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Research Paper

On pathways and agreement: Objective and perceived accounts of neighbourhood attributes and their associations with mental health during pregnancy

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HIGHLIGHTS

- Agreement between objective and perceived neighborhood attributes was limited.
- Sociodemographic variables did not explain objective-perceived mismatching.
- Relationships between different objective and subjective attributes were detected.
- Effects of neighborhood attributes on mental health were small in size.

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ABSTRACT

There is growing interest in understanding the links between neighbourhood environmental attributes (i.e. greenness, walkability and air pollution) and human health. Recent research has analysed the mediating role of a diverse set of potential factors and studied the agreement between objective and perceived modalities of those attributes. In this study, we explored the connections between objective neighbourhood attributes, their perceived accounts and mental health during pregnancy, using a measure of social cohesion as potential mediator with data from two samples of pregnant women recruited during the 12th week of pregnancy in two Spanish cities (Donostialdea, n = 440; Barcelona n = 364). Besides, we ran analyses on the agreement between objective and perceived measures. We fitted four separate Structural Equation Models and detected associations between objective neighbourhood attributes and mental health occurred only through their perceived counterparts and the strengthening of social cohesion. We also found poor to fair agreement between greenness measures in both cities, walkability measures only in Donostialdea, and were unable to detect any meaningful agreement between air pollution variables. Using rescaled versions of neighbourhood attribute variables and in

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some instances, we saw that the higher the objective value of a given attribute, the larger the differences between objective and perceived accounts of such attributes.

1. Introduction

The conditions and quality of immediate urban environments have important implications for human health (WHO, 2008; 2012). A variety of urban environmental attributes (e.g. green infrastructure, walkability, air pollution, food environments and noise) has been studied in relation to several health-related behaviours and outcomes, including physical activity (Bracy et al., 2014; Foraster et al., 2016), obesity (Sallis et al., 2020), pregnancy outcomes (Anabitarte et al., 2020) and mental health in various forms (Banay et al., 2019; Song et al., 2019). In recent years, researchers' attention has shifted towards the mechanisms explaining the associations between such neighbourhood attributes and the outcomes of interest, or so-called *pathways* (Dzhambov, Browning, Markevych, Hartig, & Lercher, 2020; Markevych et al., 2017). Generally, physical activity and social cohesion have been used as potential mediators in such associations, with the theoretical expectation that higher quality neighbourhoods might make citizens more physically active and socially closer to their neighbours, all of which would contribute to a better general health, including psychological health and well-being.

Pregnancy is a very particular period of life in which women are at a greater risk of developing mental health problems (Dadi, Miller, Bisetegn, & Mwanri, 2020; Dennis, Falah-Hassani, & Shiri, 2017; Dunkel, 2011). Psychological health during pregnancy is key because it is related not only to general and physical health during pregnancy but with other important health variables in the medium and long terms for both the mother and the child. Prenatal mental health has been linked to postnatal mental health of the mother (Van Bussel, Spitz, & Demyttenaere, 2006), pregnancy outcomes such as preterm birth (Accortt, Cheadle, & Dunkel Schetter, 2015; Grigoriadis et al., 2018; Lima et al., 2018) and infant health conditions like sleeping quality, asthma or allergic symptoms (Baird, Hill, Kendrick, & Inskip, 2009; Flanigan et al., 2018; Rusconi et al., 2019). Pregnant women are also an interesting collective to study due to the social, psychological and behavioural specificities of such a particular period of life and therefore warrant further investigation. Furthermore, in a recent review of empirical studies using the *pathways perspective* (Dzhambov et al., 2020), only a handful of studies had incorporated pregnant women samples (McEachan et al., 2016; Subiza-Pérez et al., 2021). Observational and epidemiological pregnancy cohort studies offer a great opportunity to analyse the links between neighbourhood attributes and, among other outcomes, mental health.

Literatures on environmental epidemiology, urban planning and related scientific areas have identified a number of neighbourhood attributes linked to human health and health-related behaviors (e.g. physical activity). In the mental health domain, previous studies support its positive association with greenness (Gascon et al., 2015; McEachan et al., 2016; Subiza-Pérez et al., 2021) and its negative association with air pollution (Borroni, Pesatori, Bollati, Buoli, & Carugno, 2022; Braithwaite, Zhang, Kirkbride, Osborn, & Hayes, 2019). Several studies have found positive associations between neighbourhood walkability and mental health and well-being (Chen et al., 2020; Chen et al., 2016; Domènech-Abella et al., 2020; Li, Li, Xia, & Han, 2021), although researchers in this area have generally worked with elder and aging populations. More interestingly for this study, a number of studies have confirmed that social cohesion is one of the involved pathways in the greenness – mental health connection (Liu et al., 2020; Liu, Wang, Grekousis, et al., 2019; Liu, Wang, Xiao, et al., 2019; Sugiyama, Leslie, Giles-Corti, & Owen, 2008) but it is still to be confirmed in the case of air pollution (Dzhambov et al., 2018; Generaal et al., 2019) and walkability (Li et al., 2021; Mazumdar, Learnihan, Cochrane, & Davey, 2018; Subiza-Pérez et al., 2021) because studies are scarce and mixed. Within this body of literature, there is a limited but growing number of studies conducted with samples of pregnant women (McEachan et al., 2016; Nichani, Dirks, Burns, Bird, & Grant, 2017; Roberts, van Lissa, & Helbich, 2020; Toda et al., 2020). Some authors have suggested that strengthening social cohesion can be key to ensure psychological health during this period of life (Norbeck, Dejoseph, & Smith, 1996) and, in a recent systematic review of 67 studies, Bedaso and colleagues found that pregnant women reporting low social support were twice as likely to experience antenatal depression or anxiety (Bedaso, Adams, Peng, & Sibbritt, 2021). Therefore, the interest understanding the neighbourhood correlates of social cohesion and mental health during pregnancy is warranted. However, even though pregnancy is a very particular period of life in the psychological, behavioural and health domains, we do not expect that the connection between the selected neighbourhood attributes and mental health greatly varies in pregnant women as compared with other populations.

In this context, socio-ecological studies have suggested that environmental perceptions might play a mediating role between the objective attributes of a given environment and subsequent health-related behaviours and outcomes, including the potential mediators mentioned above. The study by Guo and colleagues (Guo et al., 2021) showed that objective residential density was positively associated with subjective well-being through a path comprising perceived built environment indicators and social cohesion as mediators. Ma and Cao (2019) confirmed the mediating role of the perceived presence of shops in the pathways linking their objective availability and walking and biking to these types of destinations. This was also confirmed for religious and civic buildings. In a study of young Hungarians, noise annoyance acted as a mediator between objectively defined road traffic noise and mental health (Dzhambov, Tilov, Markevych, & Dimitrova, 2017), as participants exposed to higher levels of objective road traffic noise expressed higher noise annoyance, which in turn increased mental health problems.

Besides, due to interest in examining the health implications of neighbourhood attributes, one might wonder whether objective and subjective accounts of these might be differently associated to health outcomes. It is plausible that the strength and/or direction of the association varied across outcomes. For instance, perceived availability of green and blue spaces predicted quality of life in a sample of elderly people with dementia, yet objective availability did not (Wu et al., 2021). Interestingly, a study conducted in China revealed that the objective characteristics of the built environment were more strongly related to physical and social health, whereas the perceived features were more relevant for mental health (Zhang, Zhou, & Kwan, 2019). Lin and Moudon (2010) found that objective features were more explanatory of walking behaviour than subjective ones. Finally, another study revealed that objective neighbourhood bikeability predicted both biking for transportation and total biking frequency, whereas subjective neighbourhood bikeability only predicted frequency (Ma & Dill, 2015).

Fig. 1 shows the conceptual model we wanted to test in this study which incorporates the results of the literature reviewed above.

1.1. Objective and perceived accounts of neighbourhood attributes

Past research has informed about slight to poor agreement between objective and perceived accounts of urban attributes (Orstad, McDonough, Stapleton, Altincekic, & Troped, 2017). This has been found for a long list of attributes such as greenness and availability of green spaces (Lackey & kaczynski, 2009; Stefler et al., 2021; Tilt, Unfried, & Roca, 2007), walkability (Arakawa Martins, Taylor, Barrie, Lange, & Kho, 2021; Gebel, Bauman, & Owen, 2009), bikeability (Ma & Dill, 2016),

destinations and services (Bailey et al., 2014; MacDonald, Kearns, & Ellaway, 2013; Roda et al., 2016) or route characteristics (Shatu, Yigitcanlar, & Bunker, 2019).

Apart from the psychological interest of knowing why, when and how people misperceive their environments, mismatches are also relevant from a public health perspective. If someone lives in a neighbourhood offering good opportunities for exercising and well-being, yet they is not aware of it, their health might be compromised. One clear example of this dynamic is the study conducted by Gebel and colleagues (2011) in which, after a four-year follow-up, those *mismatchers* who perceived their neighbourhood as less walkable when it was indeed highly so reduced their walking to a greater extent and gained more weight. Some studies using quantitative walkability/bikeability measurements[1] found that around a third of participants would perceive their neighbourhood as limitedly supportive of walking or biking (Gebel et al., 2009, 2011; Ma & Dill, 2016) when the objective indicators say the opposite. These studies have operationalized mismatching as the lack of correspondence between the objective and perceived scores tertiles. For instance, a person would be classified as "mismatcher" if they were in the first objective walkability tertile and in the second or third perceived walkability-one.

This methodological approach is not sensitive to the actual extent to which objective and perceived accounts differ, and might similarly label people in quite different situations as shown in Fig. 2. Following the former procedure, a hypothetical participant represented with a red square in the figure would be labelled as a mismatcher because they are in in the first and second tertiles for the objective and perceived modalities respectively. The same would happen to the "blue circle" participant. However, it is evident in the figure that although the first participant is doing an inaccurate assessment of the neighbourhood attribute of interest, the second is doing a pretty good job and still being labelled as a mismatcher. Another problem that emerges when using this methodology is that two people having a similar distance between the location they occupy in the objective and perceived tertiles (green triangle and purple rhomboid) get a different classification; the former is a mismatcher and the latter is not.

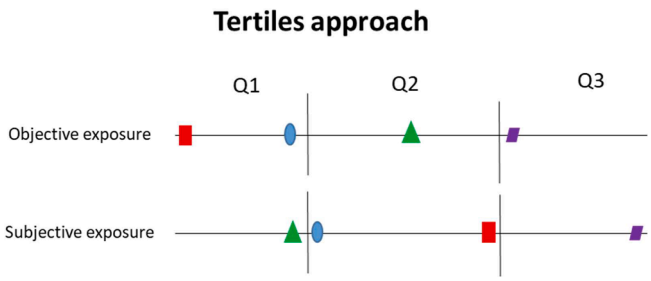

Fig. 2. Graphical display of the tertiles approach to environmental mismatching used in previous studies.

In this study we wanted to weight the actual differences between both measurement modalities and, for that, we developed a method that is described in section 2.3.1. Using flawed operationalisations of environmental mismatching is problematic because the scientific evidence generated with those might be inaccurate. More importantly, potential public health interventions could be negatively affected due to a poorer understanding of the problem to be addressed and the suitable targets for the intervention.

1.2. Study aim and objectives

In this paper, we took advantage of the data collected for the *Urban Green Activity and Reproductive Effects* Study (UGARE) in two Spanish cities, namely Donostia-San Sebastián and Barcelona. The analyses presented here were performed with a twofold objective. In a previous paper, we modelled the relationships between such perceived neighbourhood attributes and mental health during pregnancy and found a mediating effect through social cohesion (Subiza-Pérez et al., 2021). This time, we wanted to deepen on the models by adding the objective versions of these attributes and establish whether their inclusion modified the previously found relationships among selected variables and added further insight in the issues of interest. As a result, this study

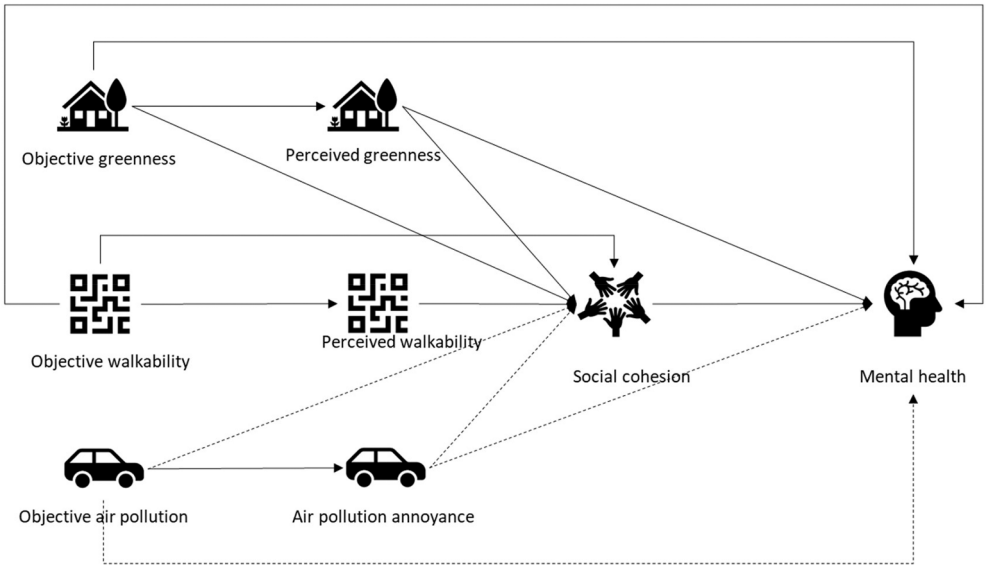

Fig. 1. Substantive model to be tested in the study. Dashed arrows indicate expected negative relationships.

differentiates between *proximal mediators*, which are the perceived versions of the neighbourhood attributes of interest, and *distal mediators*, defined as the processes through which those attributes affect mental health (i.e. social cohesion). The second objective of this specific study was to assess the agreement between objective and perceived accounts

[1] Studies using dichotomous variables like the availability of green space or presence of a given amenity in a given radius have usually resorted to kappa indexes to study environmental mismatch.

of neighbourhood attributes and to develop a new method to analyse the extent both accounts differ and test it.

2. Methods

2.1. Sample and procedure

We recruited 440 pregnant women in the metropolitan area of Donostia-San Sebastián[2] and 364 in Barcelona from the gynaecological services of the Public Health Service System when they received routine ultrasounds during the 12th week of pregnancy. Inclusion criteria were: 1) residence in the areas of study; 2) ability to communicate in Spanish, Basque or Catalan; and, 3) single non-high risk pregnancy. Women meeting these criteria were invited to participate and sign an informed consent form if interested. Enrolled participants were given information about the study and instructions to fill in the study questionnaire. The protocol for this study was approved by the Research Ethics Committee of the Health Department of the Basque Government (reference number: PI2018108) and the Ethics Committee of the Hospital del Mar (reference number: 2018/8373/I). More information about the UGARE project and its sample can be found in the Supplementary Material.

General descriptive data for both samples is shown in Supplementary Table 1. Most participants had normal weight (BMI 18–25), university education (56 %) and paid work (70 %) at the time of data collection. The proportion of working women and educational attainment were both higher in the Donostia sample.

2.2. Study variables

2.2.1. Objective environmental attributes

For this study, we calculated three objective neighbourhood attributes after geocoding participant residence at the time of data collection using QGIS Software (Q. D. Team, 2020). The residential greenness metric chosen for this study was the Normalized Difference Vegetation Index (NDVI), which indicates the level of greenness in a given area using a value range from −1 to + 1 (Rugel et al., 2017). In the analyses below we used NDVI values in 500 m and 1000 m buffers around the home. These indexes were calculated from 30 × 30 m resolution satellite images from Landsat 8 OLI + TIRS taken during the maximum vegetation period in Donostia (03.08.2019). For Barcelona, aerial orthoimages and associated NDVI values corresponding to year 2019 were obtained from the Cartographic and Geologic Institute of Catalonia.

Based on previous works (D'Sousa, Forsyth, Koepp, Larson, Lytle, Mishra, Neumark-Sztainer, Okaes, Schmitz, Van Riper, & Zimmerman, 2012; Ribeiro & Hoffimann, 2018; Sallis et al., 2016), an objective walkability index was built using six built environment indicators, namely population density, destination density, street connectivity, land use mix, slope and public transport stops, all of which were obtained from digital cartographies of the cities where the study took place. Individual scores were computed for each indicator in 500 m and 1000 m network buffers, then standardized and summed to obtain an aggregate walkability index.

Exposure to NO_2 during the first trimester of pregnancy was estimated via land-use regression (LUR) models developed for the ESCAPE project (Beelen et al., 2013). These models included road length within a 1000 m buffer, main road length within a 25 m buffers and area of low residential density within a 5.000 m buffer (Anabitarte et al., 2020). In Donostia, once participants were assigned an LUR-based NO_2 exposure level, we applied a time correction to account for seasonal changes. To do so, we gathered daily air-quality data through eight Basque Government Air Quality Network stations located in the study area. Each participant was assigned to the station closest to her residence. Individual LUR values were divided by the average value of all the stations during the study period (October 2018– February 2020) and then multiplied by the daily value of the corresponding station. Hence, an individual daily value adjusted for spatial and time variation was obtained for each participant. Finally, we calculated individual average value for the first trimester of pregnancy by compiling the exposure scores during such period. In Barcelona, variables included in the LUR model were high-density residential land within a 300 m buffer, road length within a 1000 m buffer and distance to the nearest major road. Given that we lacked traffic data in Barcelona, we could not include one of the variables the product of traffic intensity and the inverse distance to the nearest road) originally included in the Barcelona ESCAPE LUR. Seasonal changes were also accounted for with information from eight air quality stations during the study period too (December 2018 – August 2020).

2.2.2. Perceived environmental attributes (proximal mediators)

We collected the perceived equivalents of objective neighbourhood attributes through the study questionnaire. Perceived residential greenness was measured via two items presented on a 5-point Likert scale (1 = *not at all green*, 5 = *extremely green*). Participants were asked to rate the extent to which: 1) the views from their homes' windows and; 2) their neighbourhoods were green. Scores were averaged and showed good and fair reliability in Donostia-San Sebastian (α =. 79) and Barcelona (α =. 65) respectively.

Perceived walkability was operationalized using the Neighbourhood Environment Walkability Scale – Abbreviated version (Cerin, Conway, Saelens, Frank, & Sallis, 2009), composed of 53 items covering the main walkability domains. Following prior recommendations (Nichani, Vena, Friedenreich, Christie, & McCormack, 2019), the raw scores were converted in z-scores. This scale showed very good internal consistency in both cities (α = 0.91 and 0.88), with higher z-scores indicative of the person's residential environment being more walkable.

Finally, air pollution exposure was measured with one item in which participants indicated the extent to which they were annoyed by the air pollution in their neighbourhoods on a 0 (*no annoyance at all*) to 10 (*unbearable annoyance*) scale.

2.2.3. Distal mediator

To measure social cohesion, we resorted to four items of Sampson and colleagues' scale (Sampson, Raudenbush, & Earls, 1997) on a 0 (totally disagree) to 4 (totally agree) Likert scale. This instrument clearly reflects the notions of a) community trust and attachment, and, b) social capital, the two main traditions in the literature on social cohesion (Carpiano, 2006; Ehsan, Klaas, Bastianen, & Spini, 2019; Yip, Sarma, & Wilk, 2016). This scale was adequate in terms of reliability (α = 0.77 and 0.80), with higher average scores indicating higher lived social cohesion.

2.2.4. Outcome

We measured psychological health during the first trimester of pregnancy using the Spanish version of the General Health Questionnaire (Rocha, Pérez, Rodríguez-Sanz, Borrell, & Obiols, 2011). This instrument includes 12 items that register psychological symptoms (e.g. *have you felt sad or depressed)* and aspects of daily functioning. Respondents rated these on a 0 (*better than usual*) to 3 (*much worse than usual*) scale, depending on the extent to which they had experienced them lately. The scores are added in a total score that ranges from 0 to 36, where higher scores indicate worse psychological states and/or greater stress. In this case, Cronbach's alpha scores were appropriate (0.77 and 0.75).

[2] This metropolitan area also includes the municipalities of Astigarraga, Donostia-San Sebastián, Errenteria, Hernani, Lasarte-Oria, Lezo, Oiartzun, and Pasaia and Usurbil. To ease the readability of the manuscript, we will use the generic "Donostia" along the text.

2.3. Data analyses

We used R software version 4.1.1 (R Core Team, 2021) to conduct all analyses, specifically the *lavaan* (Rosseeel, 2012), *irr* (Gamer, Fellows, & Singh, 2012) and *scales* (Wickham & Seidel, 2020) packages. We began by calculating the means, standard deviation and other descriptive statistics (e.g. median or IQR) for the study variables.

2.3.1. A new method to operationalize the individual differences between objective and perceived accounts of neighbourhood attributes

The procedure we developed for this study aims to overcome the limitations of previous approaches to environmental mismatch (see section 1.2) by operationalizing environmental mismatching as a continuous magnitude reflecting the numerical difference between the objective and perceived accounts. To ensure the comparability of the score ranges for each pair of objective and perceived neighbourhood attributes, they were rescaled to a 0 to 10 range using the rescale() function included in the *scales* package. Then, we proceeded to estimate the degree of agreement between objective and perceived neighbourhood attributes using Intraclass Correlation Coefficients (ICC; Hallgren, 2012). Following the recommendations of Hallgren (2012), we computed the consistency variants of ICCs for each city and interpreted agreement as follows: < 0.40 = poor, 0.40 - 0.59 = fair, 0.60 - 0.74 good and 0.75 – 1 = excellent.

As a complementary analysis, we calculated the differences between rescaled objective and perceived scores. Positive differences were obtained when the objective score was larger than the perceived one and were thus interpreted as environmental underestimations. On the other hand, if the result of this operation was negative (i.e., with an objective score lower than the perceived one), we took it as evidence of environmental overestimations. Objective and perceived attributes' scores were also compared with paired t-tests and Hedges' g was calculated as an indicator of effect size We then conducted correlation analyses to check whether age, educational attainment, BMI, physical activity (data described in Supplementary Material; see also Mendinueta et al., 2020), district-based area income (data from the Spanish National Statistics Institute (INE3)) and the objective score of the attribute predicted the discrepancy between objective assessments and perceptions. Here we used the absolute difference values so we could interpret correlation coefficients as follows; positive indexes would indicate that the higher or larger each of the covariates, the higher the mismatch and the opposite if they were negative. All the analyses described in this paragraph were ran using the two objective accounts of greenness and walkability available for this study (500 m and 1000 m buffers). This procedure allows to: 1) overcome some of the caveats of previous mismatch operationalizations, 2) obtain individual and sample estimates of the direction of the mismatch (i.e. over or underestimation), and, 3) obtain individual and sample absolute values on the actual extent of the mismatch.

2.3.2. Structural equation modelling

We used structural equation modelling to analyse the relationships between variables hypothesized in Fig. 1. We expected objective greenness, walkability and air pollution to predict their perceived counterparts (proximal mediators) and be associated with social cohesion (distal mediator) and mental health. For the latter association, we thought objective neighbourhood attributes could predict mental health both directly and indirectly through: 1) perceived attributes (proximal mediators) with social cohesion as a distal mediator; and 2) social cohesion. We followed (Grace et al., 2012) guidelines and adjusted separate models for each city using the complete cases in each sample. To ensure the linearity of the relationships, we square-rooted social cohesion. We also tested the *meta*-model with the sem () function of the *lavaan* package and updated it by incorporating meaningful suggestions resulting from the use of modindices(). This iterative process ended when a model with satisfactory fit was achieved and no further meaningful modifications were suggested. Fit was considered satisfactory when the chi-squared p-value was greater than 0.05, comparative fit index (CFI) was greater than 0.95 and root mean squared error of approximation (RMSEA) was lower than 0.05. Relationships were kept in the model if their coefficients fell within the $p < 0.10$ level. Due to missing data in the study variables, final models were fitted with information from 298 and 174 participants respectively. Following this procedure we fitted two models for each city, one per objective greenness and walkability buffer extension available (500 m and 1000 m).

3. Results

The description of study variables using standard descriptive statistics can be found in Supplementary Tables 2 and 3, and Supplementary Table 4 presents the correlations between study variables.

3.1. Agreement between objective and perceived modalities of neighbourhood attributes

According to ICC scores (see Table 1), the agreement between each pair of rescaled objective-perceived neighbourhood attributes was rather mixed. In the case of Donostia, agreement between objective and perceived greenness and walkability was fair to good in the 500 m and 1000 m buffers but was not statistically different from zero for NO_2.

In Barcelona only greenness metrics showed fair and poor agreement. ICC scores for walkability and NO_2 measures did not reach the $p <$ .05 level which indicated an absence of agreement between objective and perceived accounts.

Following the procedure described in Section 2.3, we estimated the differences between the rescaled versions of the objective and perceived modalities of neighbourhood attributes (see Supplementary Table 6). Also in Table 1, paired t-tests showed small to large size differences between objective and perceived neighbourhood attributes in Donostia and Barcelona when using 500 m buffer variables. When using 1000 m buffer variables, the results were the same for walkability in Donostia and greenness in Barcelona but changed for greenness in Donostia (with objective scores being higher than the perceived ones) and for walkability in Barcelona, where no differences between measurement modalities were found.

In Donostia, perceived greenness (500 m) and walkability (500 m and 1000 m) scores were higher than objective accounts, and the opposite was true for air pollution variables. In Barcelona, a different picture emerged and all the objective variables were significantly higher than their perceived counterparts. According to mean and median values displayed in Supplementary Table 6, participants in Donostia

Table 1
Agreement (ICC values) between objective and perceived neighbourhood attributes and buffer size and differences between objective and perceived accounts.

	ICC		Objective – perceived differences	
	Donostia	*Barcelona*	*Donostia*	*Barcelona*
Greenness (500 m)	0.65***	0.52***	$t = -3.63$ $p < 0.001$ $g = 0.30$	$t = 12.80$ $p < 0.001$ $g = 1.07$
Greenness (1000 m)	0.58***	0.38***	$t = 6.32$ $p < 0.001$ $g = 0.32$	$t = 9.13$ $p < 0.001$ $g = 0.50$
Walkability (500 m)	0.59***	0.17	$t = -5.92$ $p < 0.001$ $g = 0.48$	$t = 10.81$ $p < 0.001$ $g = 0.91$
Walkability (1000 m)	0.59***	0.02	$t = -5.48$ $p < 0.001$ $g = 0.28$	$t = -0.57$ $p = 0.59$ $g = 0.04$
NO_2	0.10	-0.07	$t = 10.40$ $p < 0.001$ $g = 0.78$	$t = 2.15$ $p = 0.03$ $g = 0.20$

Note: *** = $p < 0.001$.

tended to overestimate the greenness and walkability and underestimate air pollution levels. In the case of Barcelona, they underestimated all the attributes but walkability (when using the 1000 m buffer). Correlational analyses (see Table 2) revealed limited associations between objective – perceived differences and sociodemographic variables and physical activity. However, a clearer trend emerged for BMI, income and objective neighbourhood attribute scores. In three occasions, BMI was positively related to difference scores, indicating that the higher BMI the larger the difference between objective and perceived accounts. Most of the time, income was negatively associated to difference scores, meaning that the higher the average household income in the district one lives, the lower the difference between objective and perceived accounts of the neighbourhood attributes of interest for this study. This means that participants residing in more affluent districts performed more accurate environmental assessments and held more realistic environmental perceptions. The only exception to this trend was air pollution in Donostia, in which the effect was in the opposite direction. Finally, the objective score of the attribute was moderately and positively associated to differences in greenness and air pollution but negatively to walkability.

3.2. Structural equation models

In this section we will review the results of the models using objective neighbourhood variables in 500 m. The tables and figures regarding the 1000 m buffer models can be found in the Appendix (Supplementary Tables 7 and 8 and Supplementary Figs. 1 and 2).

We were able to fit the model to the Donostia sample with very satisfactory goodness of fit [$X^2(6) = 8.17$, $p = 0.226$, CFI = 0.991, RMSEA 0.035]. This model, shown in Fig. 3 and Table 3, explained 8 % of the variance in mental health. Six of the thirteen originally proposed pathways achieved statistical significance and two extra pathways were included based on the modification indices suggested by the modindices () function. Arrows connecting mediators with mental health need to be interpreted under the premise that higher mental health scores are indicative of greater stress and/or worse mental health. As a whole, the model confirmed the expected associations between objective and perceived greenness and walkability, and the association between two perceived neighbourhood attributes and mental health. This time, as compared with our previous study (Subiza-Pérez et al., 2021), social cohesion mediated only the effects of perceived greenness because the air pollution annoyance effects were direct. We did not observe any association between perceived walkability and social cohesion or mental health. Among the additional paths included through model iteration, one lays out the relationships between one objective neighbourhood attributes and perceived modalities other than their counterparts. More specifically, we found that objective walkability negatively predicted perceived greenness.

Nevertheless, results did not support the expected association between objective air pollution and air pollution annoyance, nor did they show any link between objective neighbourhood attributes and mental health. Surprisingly, objective walkability was negatively associated with social cohesion.

Compared to the 500 m buffer models, the model using 1000 m buffers (shown in Supplementary Fig. 1 and Supplementary Table 7) showed lower explanatory power of proximal mediators, a weaker relationship between walkability and perceived walkability and a stronger one between objective greenness and air pollution annoyance. Besides, an extra originally proposed pathway (perceived walkability – mental health) could be confirmed. Despite the former, the general association patterns between main study variables remained the same.

The Barcelona model also achieved satisfactory goodness of fit [$X^2(4) = 3.71$, $p = 0.447$, CFI = 1, RMSEA ≤ 0.001] and preserved 5 of the original paths (Fig. 4, Table 4). In this solution, objective greenness and walkability were related to their perceived modalities and no associations were found for air pollution variables. In line with results from our previous study (Subiza-Pérez et al., 2021), the three perceived neighbourhood attributes exerted an influence on social cohesion but no further effects on mental health received statistical support.

The model was updated with 4 new paths that had to be specified to achieve a robust statistical solution. This time, we also observed relationships between different objective and perceived attributes: objective walkability negatively predicted perceived greenness and objective air pollution predicted perceived accounts of greenness. Perceived greenness was also found to be a positive predictor of perceived walkability.

In the model fitted with objective greenness and walkability estimated in 1000 m buffers (see Supplementary Fig. 2 and Supplementary Figure 8), weaker relationships were found between objective and perceived neighbourhood variables but evidence on the mixed prediction pattern (e.g. a given objective variable being associated to the perceived version of another) was also found. The model also informs about a negative association between objective air pollution and air pollution annoyance. Despite the former, the most relevant finding here was the confirmation of the association between social cohesion – which mediated the three perceived neighbourhood variables – and mental health at the $p < 0.10$ level.

4. Discussion

Ecological approaches to health and well-being have long studied the associations between environmental and urban variables and multiple outcomes. In recent years, attention has turned to understand the mechanisms that would explain their salutogenic potential (Dzhambov et al., 2020; Markevych et al., 2017; Sugiyama et al., 2008; White,

Table 2
Correlations between rescaled objective-perceived absolute differences, sociodemographics, BMI, physical activity and attributes' objective scores.

Variable (absolute rescaled objective-perceived differences)	Age	Education	BMI	LPA	MVPA	Income	Obj. Att
Donostia							
Greenness (500 m)	0.01	0.06	0.01	0.03	0.11*	-0.02	0.01
Greenness (1000 m)	−0.06	0.06	0.05	-0.09	0.05	-0.15**	0.11*
Walkability (500 m)	0.03	−0.08	0.11*	−0.02	−0.09	0.02	−0.17**
Walkability (1000 m)	−0.01	−0.05	0.08	0.01	−0.07	0.03	−0.12*
NO_2	−0.01	0.02	−0.15**	0.03	−0.01	0.12*	0.51***
Barcelona							
Greenness (500 m)	0.01	< 0.01	0.03	< 0.01	−0.04	−0.06	0.46***
Greenness (1000 m)	−0.03	−0.02	−0.01	−0.05	0.01	−0.08	0.20***
Walkability (500 m)	−0.20***	−0.21***	0.19**	0.10	−0.08	−0.29***	−0.04
Walkability (1000 m)	−0.08	−0.06	0.14*	0.05	−0.04	−0.11†	−0.11†
NO_2	−0.03	< 0.01	−0.03	0.03	<0.01	0.07	0.15*

Note: BMI = Body Mass Index, LPA = Light Physical Activity, MVPA = Moderate to Vigorous Physical Activity, Obj. Att = Objective Attribute Score. † = $p < 0.10$,* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

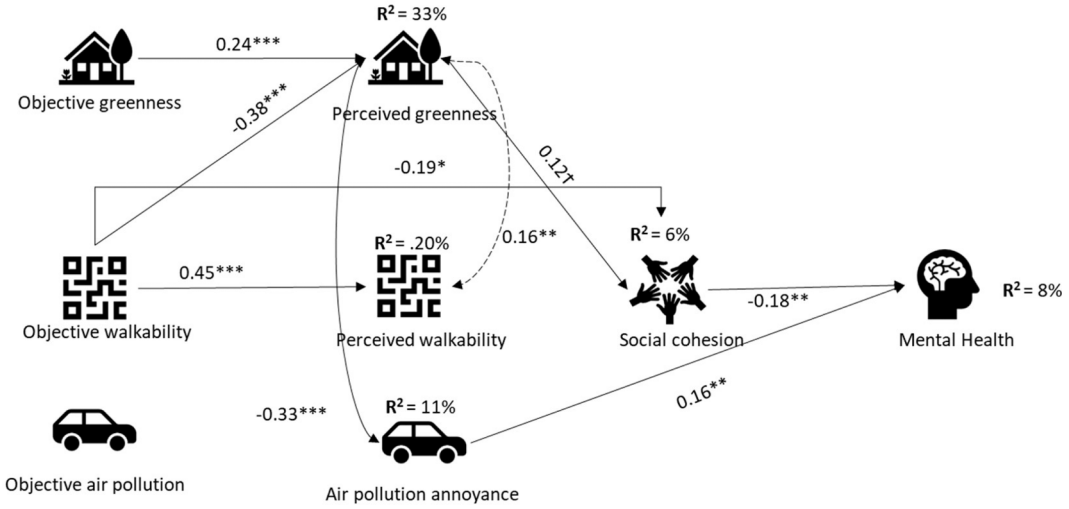

Fig. 3. Final structural equation model fitted with data from the Donostia sample and objective greenness and walkability measures in 500 m buffers. † = $p < 0.10$, * = $p < 0.05$, *** = $p < 0.001$. R^2 = explained variance. Double headed dashed arrow between perceived greenness and perceived walkability indicates the covariance between both (specified in the model after running *modindices()*.

Table 3
Standardized effect sizes, together with standard errors, z−values and p-values for the structural equation model depicted in Fig. 3. These results correspond to Donostia sample.

From	To	Estimate	Std. Error	95 % CI	*z*-value	*p*-value
Objective greenness	Perceived greenness	0.24	0.07	0.10–0.37	3.50	<0.001
Objective Walkability	Perceived walkability	0.45	0.04	0.36–0.53	10.19	<0.001
	Perceived greenness	−0.38	0.07	−0.51–(−0.25)	−5.82	<0.001
	Social cohesion	−0.19	0.09	−0.37–(−0.02)	−2.13	0.033
Perceived greenness	Air pollution annoyance	−0.33	0.05	−0.43–(−0.22)	−6.29	<0.001
	Social cohesion	0.12	0.07	−0.02 – 0.26	1.69	0.092
Air pollution annoyance	Mental health	0.16	0.06	0.04–0.27	2.72	0.007
Social cohesion	Mental health	−0.18	0.06	−0.29–(−0.07)	−3.22	0.001

Note; Std.: standard.

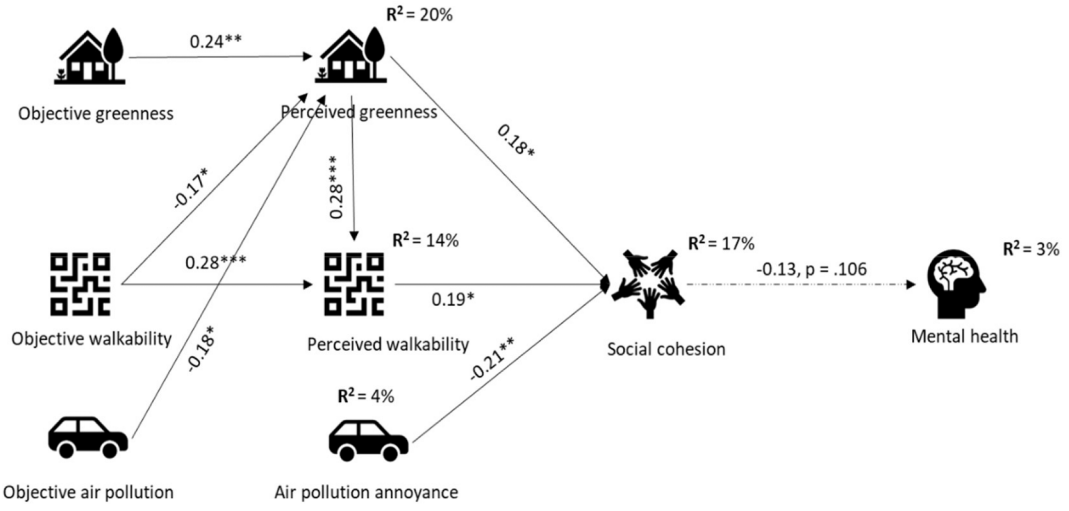

Fig. 4. Final structural equation model fitted with data from the Barcelona sample and objective greenness and walkability measures in 500 m buffers. p < 0.05, *** = p < 0.001. R2 = explained variance. Discontinuous arrow between social cohesion and mental health shows the non-statistically significant association between both.

Elliott, Gascon, Roberts, & Fleming, 2020). In this study we also wanted to contribute to these efforts by testing a model in which three neighbourhood attributes, namely greenness, walkability and air pollution, were expected to have an influence on mental health through neighbourhood perceptions and social cohesion. Using two samples of Spanish pregnant women, we were able to fit four structural equation models that, as a whole, validated most of our theoretical expectations. Even though several model paths could not be confirmed, we saw that

Table 4
Standardized effect sizes, together with standard errors, z-values and p-values for the structural equation model depicted in Fig. 4. These results refer to the Barcelona sample.

From	To	Estimate	Std. Error	95 % CI	*z*-value	*p*-value
Objective greenness	Perceived greenness	0.24	0.08	0.08–0.40	2.96	0.003
Objective Walkability	Perceived greenness	−0.17	0.07	−0.31–(−0.02)	−2.26	0.024
	Perceived walkability	0.28	0.07	0.13–0.42	3.72	<0.001
Objective air pollution	Perceived greenness	−0.18	0.09	−0.35–(−0.01)	−2.03	0.043
Perceived greenness	Perceived walkability	0.28	0.07	0.14–0.43	3.81	<0.001
	Social cohesion	0.18	0.08	0.02–0.33	2.22	0.027
Perceived walkability	Social cohesion	0.19	0.08	0.04–0.33	2.48	0.013
Air pollution annoyance	Social cohesion	−0.21	0.07	−0.35–(−0.08)	−3.08	0.002
Social cohesion	Mental health	−0.13	0.08	− 0.29–0.03	−1.62	0.106

Note; Std.: standard.

objective neighbourhood attributes predicted their perceived counterparts and that these exerted significant but small direct or indirect (via social cohesion) effects on mental health. Of great interest, too, was the observation that some perceived attributes were not only predicted by their objective counterpart but also by other objective attributes. For instance, this was the case for perceived greenness in the Donostia sample, which was found to be a function of not only of NDVI but also objective walkability. We know from previous studies that the relationship between objective and perceived neighbourhood attributes is complex (Gebel et al., 2009; Ma & Dill, 2016; Orstad et al., 2017; Wu et al., 2021) and that common sense does not always apply. Our results, which require further replication and extension, may indicate that, when forming perceptions and attitudes about specific features of one's environment, people do not draw exclusively from those features but also from other related characteristics. This idea is further supported by the finding that perceived greenness predicted perceived walkability and air pollution annoyance in the Barcelona sample.

We fitted two models for each city using objective greenness and walkability variables in 500 m and 1000 m. The four models show the association between objective and perceived accounts of neighbourhood attributes (absolute coefficients between 0.10 and 0.40), with the sole exception of air pollution in the Donostia models and walkability in the Barcelona 500 m model. The association of perceived neighbourhood variables and social cohesion was more apparent in the Barcelona models and was only confirmed for perceived greenness in the Donostia models. Perceived walkability (only in the 500 m model) and air pollution annoyance exerted a direct effect on mental health though. In sum, most of the models inform about the direct or mediated relationship between objective and perceived neighbourhood variables and mental health during pregnancy and therefore support a relevant number of the theoretical assumptions expressed in the theoretical model depicted in Fig. 1. The differences between the cities observed in the models (e.g. size of coefficients or path structure) might be attributable to their social, economic or urban characteristics. However, we could not explore this possibility due to the fact that our samples were not representative of the pregnant populations in each city. Besides, from a statistical point of view, this question should be addressed through multilevel modelling, which would require a larger number of cities.

With a sample of over 1000 Chinese citizens, Zhang and colleagues (Zhang et al., 2019) showed that objective neighbourhood attributes predicted physical health and subjective ones predicted mental health (see also Wu et al., 2021). Our results seem to further support their findings and are totally compatible with socio-ecological and cognitive approaches (e.g. planned behaviour theory, socio-cognitive theory and stimulus-organism-response models, see Ma & Cao, 2019; Ma & Dill, 2016). In sum, this would involve people building mental representations of their residential environment, which in turn guide their behaviour and have an impact on their health. Which health outcomes are more directly linked to objective features of the environment and which are more dependent on people's perception of those remain to be elucidated. In the mental health domain, despite the apparent benefits of resorting to perceptions (Subiza-Pérez et al., 2021; Wang et al., 2020), including objective neighbourhood attributes helps achieve a deeper and more insightful picture and this study clearly proves that.

4.1. *Environmental mismatching*

We also sought to analyse the correspondence between objective and subjective accounts of neighbourhood attributes. Taking advantage of the availability of both objective and perceived neighbourhood attributes measures in the UGARE project, we studied agreement between both modalities. In general, and in line with previous research (Gebel et al., 2009; Ma & Dill, 2016; MacDonald et al., 2013; Orstad et al., 2017; Wu et al., 2021), we found moderate to good agreement for greenness in both samples, moderate agreement for walkability in Donostia and failed to find it for air pollution in either case. The absence of a link between air pollution and annoyance is not surprising given that we did not strictly measure perception but annoyance, which would be one of its outcomes, and that contrary to greenness and walkability, air pollution is usually difficult to perceive with our senses and only detectable in situations of high concentrations or due to the presence of irritants.

Contrary to previous work on environmental mismatching, which compares objective and perceived variables expressed in tertiles or binary categories, we developed a new method to estimate the actual differences between objective and perceived measures through rescaling. This method allowed us to discover that a certain degree of mismatching existed in both samples although its direction was different. In Donostia, rescaled perceived attributes scores were usually higher than the objective accounts and the contrary happened in Barcelona. Regardless of the mismatch valence, age, education level and physical activity measures were hardly explicative of mismatching. In line with previous research (Gebel et al., 2009; Ma & Dill, 2016), we found some associations with BMI, income and the objective levels of the attribute. In some cases, district income was negatively correlated with difference scores, meaning that the higher the income, the smaller the mismatching size. More interestingly, we found that mismatch in a given attribute grew as its objective level varied. It was observed that mismatch increased in objectively greener and more polluted residential settings, the opposite being true for walkability. Our ability to provide an explanation for these results is certainly limited due to the absence of other variables in the study that could help us to account for them. Also, the fact that mismatch worked in different directions in each sample makes interpretation even more puzzling. However, we can speculate that more affluent participants spend more time in settings other than their residential (Godhwani, Jivraj, Marshall, & Bécares, 2019), and enjoy activities in other parts of the city or the country which both would lead to more accurate environmental assessments.

From a public health perspective and depending of its direction, environmental mismatching can have two main implications. Underestimating the level of a positive attribute might reduce its impact on

health, since it would reflect a person who, believing that his/her neighbourhood is not green enough, does not use its public spaces and thereby avoids their psychological benefits. On the other hand, overestimating a neighbourhood's walkability may make a person select that environment for leisure walking when other places (e.g. other destinations in the city) could be more supportive and eventually beneficial. In the case of negative attributes, such as air pollution, the implications of mismatching are the opposite. Underestimating the presence of pollutants in residential settings might make a person more vulnerable to their deleterious effects on health, whereas overestimating it might increase maladjusted stress and protective behaviours (Subiza-Pérez et al., 2020). This implies that health communication efforts should stress the salutogenic value of residential green spaces and raise awareness about residential air pollution hot spots for most people. This could be paired with interventions to enhance walkability. However, due to the proportion of participants showing the opposite pattern of objective vs perceived scores, targeted interventions for specific profiles are likely most appropriate. It has been already described that low-income populations might be affected by a double jeopardy (Bolte, Pauli, & Hornberg, 2011) that would emerge from the joint action of limited individual resources (education, income, and prospects) and unequal distribution of environmental exposures (Gerrish & Watkins, 2018; Gray, Edwards, & Miranda, 2013; Rigolon, 2017). Our findings might help to deepen in the understanding of such health inequalities as low income participants seemed to be more prone to environmental mismatch and therefore potentially more exposed to the deleterious implications of environmental mismatching described above.

One question that remains clearly open for future study is the establishment of relevant mismatch thresholds. We defined over- and underestimations when the scores of perceived attributes exceeded or were inferior to their objective counterparts and found statistically significant differences between objective and perceived scores of small and moderate magnitudes. However, it might well be that not every statistically significant difference in this regard has an actual psychological or health-related meaning. Therefore, there is a need to identify the point at which environmental mismatching has a specific effect on human health (e.g., it modifies the duration of physical activity or affects mental health). Interventions like those described in the paragraph above would make sense only for people above these health-relevant thresholds.

4.2. Strengths and limitations

By integrating objective and perceived measurements of three key neighbourhood attributes, this study makes a relevant contribution to the field that has not always been possible in previous studies (Dzhambov et al., 2017; Liu et al., 2020; Liu, Wang, Grekousis, et al., 2019; Liu, Wang, Xiao, et al., 2019; Sugiyama et al., 2008; Wang et al., 2020). This allowed us to estimate the effects of each specific attribute on mental health when controlling for the others and simultaneously assess the impact of objective and perceived attributes.

However, the former strength can also be seen as a limitation, as it refers to a highly specific moment of life in social and psychological terms (De Tychey et al., 2005; Lorén-Guerrero, Gascón-Catalán, Pasierb, & Romero-Cardiel, 2018; Pais & Pai, 2018; Van Bussel et al., 2006). As a result, our conclusions might not be easily generalizable to other, broader population groups or even to pre-pregnancy or latter-pregnancy mental states. It might be that some of the psychological changes experienced during pregnancy (Brown & Schaffir, 2019; Lynn, Alderdice, Crealey, & McElnay, 2011) alter environmental perception processes although this has to be scientifically tested. Nevertheless, pregnant women are a very interesting study population due to the impact of well-being determinants on not only their health but also that of the baby. Due to the recruitment strategy we followed, which depended on voluntary participation, our results are also likely affected by a self-selection bias. Meanwhile, the models used to estimate participant exposure to NO_2 are reliable to detect inter-individual differences, but could lead to overestimation (Anabitarte et al., 2020). Moreover, in the case of Barcelona our imputation strategy was relatively compromised due to the absence of traffic intensity. Another point that deserves some discussion here is the fact that, even though we used two different buffers for the objective neighbourhood variables (500 m and 1000 m), we cannot determine whether they actually corresponded the mental representation (and boundaries) of the neighbourhood that each participant held and used to respond to the questionnaire variables. Although pervasive in this area of research, this issue could be solved by inviting participants to define their neighbourhoods and use that information to calculate objective exposures later (Kwan, 2009; Vallée, Le Roux, Chaix, Kestens, & Chauvin, 2015) or using GPS data. Finally, even though we recruited participants in two Spanish cities and gathered relevant information from different sources, our samples sizes were limited.

The inclusion of socio-political or ideational factors might also constitute an interesting avenue for future studies. For instance, people with political preferences that are in opposition to the governments implementing specific measures in the selected policy areas may be more or less prone to "disagreement" between objective and subjective measures. In addition, people's desires or inclinations about these neighbourhood attributes might modify their effects on health.

5. Conclusion

Strong institutional and scientific efforts are being undertaken to improve urban environments for the sake of health and sustainability. Environmental epidemiology and psychology must provide stakeholders, politicians and practitioners with evidence on how urban conditions modify behaviour and strengthen or undermine health. By disentangling the relationships between objective urban attributes and their perceptions, this study clarifies the precise pathways linking these attributes to the social cohesion and mental health in pregnant women, two valuable assets with critical implications for not only their health and that of the offspring but for the societal challenges likely to define the years to come.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104612.

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