to green space was important for performing leisure activities during COVID-19. This is in line with earlier studies on COVID-19 and green space (e.g. Ugolini et al., 2020; Venter et al., 2020; Xie et al., 2020). Although the present study does not include specific data on private versus public green space, the analysis included a variable on dwelling type: apartment versus detached house or duplex. Detached houses and duplexes in Oslo and Viken typically have private gardens while apartments do not. Detached houses or duplexes were not found to be associated with more positive health and well-being outcomes during COVID-19 in the present study. However, it might be the gardening activity that contributes to positive well-being outcomes during COVID-19 (Corley et al., 2021), and not just the presence of a private green space itself.

5.2. COVID-19, sustainable urban planning, and compact cities

Findings from this study challenge the compact city as a model for sustainable urban planning and policy, providing insights for reflection and improvement during COVID-19 but also post-COVID-19. The compact city provides multiple societal and environmental (e.g. for urban sustainability and climate change mitigation and adaptation) benefits (Ahfeldt et al., 2018; Tonne et al., 2021), and, therefore, it is important that societies and policymakers do not lose interest in compact city policies. Measures need to be taken so that events such as the COVID-19 pandemic will not lead to further sprawl, suburbanization, and an abandonment of compact city policies.

Some possible implications for the compact city and sustainable urban planning and policy are presented here. Public transport accessibility – one of the strengths of the compact city – was found to be negatively linked to some health and well-being outcomes during COVID-19, possibly due to increased risk of infection and related stress. To mitigate this issue, public transport departures need to be frequent enough to guarantee safe social distancing during pandemic crises. In addition, alternative transport options need to be available in compact, transit-oriented neighborhoods, especially during pandemic events. Such options may include active travel modes as well as affordable and accessible carsharing in case residents need to travel longer distances. All these may provide safer alternatives in terms of virus transmission. Results from this study also suggest that dwelling size mattered for well-being during COVID-19, as living in a smaller dwelling – often characterizing compact city living – was associated with lower life satisfaction and lower happiness during COVID-19. As teleactivities are expected to be increasingly adopted in the post-COVID-19 period, and several of them may take place at home, a minimum dwelling size might need to be established in compact cities in order to avoid negative impacts on health and well-being from overcrowded or tight dwellings. This would be particularly important for families with children as well as poorer households that are more likely to live in smaller, overcrowded dwellings. Another alternative is the development of multifunctional shared spaces where local residents can perform a variety of activities and teleactivities. Such spaces would need to be appropriately designed if they are to be used during pandemic events. Access to green space was found to be possibly important for leisure activities during COVID-19, as larger green space was associated with a smaller reduction in leisure satisfaction before-during COVID-19. Using green spaces for several purposes, including social and physical activities and connecting with nature, is particularly important during pandemics, and especially in more urban, compact areas (Douglas et al., 2020; Hamidi and Zandiatashbar, 2021; Shoari et al., 2020; Xie et al., 2020). The importance of easy access to numerous local facilities (enabled by compact cities) during COVID-19 was also illustrated by the study’s findings, as it was associated with higher happiness and personal relationships satisfaction during COVID-19. Proximity to a wide range of facilities is key during pandemic crises (Litman, 2020a) as it allows participation in activities and access to healthcare provision. Finally, outcomes from this study suggest that the worsening of health and well-being due to COVID-19 was more severe for certain groups of people such as females and individuals who live alone. Urban policies, but also country-level policies, should provide greater support for these groups of people during and post-COVID-19. Relevant measures could aim at reducing transport-related gender inequalities (e.g. Uteng et al., 2020) and improving social cohesion at a local community level to reduce loneliness and social isolation (e.g. Anderson et al., 2017).

5.3. Limitations and future research

This study has some limitations that should be taken into consideration when interpreting the results. The overview of changes in health and well-being due to COVID-19 concerns the context of Oslo and Viken, in Norway. Studies could explore these changes in other contexts with different social, cultural, and spatial characteristics. The study employed retrospective data measuring respondents’ evaluations of health and well-being before and during COVID-19. Due to the retrospective nature of the data, individual
recall of health and well-being evaluations may be imprecise and subject to biases. It is also possible that the survey's timing itself, in the middle of the pandemic and therefore in an extraordinary situation, might have created bias. Future research could additionally investigate possible links between these health and well-being variables with more complex statistical approaches such as structural equation modeling. Results from the present analysis on compact city characteristics and health/well-being should be interpreted with caution since they indicate associations but not necessarily causal relationships. Qualitative research findings could be particularly useful for shedding more light on the complex pathways behind the relationships examined in this paper. Prospective longitudinal designs would also help identify possible causal relationships.

CRediT authorship contribution statement

Kostas Mouratidis: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The study is part of the research project “App Cities: New urban technologies, daily travel, and quality of life” (project number: 1850051060), funded by the Norwegian University of Life Sciences. Additional support for the data collection of the project was provided by Viken County Municipality (Viken Fylkeskommune) and the Norwegian Public Roads Administration (Statens Vegvesen). I am grateful to Sebastian Peters for valuable feedback on an earlier draft of the paper and for the collaboration throughout this research project. I would also like to thank the three anonymous reviewers for their insightful comments and suggestions.

Appendices. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.152322.

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