

Research Paper

A greener urban environment: Designing green infrastructure interventions to promote citizens' subjective wellbeing

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ABSTRACT

Research using subjective wellbeing (SWB) measures finds that the greener an individual's local environment is, the higher the levels of happiness and the lower levels of stress they tend to report experiencing. This literature presents positive associations between existing large-scale green spaces, such as urban parks or squares, and the wellbeing of residents living in close proximity to them. In contrast, in the current work, we present a novel approach which combines SWB measures with photo simulation in order to examine the impact of street-level green infrastructure interventions on the people's perceptions of the SWB associated with urban sites. We tested the approach with the attendees of the 20th Biennale on Architecture and Urbanism in Chile in 2017, exploring the impact of four different types of street-level green interventions. The results indicate that all types of green interventions considered significantly increase the perceived happiness and reduce the perceived stress associated with the sites during short exposures, with varying effect sizes across different types and scales of interventions. The proposed technique could be used in urban planning processes to examine the potential SWB benefits of green infrastructure investments prior to their being rolled out.

1. Introduction

Over half of the world's population now live in urban areas and this proportion is predicted to grow rapidly over the next 30 years ([UN DESA, 2018](#)). While there are benefits to living in towns and cities compared to rural areas, including enhanced economic and social opportunities, a major downside of life in many urban areas around the world is the relatively low level of green space that residents have access to ([Bettencourt & West, 2010](#); [WHO, 2017](#)). In addition to the urban-rural divide, inequalities in access to green space exist within cities too: recent research indicates that those with low socioeconomic status have less access to high-quality green space in the Global North and to green space of any kind in the Global South than their economically better off counterparts ([Rigolon, 2016](#); [Rigolon, Browning, Lee, & Shin, 2018](#)). These inequalities go beyond green spaces and also apply to small-scale green elements such as the trees and shrubs ([Gerrish & Watkins, 2018](#); [Pedlowski, Da Silva, Adell, & Heynen, 2002](#)). As towns and cities around the world grow to accommodate more and more people, a key priority for urban planners is the greening of urban spaces in ways that effectively promote the wellbeing of all residents.

Capturing the value of greenery for the wellbeing of urban residents

is central to efforts to encourage its provision. However, this is no easy task. First, like many other elements of environmental quality, such as air and noise pollution, elements of green infrastructure, including street trees, playing fields, parks and other open green spaces, are not typically bought and sold in markets ([Choumert & Salanié, 2008](#)). Second, wellbeing itself is a broad and multidimensional construct which covers how well individuals are doing in their lives across material, social, health and subjective dimensions ([Dolan & Metcalfe, 2012](#)). How best to operationalise wellbeing in order to examine how it is impacted by green space is, therefore, open to debate ([Atkinson, Bateman, & Mourato, 2012](#)). It has been suggested that the resulting difficulties in assessing the overall value of urban green space are to blame for the widespread underinvestment in green infrastructure and the encroachment of urban sprawl into green spaces in cities around the world ([Kong, Yin, & Nakagoshi, 2007](#); [Mell, Henneberry, Hehl-Lange, & Keskin, 2013](#)).

Traditional approaches to valuing the benefits of green space have centred on using people's preferences as measures of their wellbeing, in accordance with a preference satisfaction account of wellbeing that says that people are well when they get what they prefer ([Dolan & Metcalfe, 2012](#)). Such approaches include both revealed and stated preference

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methods (Atkinson & Mourato, 2008; Brander & Koetse, 2011). Revealed preference studies look to how people behave in markets for related goods to infer their preferences for, and therefore the value of, green spaces. Hedonic price estimates, for example, are based on the premium associated with external non-market factors such as green space in related markets such as housing or labour markets (Irwin, 2002; Kong et al., 2007; Mazzotta, Besedin, & Speers, 2014; Poudyal, Hodges, & Merrett, 2009; Panduro & Veie, 2013). Stated preferences, on the other hand, bypass real markets and value green spaces based on what individuals say they would be willing to pay to access it, or willing to accept to forgo doing so, most often based on hypothetical scenarios (Jim & Chen, 2006; Scarpa, Hutchinson, Chilton, & Buongiorno, 2000; Tyrväinen, 2001). These standard methods have been critiqued, however, for failing to fully capture the wide range of positive health, ecosystem services and wellbeing benefits that green space gives rise to (Nowak, Hirabayashi, Bodine, & Greenfield, 2014; Wolf & Robbins, 2015).

In recent years, and in response to the challenges levelled at standard preference-based methods of valuation, researchers have begun to examine the benefits of green infrastructure using non-preference based measures of wellbeing. While some of this work has focused on documenting the links between green space and objective health and wellbeing indicators such as body mass index and cortisol levels (Fong, Hart, & James, 2018; Kondo, Fluehr, McKeon, & Branas, 2018; Lachowycz & Jones, 2011; Thompson et al., 2012), other work has looked to measures of subjective wellbeing (SWB) – individuals' own reports of how they think about their lives and feel as they go about them (Stone & Mackie, 2013) – to investigate the value of green space. This work finds, for example, that living in a greener environment is linked to higher levels of life satisfaction and happiness and lower levels of stress (Ambrey, Fleming, & Manning, 2014; Hazer, Formica, Dieterlen, & Morley, 2018; MacKerron & Mourato, 2013; White, Alcock, Wheeler, & Depledge, 2013).

Of particular importance, is evidence from the literature using both objective wellbeing indicators and SWB measures which indicates that more green space is linked to lower levels of stress in deprived urban communities and that green space can act as a buffer for stressful life events (Thompson et al., 2012; Thompson, Aspinall, Roe, Robertson, & Miller, 2016; Van den Berg, Maas, Verheij, & Groenewegen, 2010). These findings suggest that access to green space may be of particular importance for the wellbeing of the most vulnerable in society. This evidence has strengthened the case for integrative sustainability policies which look to promote social as well as ecological sustainability in urban communities by greening urban spaces in ways that limit the potential risks of gentrification that green infrastructure investment can pose (Wolch, Byrne, & Newell, 2014).

While demonstrating the importance of green space for wellbeing, research using objective and SWB measures has had far less to say about how best to channel green investments so as to maximise their positive impact on urban residents. Additionally, with the exception of a few studies which have considered the impact of street-level green infrastructure, such as street trees, on residents' levels of neighbourhood satisfaction (Hur & Morrow-Jones, 2008; Kearney, 2006; Kweon, Ellis, Leiva, & Rogers, 2010; Zhang, Van den Berg, Van Dijk, 2017), the SWB work that does exist has tended to focus on large-scale green spaces with substantial land requirements (Ambrey et al., 2014; Hazer et al., 2018; White et al., 2013). Understanding how to design small-scale green infrastructure in ways that can promote wellbeing is of particular importance in urban areas around the world where such infrastructure must be incorporated in built-up city areas where public land is costly and scarce.

In the current work, and with a view to contributing to these gaps and expanding current techniques in green infrastructure planning and design, we use photo simulation in combination with SWB measures to study the impact of street-level green infrastructure interventions (henceforth green interventions) on people's perceptions of the SWB

associated with urban sites prior to their being rolled out. More specifically, we explore the impact of 'greening' tram lines, pedestrian streets, avenues and small streets on the feelings of happiness and stress that people associate with images of urban sites. Additionally, we compare our SWB results to those relating to a third outcome variable which has been considered in some of the existing photo simulation literature – individuals' perceptions of the safety of sites (Jiang, Mak, Larsen, & Zhong, 2017; Jorgensen, Hitchmough, & Calvert, 2002).

We carried out the study with attendees to the 20th Biennale on Architecture and Urbanism in Chile in 2017. The results of the study indicate that all of the different types of green interventions we consider increase the average ratings of happiness and reduce the average ratings of stress associated with the images of the sites, with the magnitude of the impact varying across the different types and scales of green interventions. Moreover, we find that people's perceptions of safety are less consistently impacted by green interventions than are their ratings of SWB. Overall, the study demonstrates the benefits of using photo simulation in conjunction with SWB measures, in addition to more traditional measures like people's perceptions of safety, to compare and contrast the potential benefits of different types of green interventions.

In what follows, we first review the existing literature on SWB and green space and the use of photo simulation in the urban planning literature. We then go on to present our new approach which builds on these two, thus far, separate bodies of literature.

1.1. SWB and green space

SWB is an umbrella term for how people think and feel as they go about their lives (Dolan, Peasgood, & White, 2008). It includes both evaluative measures of SWB, such as people's overall evaluations of their lives and of domains of their lives such as their neighbourhood satisfaction, as well as experiential measures of SWB which reflect their affective experiences, such as the levels of happiness and stress they experience day to day (Dolan & Metcalfe, 2012). SWB measures have gained prominence in both economics and psychology over the past two decades and are now widely understood to provide valuable and reliable information about how individuals' lives are going (Stone & Mackie, 2013). These measures are also increasingly being used to inform public policy. For example, many national statistical agencies, including those in France, Italy, Canada, New Zealand, the UK and Australia, are now collecting and using SWB data to monitor national wellbeing. In 2011, the UK government's Green Book – its guidance on cost-benefit analysis – was amended to include recommendations on the use of SWB measures in the valuation of non-market goods like green space (Fujiwara & Campbell, 2011).

In recent years, a burgeoning body of literature has emerged which uses SWB measures to document the benefits of green infrastructure for individual wellbeing (Krefis, Augustin, Schlünzen, Oßenbrügge, & Augustin, 2018). Existing correlational evidence from this literature indicates that living in environments with higher levels of green space is associated with lower levels of depression, stress and anxiety (De Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Maas et al., 2009; Van den Berg et al., 2010), and higher levels of happiness and life satisfaction (Ambrey et al., 2014; MacKerron & Mourato, 2013). For example, in a nationally representative longitudinal sample of UK residents, White et al. (2013) find that, controlling for individual and regional covariates, individuals report both lower mental distress and higher life satisfaction on average when they live in urban areas with relatively high levels of green space. Krekel, Kolbe, and Wüstemann (2016) find similar results when looking at the relationship between green space in urban areas in Germany, while also documenting a particularly strong positive relationship for older residents.

There is also some experimental work which suggests that green infrastructure may have a causal impact on how people feel. For example, some small-scale work finds that incorporating natural elements

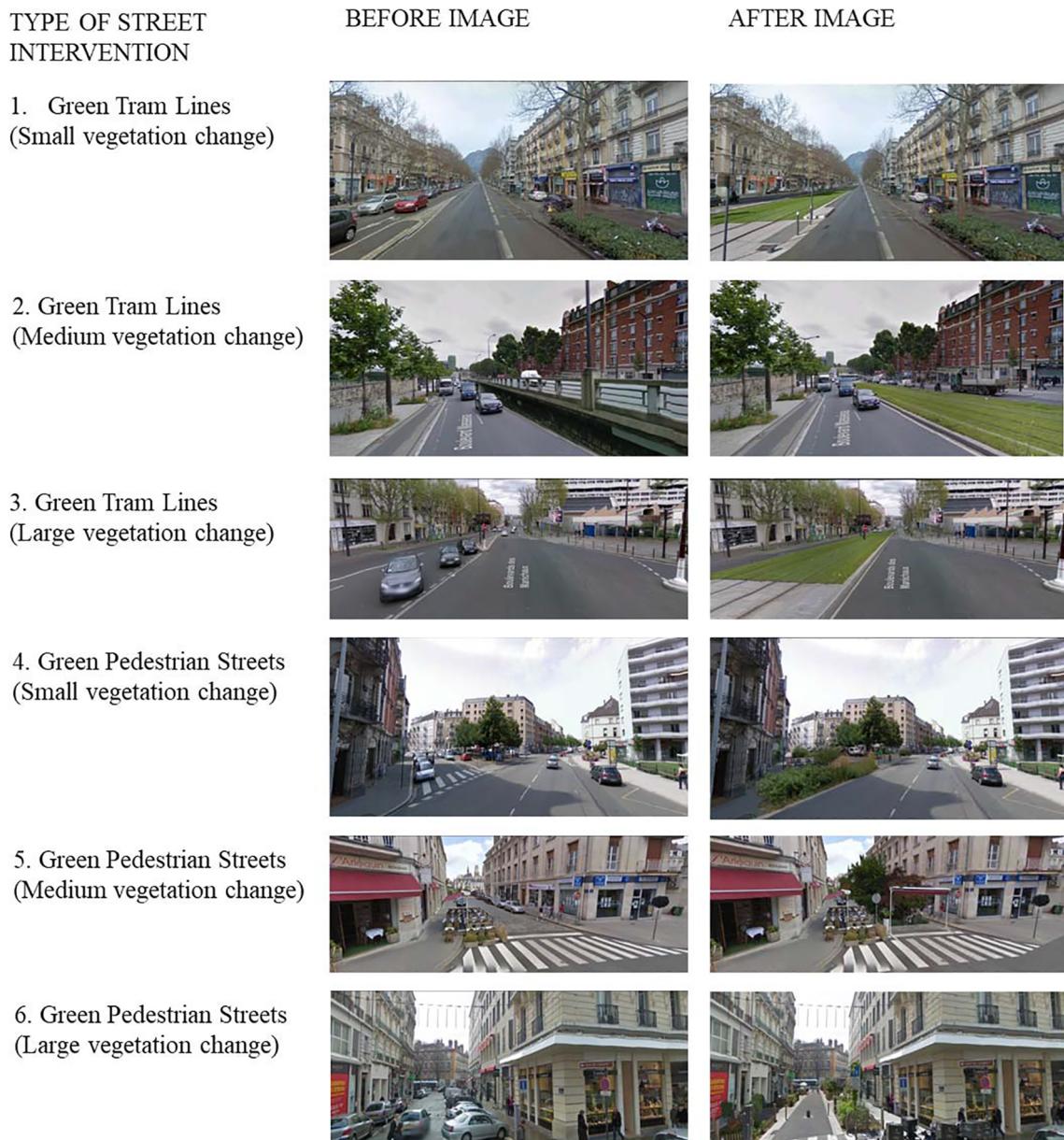


Fig. 1. Photographic Simulations of Street Vegetation.

into individuals' indoor environments, for example, by adding plants to their office places, classrooms or hospital waiting rooms, can serve to enhance their SWB (Beukeboom, Langeveld, & Tanja-Dijkstra, 2012; Küller & Lindsten, 1992; Larsen, Adams, Deal, Kweon, & Tyler, 1998). Other studies compare the impact of walking in natural versus built-up environments, finding that walking in green space results in higher levels of happiness and lower levels of anger than doing so in built-up environments (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Nisbet & Zelenski, 2011). All of this evidence suggests that policymakers should take seriously the potential wellbeing benefits of increasing the amount of green space citizens are exposed to in their daily lives.

While the above work provides insights into the value of having green infrastructure nearby, it cannot shed light on how to invest in such infrastructure so as to maximise its potential wellbeing benefits. In order to address this, the current work goes a step further in the use of SWB measures by integrating them into the planning process with the help of photo simulation.

1.2. Photo simulation

Photo simulation (PS) is a technique that has been widely used in planning research and environmental psychology (Jorgensen et al., 2002; Kuo, Bacaicoa, & Sullivan, 1998; Rodiek & Fried, 2005). It involves adapting photographs of sites so that they incorporate different changes to the physical environment under consideration. PS has been used to capture the impact of different physical interventions on people's preferences. For example, one study explored residents' preferences over a commercial strip development and used photo simulation to explore the impact of including a car park and natural elements, such as trees and flowers, on people's preferences over the development (Sullivan & Lovell, 2006). Another study based in Switzerland explored how different forms of river restoration impacted upon the extent to which individuals perceived it satisfied their needs, among other outcomes (Junker & Buchecker, 2008). Photo simulation has also been used in a recent study to explore the impact of different architectural design features of care homes on older adults' attitudes toward these facilities (Cerina, Fornara, & Manca, 2017).

Another line of research, relating specifically to green infrastructure, has used photo simulation to explore the impact of the addition of green elements to physical environments on people's perceptions of sites, with a particular focus on perceptions of safety. In an early study, Kuo and colleagues (1998) used PS to examine the impact of tree placement, tree density and levels of grass maintenance on Chicago residents' preferences and sense of safety of their local area, finding that both tree density and grass maintenance positively impacted the outcomes in question. A more recent study by [Jiang and colleagues \(2017\)](#) used PS to investigate the impact of green interventions on people's perceptions of the safety of alleyways. They found that green interventions involving geometric vegetation increased perceptions of safety to a greater extent than did naturalistic vegetation. Finally, [Nejati, Shepley, Rodiek, Lee, and Varni \(2016\)](#) used PS to demonstrate how adding natural elements to hospital staff break areas positively impacted upon staff members' perceptions of the restorative nature of these areas. This literature demonstrates that this technique can inform our understanding of individuals' perceptions of, as well as preferences over, sites. Moreover, PS can produce insights which inform the design and maintenance of both indoor and outdoor green infrastructure. In the current work, we use PS in conjunction with SWB measures to examine the potential benefits of urban green interventions.

2. Methods

We demonstrate our proposed approach in a study constructed using a specially developed online platform – www.urban-experiment.com – and implemented in person with attendees to the 20th Biennale of Architecture and Urbanism in Valparaiso in 2017.

2.1. Study design

We designed the study to gather data on individuals' perceptions of a series of computerized visual simulations of street-level green interventions (see Fig. 1). We chose to use photo simulation, instead of other more technologically advanced methods such as 360-degree videos, as it represents a very low-cost technique to generate insights into the green interventions under consideration. In the planning process, it is typical for urban planners, architects and others to produce computerized images of their proposed interventions. In this study, we demonstrate how such images could be used in combination with images of the existing sites to gain low-cost insights into how the interventions might impact people's perceptions of those sites. While generating 360-degree videos of existing sites is affordable, generating a 360-degree simulated video of high enough quality to render the green interventions believable is still relatively expensive and time-consuming. With a view to maximising the potential uptake of our approach among practitioners working on green infrastructure projects in both cities in the developing and developed world, we therefore opted to use photo simulation.

We briefly expose participants to images urban sites either before or after the incorporation of a green intervention. They rated these images according to the happiness and stress they associated with them on a ten-point scale: from completely unhappy to completely happy and completely stressed to completely relaxed, respectively. Self-reports of happiness and stress represent affective measures of SWB that assess individuals' experiential rather than evaluative wellbeing. These two types of affect have dominated the SWB-green space literature to date (see for example [Hazer et al., 2018; MacKerron & Mourato, 2013](#)). In the current work we adapt SWB measures that have been widely used to investigate people's affective wellbeing on the previous day (as in large scale surveys, see for example [Dolan & Metcalfe, 2012](#)) or in the moment using experience sampling (see for example the app data used in [MacKerron & Mourato, 2013](#)). In addition to the two SWB measures, we also asked individuals to report their perceptions of the safety of the

sites in question. As previously discussed, individuals' perceptions of safety commonly feature in the photo simulation literature.

We used twelve pairs of images of urban sites before and after the incorporation of vegetation in the study. All images represent urban areas in France. The images represent four different types of green interventions: 1) green tram lines (where car lines are replaced with grass); 2) green pedestrians streets (a street is closed to traffic and vegetation is incorporated instead); 3) green avenues (vegetation is incorporated in wide streets); and 4) small green streets (vegetation is incorporated in small local streets).

We further categorised image types into three different scales of green interventions: small, medium and large. We modified the before and after images slightly to hold constant important features of the images (weather, number of people, cars, facades, lighting and brightness) between the before and after pairs of images. As a result, we obtained twelve pairs of computerized images with each pair being equal in all its components but the incorporation of street vegetation.

2.2. Sampling method

We installed a stand at the Biennale of Architecture and Urbanism from Friday to Sunday over the last week of October and the first week of November 2017. We chose this site as it gave us access to a convenience sample with which to demonstrate our approach of combining photo simulation with SWB measures to inform urban planning and design decisions. We specifically targeted this event as we expected to find enthusiastic volunteers among the attendees who would participate in our study without material incentive to do so. We were proven correct: of a total of 252 walking-by visitors who stopped at the urban experiment stand and we asked to participate in the study, 240 accepted. We approached potential participants and gave them a flyer about the urban experiment platform and asked them to participate in a 6-minute long study on urban perceptions. No monetary incentives or gifts were offered for participation. Once they had agreed to participate, the attendees completed an online registration process which included a questionnaire about their socio-demographic information (see Table 1 for descriptive statistics), a brief about the study protocol and an informed consent form.

"After registering, we presented participants with a sequence of 12 images of urban sites on a 24-inch screen in full-screen display mode. Participants saw each street image for a minimum of 6 s before rating the happiness and stress they associated with the site, as well as their perceptions of its safety (all on a scale of 1–10). Participants took an average of 4:12 min to rate the series of 12 images we presented to them."

To ensure that the covariates were balanced between participants in the before and after groups, we applied a double randomization process using our computer programme: a random image-order assignment and a random before-or-after assignment. First, the programme randomly allocated the order of the twelve pairs of images for each participant. This allows us to control for potential spillover effects or fatigue affecting participants' responses from one picture to the next. Second, for each pair of images, the programme randomly assigned the participant to see either a before or after image. This double random assignment generated a unique order of appearance and combination of before/after images for each respondent. Prior to conducting our analysis, we carried out balance tests at the image level to investigate whether there were differences across the before/after groups in the observed characteristics age, gender, student status, household size, nationality, subject of study, native language, educational level, employment status, image order, day of the test and hour of the test. Across the 156 tests we carried out only 5 were significant at the 5% level indicating the the randomisation was successful (Tables with the output of these tests are available on request).

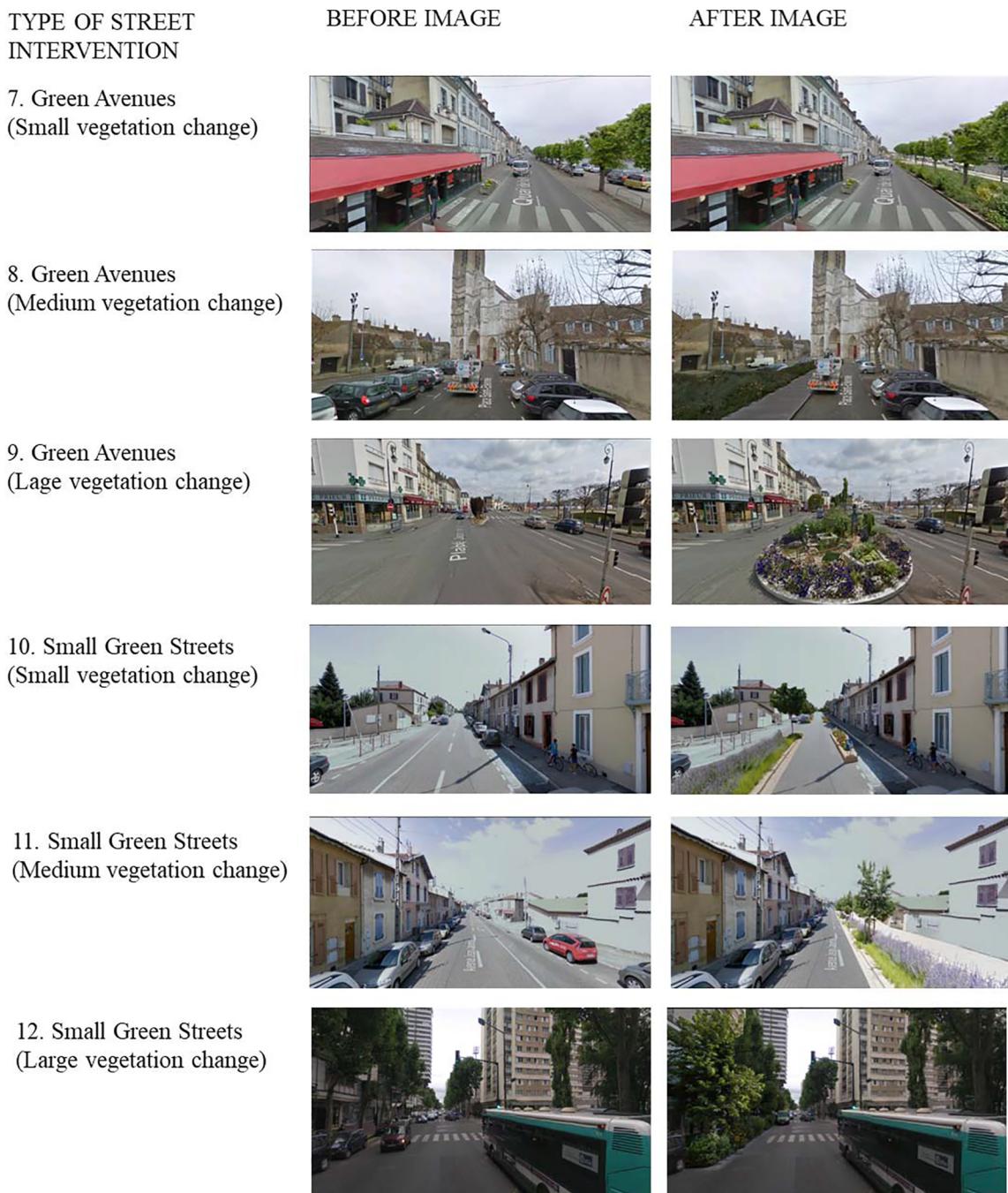


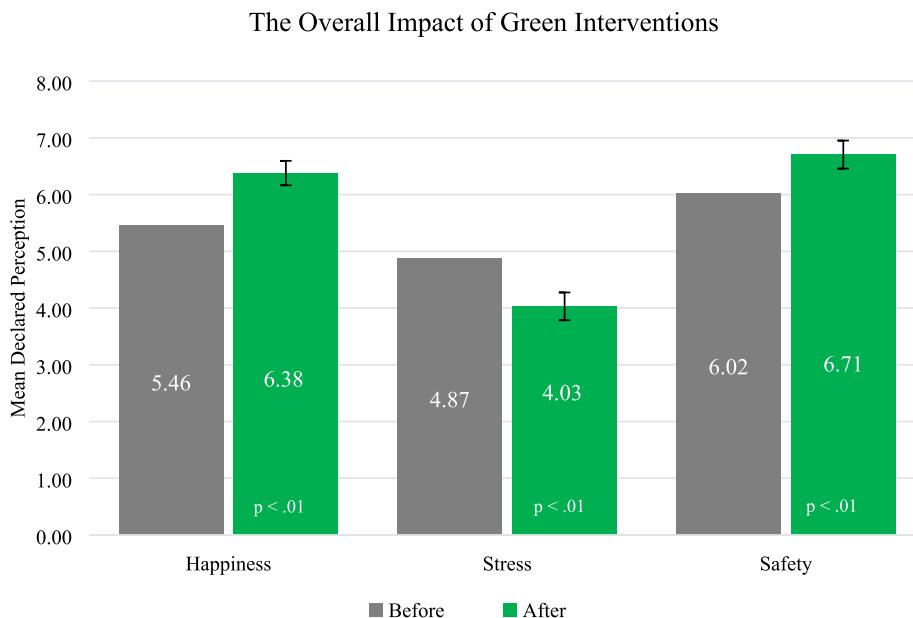
Fig. 1. (continued)

Table 1
Descriptive Statistics.

Variables	N	Mean	Median	Range	S.D.	Min	Max
Age	5767	29	25	64	10.18	10	74
Household Size	5767	3.108	3	6	1.535	1	7
Student Status (yes)	5767	0.581	–	–	–	0	1
Gender (male)	5767	0.495	–	–	–	0	1
Non-Chilean	5767	0.0135	–	–	–	0	1
Related to Design, Art, Architecture	5767	0.749	–	–	–	0	1
Spanish as mother tongue	5767	0.921	–	–	–	0	1
Educational Level (Bachelor or higher)	5767	0.732	–	–	–	0	1
Employed (yes)	5767	0.351	–	–	–	0	1

2.3. Data

To perform the analysis, we use three data sources collected during the study: 1) background characteristics, 2) measures relating to the experimental conditions and 3) participants' subjective perceptions. Participants' background characteristics include their age, gender, student status, household size, nationality, the subject of study, native language, educational level and employment status. The experimental condition measures include treatment status, the date and the time of participants' responses, image order and the size of the treated area. Subjective perception measures involved the declared perceptions of happiness, stress and safety for each image. Table A1 in the Appendices provides a detailed description of the measures used to assess these characteristics.



2.4. Empirical strategy

The main outcome of interest in this study is whether green interventions at the street-level result in improvements in participants' perceptions of the happiness, stress and safety associated with the sites in question. In the analysis, we use random intercepts models with fixed effects at the image level to explore this question. We include the random intercept to account for the fact that each respondent reports on their perceptions of 12 different images, and as a result, these reports are not independent of one another. We include the image fixed effects to control for each image's average SWB and safety ratings. The models take the following form:

$$\text{Perception}_{ij} = \beta_1 \text{Treatment}_i + \beta_2 \text{Image}_i + U_j + E_{ij} \quad (1)$$

where Perception_{ij} is the perception rating given on a scale of 1 to 10 to the i th photo by the j th individual. Treatment is a dummy variable equal to one if the i th image contains a green street intervention (after) and 0 otherwise (before). The coefficient of central interest to us is β_1 , the Average Treatment Effect, which captures the effect of green interventions on people's reports of the happiness, stress and safety they associate with the sites. Image_i is an image fixed effect for the i th image included to control for the fact that each image has different average SWB and safety ratings, reflected by β_2 . U_j is the random intercept associated with the j th individual, and E_{ij} is the error term. We report significance levels at the 5% and 1% while considering a 5% a reasonable threshold for the avoidance of Type 1 errors. We report the exact p-value in all cases where $p > .001$ (otherwise p is reported as $p < .001$).

In this study, we examine the impact of green interventions on people's perceptions in a number of different ways. First, we run Eq. (1) (EQ1) at an aggregate level to estimate the overall impact of the street-level interventions on people's perceptions. Following that, we run a second analysis which involves running EQ1 on the subsamples of different types of green interventions to examine their impacts separately. Lastly, we explore whether the larger scale green interventions included in the study have a greater impact on the outcomes of interest, compared to smaller scale ones. As the interventions and sites vary across the images, we cannot make claims about the causal impact of the scale of green interventions but this analysis does provide some suggestive evidence as to whether scale matters. For this analysis, we run EQ1 on the three subsamples which divide the total sample according to the size of the green intervention. Small, medium and large

Graph 1. The impact of all types of green interventions on perceptions of happiness, stress and safety Note: Each bar represents the mean of the perception in question for all before or after images. Capped spikes represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

size interventions corresponded to the addition of vegetation of simulated images covering 5%-9.9%, 10%-14.9% and 15%-20% of the total area of the picture.

2.5. Robustness tests

In the study, we examine robustness by incorporating the socio-demographic variables age, gender, student status, household size, nationality, subject of study, native language, employment status, as well as two measures relating to the study conditions beyond treatment status: the time of participant response and image order of appearance. We provide descriptive statistics for the socio-demographic controls in Table 1. The models including these controls take the following form:

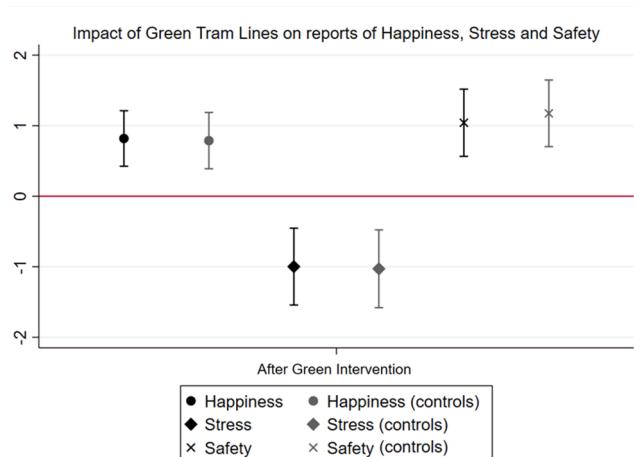
$$\text{Perception}_{ij} = \beta_1 \text{Treatment}_i + \beta_2 \text{Image}_i + \beta_3 X_{ij} U_j + E_{ij} \quad (2)$$

All variables are as in EQ1 except for the inclusion of X_{ij} which represents the sociodemographic variables and measures relating to the study conditions. β_3 reflects the associated regression coefficients. To test the robustness of the results produced by the analysis using EQ1, we re-run all versions of the models using Eq. (2).

3. Results

3.1. The impact of green interventions on perceptions of happiness and stress

First, we run EQ1 on the whole sample to explore how green interventions impact upon people's perceptions. Graph 1 displays the differences between people's perceptions of urban sites before and after green interventions, pooled across types of interventions. The results show that participants perceive streets with vegetation as happier and less stressful places. As columns 1, 3 and 5 in Table A2 (in the Appendices) show, the incorporation of vegetation significantly increases people's perceptions of happiness (estimate = 0.924, S.D. = 0.110, $p < .001$) and safety (estimate = 0.836, S.D. = 0.125, $p < .001$), while decreasing perceived stress (estimate = -0.836, S.D. = 0.125, $p < .001$). As columns 2, 4, and 6 in Table A2 indicate these results are robust to the addition of 13 controls. These results indicate that overall green interventions have a positive impact on people's perceptions of urban sites.



Graph 2. The impact of green tram lines on perceptions of happiness, stress and safety Note: Each point represents the estimated treatment effect of the green tram lines on the perception in question. Capped spikes represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. The impact of different types of green interventions on perceptions of happiness, stress and safety

In this section, we break the green interventions down into different types and explore their impact on people's perceptions. To do so, we run EQ1 on four subsamples representing the different types of green interventions depicted in Fig. 1; green tram lines, green pedestrian streets, green avenues and small green streets.

3.2.1. Green tram lines

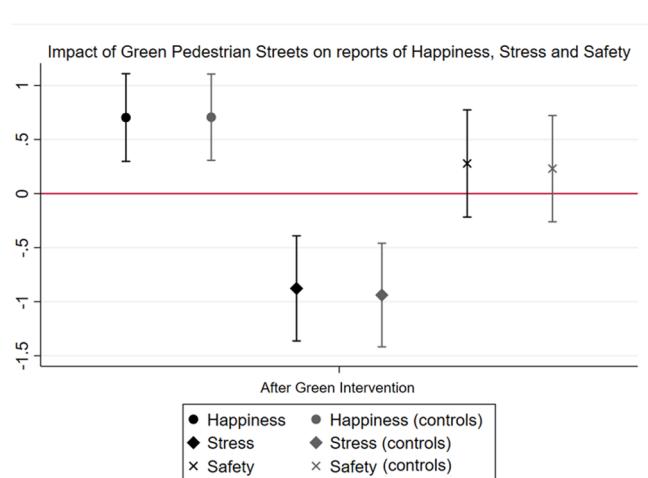
As Graph 2 shows, replacing cars with green tramlines increases the perceived levels of happiness and safety, while the decreasing stress levels associated with urban sites. As seen in columns 1, 3 and 5 in Table A3 (in the Appendices), green tram lines increase perceived happiness levels (estimate = 0.818, S.D. = 0.200, $p < .001$) and safety levels (estimate = 1.042, S.D. = 0.243, $p < .001$), while reducing perceived stress levels (estimate = -0.998, S.D. = 0.278, $p < .001$). As columns 2, 4, 6 in Table A3 show, incorporating socioeconomic and experimental condition controls does not substantively impact the estimates.

3.2.2. Green pedestrian streets

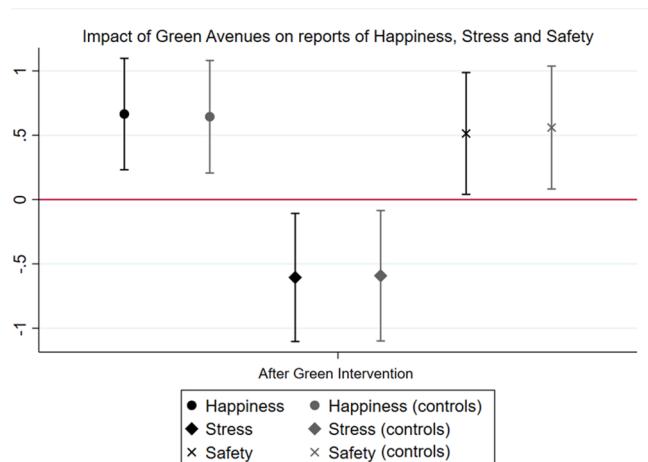
Graph 3 illustrates the differences between people's reported perceptions of streets before and after the incorporation of pedestrianized green space. As Table A4 (columns 1, 3 and 5) indicates the transformation of streets in a pedestrianized green space significantly increases the perceived level of happiness (estimate = 0.703, S.D. = 0.207, $p = .001$) and reduces the perceived levels of stress (estimate = -0.877, S.D. = 0.248, $p < .001$). We also find a positive, though statistically insignificant, increase in perceptions of safety (estimate = 0.279, S.D. = 0.253, $p = .271$). As columns 2, 4 and 6 in Table A4 indicates, these results remain stable with the addition of controls.

3.2.3. Green avenues

Graph 4 summarizes the impact of incorporating vegetation into avenues on perceptions of these urban sites. As seen in columns 1, 3 and 5 in Table A5 (in the Appendices), greening avenues significantly enhances the perceived happiness (estimate = 0.665, S.D. = 0.221, $p = .003$) and safety (estimate = 0.514, S.D. = 0.242, $p < .033$), and reduces the perceived stress (estimate = -0.606, S.D. = 0.254, $p = .017$) associated with the streets in question. The results are robust to the addition of the 13 controls.



Graph 3. The impact of green pedestrian streets on perceptions of happiness, stress and safety Note: Each point represents the estimated treatment effect of the green pedestrian street interventions on the perception in question. Capped spikes represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



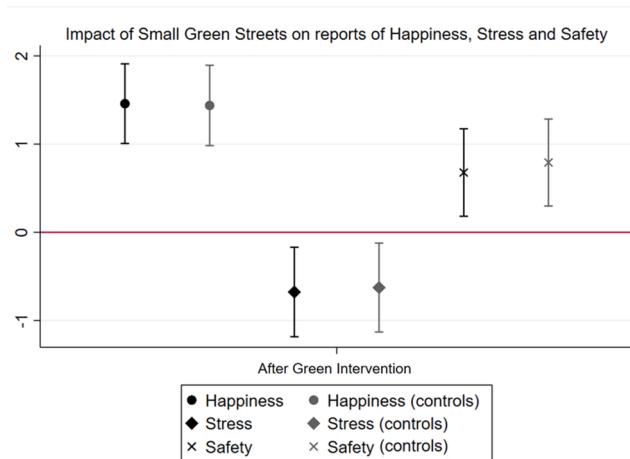
Graph 4. The impact of green avenues on perceptions of happiness, stress and safety Note: Each point represents the estimated treatment effect of greening avenues on the perception in question. Capped spikes represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2.4. Small green streets

Graph 5 indicates that there is a strong positive impact of incorporating vegetation into images of small local streets, particularly on happiness (estimate = 1.459, S.D. = 0.231, $p < .001$), perceptions of safety (estimate = 0.678, S.D. = 0.253, $p < .007$), and perceived stress levels (estimate = -0.677, S.D. = 0.259, $p < .009$) that people associate with the depicted sites. See Table A6 in the Appendices for more details. The estimate of the impact on perceived happiness and safety remains stable with the addition of controls, while for stress levels the significance threshold changes.

3.3. The effect of green interventions on perceptions of happiness, stress and safety by the scale of the intervention

In this section, we conduct exploratory analysis to examine the relationship between the scale of the green intervention and perceived levels of happiness, stress and safety associated with the sites. Graphs 6–8 present the coefficient plots for the three scales considered (small,



Graph 5. The impact of small green streets on perceptions of happiness, stress and safety Note: Each point represents the estimated treatment effect of incorporating vegetation into small green streets on the perception in question. Capped spikes represent 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

medium and large) on happiness, stress and safety respectively. While Graph 6 indicates that medium-scale green interventions have the greatest impact on perceptions of happiness, followed by large-scale interventions, none of the effect sizes are significantly different from one another. Graphs 7 and 8 indicate that the magnitude of the effect sizes on perceptions of stress and safety increases with the scale of the intervention (with the smallest scale interventions having the smallest impact and the largest scale interventions, the largest impact). However, as with perceptions of happiness, the differences across these scales in the context of stress and safety are not statistically significant. These results are robust to the addition of controls as shown in Tables A7–A9 in the Appendices.

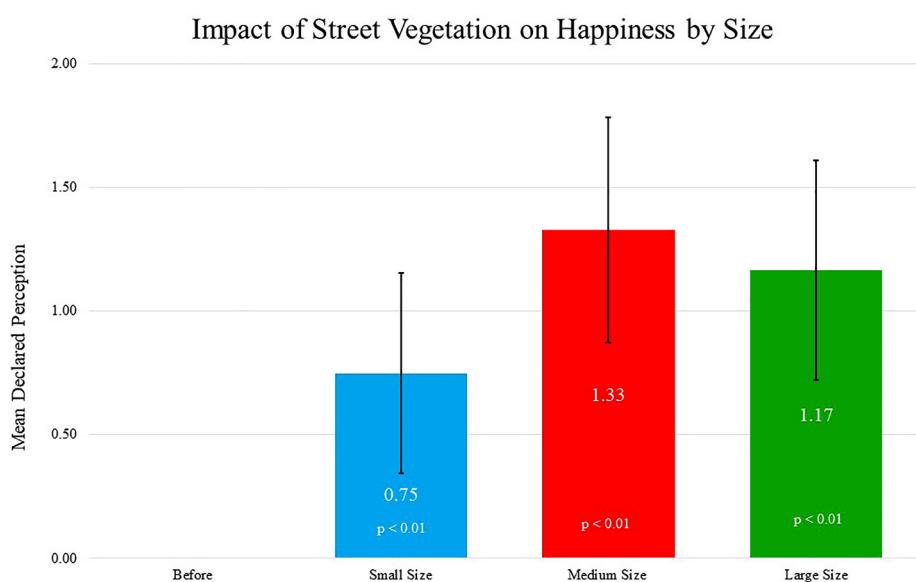
4. Discussion

In a study carried out at the 20th Biennale of Architecture and Urbanism in Chile, we tested an innovative new approach to exploring the impact of green infrastructure interventions on individuals' perceptions of urban sites. The central contribution of this work is that it

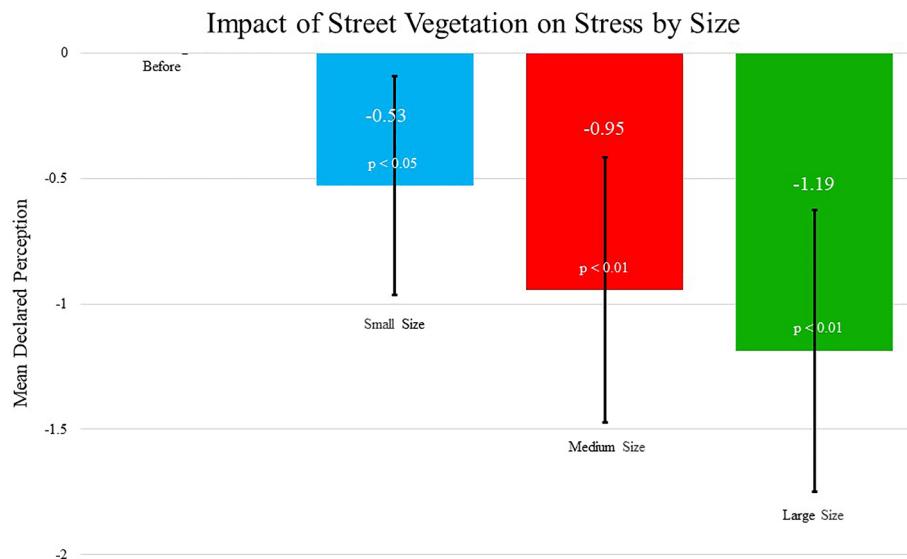
combines SWB measures with photo simulation to investigate the impact of small-scale street level greening of urban sites on the happiness and stress people associate with the images of the sites in question. In doing so, the work goes beyond the existing SWB-greenspace literature which has typically focused on the relationship between large-scale green spaces and the SWB of residents living in close proximity to them, as well as examining the impact of smaller scale green infrastructure on residents' levels satisfaction with their neighbourhood (Hur & Morrow-Jones, 2008; Krekel et al., 2016; Kweon et al., 2010; White et al., 2013). It also builds on the photo simulation work which has considered how green infrastructure impacts on people's preferences over and perceptions of the safety of urban sites (Jiang et al., 2017; Kuo et al., 1998). Bringing SWB measures together with photo simulation allows us to produce a priori evidence of the positive impacts of green interventions on people's wellbeing perceptions of urban sites.

Aggregating across a range of different types of green interventions, we find that individuals report higher levels of happiness and lower feelings of stress when exposed to simulated images which include street-level green interventions, compared to photos of the original sites. The percentage magnitude of the improvements in reports of both happiness and stress are similar. The results echo those of other work based on preference-based methods such as hedonic pricing strategies and willingness to pay studies, as well as research into neighbourhood satisfaction, which have produced evidence to suggest that small-scale green interventions are of value and can be effective strategies to create wellbeing benefits for people (Jim & Chen, 2006; Kweon et al., 2010; Mazzotta et al., 2014; Panduro & Veie, 2013).

In further analysis, we break the green interventions down by type and explore how the incorporation green tram lines, green pedestrian streets, green avenues, and small green streets impacts upon people's perceptions of urban sites. Differences in the impact of green interventions emerge from this analysis. While all types of green interventions have a positive impact according to the SWB metrics, the largest impact on perceived happiness levels is produced by the incorporation of vegetation in small streets, while the largest reduction of perceived stress is given by green tram lines. We also examine whether interventions of different scales have differing effects on people's SWB perceptions. In relation to happiness, and stress, the results suggest that scale may matter: the smallest scale interventions have the smallest impact across both these measures, but the differences across the scales are not statistically significant. In sum, the findings from the more fine-grained analysis demonstrate that not all green interventions are equal when it comes to their impact on people's SWB perceptions.



Graph 6. Exploring how the scale of the green interventions relates to their impact on perceived levels of happiness. Note: Each bar represents the difference in average reported perceptions of stress for before versus after green intervention images for the three different scales of intervention. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

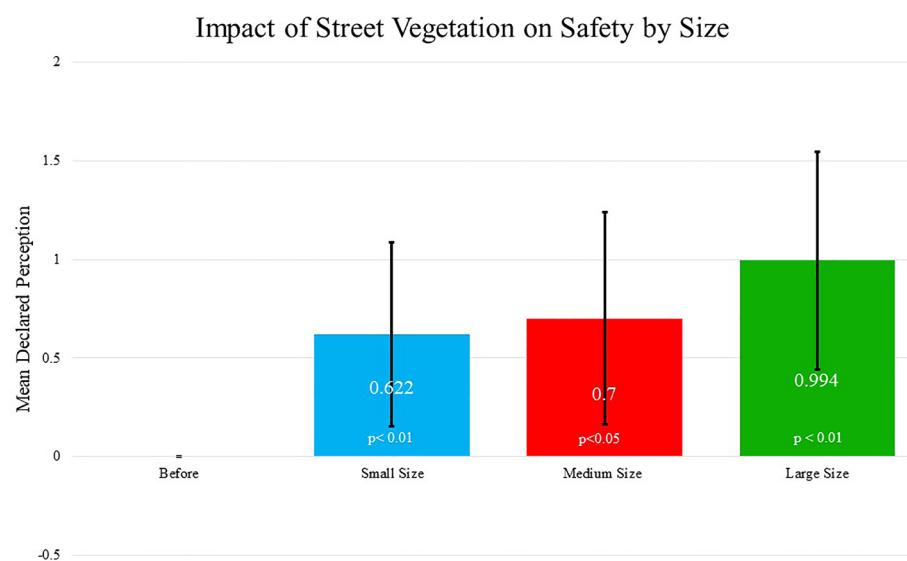


Graph 7. Exploring how the scale of the green interventions relates to their impact on perceived stress Note: Each bar represents the difference in average reported perceptions of stress for before versus after green intervention images for the three different scales of intervention. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

While SWB measures have not been traditionally used in the photo simulation literature that has looked to understand the impact of green interventions, existing work has considered the third outcome variable included in our analysis – people's perceptions of the safety of the sites in question. The incorporation of this outcome variable allows us to compare our SWB results to those found using this more common measure of individuals' perceptions. The comparison yields interesting results: although the SWB evidence indicates that all types of green interventions positively impact people's SWB perceptions of urban sites (enhancing perceptions of happiness and reducing perceptions of stress), the results relating to perceptions of safety are less consistent, with some interventions having a positive impact (e.g. green avenues) and some no impact (e.g. pedestrian green streets). Overall, and across all the different types of green interventions, bar green tram lines, the magnitude of the impact of green interventions on people's SWB reports is greater than the impact on their perceptions of safety. That the results differ significantly across the analyses of the SWB outcomes and the safety reports demonstrates that the SWB measures provide different insights to those offered by the existing literature which has mainly relied on perceptions of safety to examine the impact of green interventions on people's perceptions of urban sites.

The work is not without limitations, which highlight future directions for research. The current study's findings are limited to a convenience sample of attendees at the 20th Biennale of Architecture and Urbanism. This sample of respondents likely have a greater interest in urban planning and architecture than the general public and it cannot be assumed that the equivalent impacts would be found if the same study were carried out with other populations. There is no a priori reason to believe that effects would disappear or change direction in other samples, but future work should explore this further. Additionally, although 99.6 per cent of the sample were Chilean, the photographs used in the photo simulation technique were from urban sites in France. As a result, the sites were likely unknown to the participants. This has the positive impact of controlling for prior knowledge of the site but differs from how this technique would likely be used in real urban planning processes. Future work should investigate whether simulations of green interventions have different effects on people's perceptions of SWB when they have prior knowledge of the area, for example, if it is in their local area compared to a place that they have never been to.

Another important issue relating to the study is that there are two SWB outcomes variables involved in the main analysis. This issue is one that is more general to SWB research: there are outstanding questions in



Graph 8. Exploring how the scale of the green interventions relates to their impact on perceptions of safety Note: Each bar represents the difference in average reported perceptions of stress for before versus after green intervention images for the three different scales of intervention. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the literature as to whether SWB measures should be aggregated and if so what weighting should be given to each of the separate measures (Stone & Mackie, 2013). Although the results suggest that the green interventions explored have significant positive impacts on happiness and negative impacts on stress, it is possible that other urban interventions might increase perceptions of both happiness and stress. It is also possible that green interventions would have a negative impact on other aspects of SWB while benefiting people's happiness and stress perceptions. In order to explore these issues further, future work should look to include a wide range of theoretically-relevant SWB variables to explore the extent to which the impact of green interventions varies depending on the SWB measures under consideration.

Relatedly, the approach does not produce monetary values associated with the various interventions which can feed into cost-benefit analysis. In contrast, stated preference methods can be used to produce monetary estimates of the value that local residents place on a green infrastructure project based on how much they say they would be willing to pay for it. In future, photo simulation could be incorporated into willingness to pay studies to estimate the benefits of green interventions using the before and after technique used in the current work. If such an approach was developed, it would be interesting to examine the associations between willingness to pay reports and SWB perceptions to see which perceptions are most predictive of the monetary values people place on the green interventions under consideration.

Another limitation of this study relates to the fact that participants were only exposed to visual stimuli. Existing research indicates that combining street images with soundscapes can enhance the impact of nature simulations on people's wellbeing (Annerstedt et al., 2013). In line with this, future studies should include street background noise to further our understanding of how green interventions may shape people's perceptions of the wellbeing they associate with urban sites.

A final limitation of the study is that although this approach measures the impact of green interventions on people's perceptions, holding constant the contents of the images of the sites (e.g. number of people, cars, facades and lighting) outside of the intervention area, this technique cannot account for what is replaced by vegetation in the after images in the section of the image that includes the intervention. While it is important to recognise this as a limitation, it is also worth highlighting that the approach has external validity in that real green-interventions necessarily take up space that could otherwise be used differently, for example for parking or road space.

The approach detailed in this work has the potential to feed into green infrastructure policy-making processes. It could be adopted by urban planners when looking to make green infrastructure investments to compare the impact of a range of different green investments across different sites on perceptions of the SWB associated with the site. Importantly, this approach should be incorporated into integrative sustainability policies which look to promote social as well as ecological sustainability in urban communities, taking into account the risks of gentrification that greening urban spaces can pose (Mullenbach & Baker, 2018; Wolch et al., 2014). One way in which this approach could contribute to these efforts would be to carry out this exercise with local residents in order to ensure that the perceptions of those who will be exposed to the intervention are taken into account. This is of particular importance given that existing research indicates that perceptions of the social environment interact with perceptions of the physical environment (Ambrey, 2016; Chong et al., 2013; Fleming, Manning, & Ambrey, 2016). For example, Chong et al. (2013) found that the positive relationship between green space and

SWB wellbeing is reversed in deprived neighbourhoods where residents perceive the outdoor environment to be unsafe. The current technique could ensure that local voices are included in the planning process and that the important interactions between individual characteristics, the social environment and the physical environment are accounted for.

This technique could also be used by urban planners in ways which the current study does not directly speak to. For example, this approach could be used to test different green infrastructure project options for a single site. In this case, residents could be randomly presented with a range of different intervention options to establish which of them has the greatest positive impact on the residents' perceptions. This approach could also be used to explore the impact of other characteristics of green interventions which preference-based studies have identified as being important, such as whether the green space is protected or provides recreational amenities (Mazzotta et al., 2014) and to investigate the impact of physical changes to urban sites other than those involving green elements. The online platform built for this study — www.urban-experiment.com — could facilitate urban planners in carrying out these various forms of analysis.

5. Conclusion

In this study, we present a new approach to examining the impact of green interventions on people's perceptions of urban sites. The technique involves randomly presenting participants with photos of urban sites before or after the incorporation of a green intervention and eliciting participants' perceptions of the SWB they associate with the site. The study involved collecting over 5000 ratings of images from 240 attendees of the 20th Architecture and Urbanism Biennale in Chile in 2017, which were used to explore the impact of street-level green interventions on people's perceptions of happiness and stress. With a view to linking the findings to existing photo simulation work, people's perceptions of the safety of the sites under consideration were also collected. The results show that street-level green interventions have a positive impact on the feelings of happiness and stress people associate with urban sites and that the impacts vary by the type of green intervention. The results relating to these two SWB measures are substantively different from those produced from using measures of people's perceptions of safety.

SWB measures can be used in combination with photo simulation by urban planners looking to gain insights into the SWB impacts of various green infrastructure investment options across multiple sites. It can also be used to compare the different interventions options relating to a single site and the impact of other forms of infrastructure changes such as new commercial developments and public spaces. By placing people's SWB at the centre of infrastructure developments, the approach can feed into decisions about the greening of urban areas in order to maximise the benefits to people living in urban environments.

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Appendix

Table A1

Measures.

Variable	Definition
Treatment Status	Equals to 1 if the participant was rating an after-intervention image and equal to 0 if they were presented with a before image.
Happiness Level	Equals the happiness participants report associating with the image of the site on a 1 to 10 scale where 1 equals "completely unhappy" and 10 equals "completely happy".
Stress Level	Equals the stress participants report associating with the image of the site in question on a 1 to 10 scale where 1 equals "completely relaxed" and 10 equals "completely stressed".
Safety Level	Equals participants' perceptions of the safety of the image of the site in question on a 1 to 10 scale where 1 equals "completely unsafe" and 10 equals "completely safe".
Treatment Size:	Equals the number of pixels replaced in the after picture divided by the number of total pixels in a given image.
Hour of the test	Equals the time the participant started the experiment on a 24-hour scale.
The date	Equals the date the participant undertook the experiment.
Image order	Equals the order in which an image appears in the 12 image sequence.
Age	Equals the age in years a participant reports being on the day the experiment was conducted.
Gender	Equals 1 if the participant reported being a man and equal to 0 if the participant reported being a woman.
Student Status	Equals 1 if the participant was a student on the day the experiment was conducted and equal to 0 if the participant was not a student
Household Size	Equals the number of people, including the participant, living in the household on the day when the experiment was conducted
Nationality	Equals 1 if the participant declared to be Chilean and equals 0 if the participant is from another country
Subject of study	Equals 1 if the participant is studying or possess a degree in Art, Design, Architecture, or Landscape Architecture and equals 0 otherwise.
Educational level	Equals 1 if the participant had was studying or had obtained a bachelor, master or PhD degree on the day the experiment was conducted and equals 0 otherwise.
Native language	Equals 1 if the participant mother tongue is Spanish and equals 0 otherwise.
Employment status	Equals 1 if the participant was employed in a full or part-time job at the moment of undertaking the experiment and equals 0 if the participant was unemployed.

Table A2

The impact of all types of green interventions on perceptions of happiness, stress and safety.

VARIABLES	HAPPINESS		STRESS		SAFETY	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Interventions	0.924*** (0.110)	0.918*** (0.110)	-0.836*** (0.125)	-0.845*** (0.125)	0.677*** (0.125)	0.682*** (0.126)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	5.456*** (0.218)	-20.080 (33.85)	4.866*** (0.246)	-48.390 (69.70)	6.024*** (0.276)	43.800 (39.35)
Observations	958	958	959	959	953	941
Number of groups	80	80	80	80	82	81

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A3

The impact of green tram lines on perceptions of happiness, stress and safety Tram.

VARIABLES	HAPPINESS		STRESS		SAFETY	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Tram Lines	0.818*** (0.200)	0.788*** (0.203)	-0.998*** (0.278)	-1.029*** (0.281)	1.042*** (0.243)	1.175*** (0.241)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	4.924*** (0.225)	-79.230 (49.75)	5.537*** (0.278)	-68.130 (107.6)	5.195*** (0.304)	32.130 (62.22)
Observations	239	239	239	239	237	234
Number of groups	80	80	80	80	79	78

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A4

The impact of green pedestrian streets on perceptions of happiness, stress and safety.

VARIABLES	HAPPINESS		STRESS		SAFETY	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Pedestrian Streets	0.703*** (0.207)	0.706*** (0.204)	-0.877*** (0.248)	-0.938*** (0.244)	0.279 (0.253)	0.231 (0.251)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	6.051*** (0.228)	56.270 (42.84)	3.959*** (0.263)	-0.701 (88.99)	6.928*** (0.294)	50.060 (44.56)
Observations	240	240	240	240	243	240
Number of groups	80	80	80	80	82	81

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A5

The impact of green avenues on perceptions of happiness, stress and safety.

VARIABLES	HAPPINESS		STRESS		SAFETY	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Avenues	0.665*** (0.221)	0.644*** (0.223)	-0.606** (0.254)	-0.592** (0.259)	0.514** (0.242)	0.560** (0.244)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	5.605*** (0.254)	-81.650 (51.55)	4.748*** (0.266)	-94.800 (98.40)	6.114*** (0.294)	-9.426 (59.56)
Observations	240	240	240	240	237	234
Number of Individuals	80	80	80	80	79	78

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A6

The impact of small green streets on perceptions of happiness, stress and safety.

VARIABLES	HAPPINESS		STRESS		SAFETY	
	(1)	(2)	(3)	(4)	(5)	(6)
Small Green Streets	1.459*** (0.231)	1.438*** (0.232)	-0.677*** (0.259)	-0.627** (0.257)	0.678*** (0.253)	0.791*** (0.252)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	4.797*** (0.244)	-14.340 (47.46)	4.309*** (0.267)	-37.250 (92.55)	5.463*** (0.296)	48.440 (55.94)
Observations	239	239	240	240	236	233
Number of Individuals	80	80	80	80	79	78

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A7

Exploring how the scale of the green interventions relates to their impact on perceived levels of happiness.

VARIABLES	SMALL		MEDIUM		LARGE	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Interventions	0.748*** (0.207)	0.750*** (0.208)	1.328*** (0.232)	1.251*** (0.233)	1.165*** (0.227)	1.091*** (0.229)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	5.235*** (0.235)	-9.118 (37.75)	5.224*** (0.255)	-76.100* (45.07)	5.226*** (0.237)	-43.000 (40.51)
Observations	319	319	276	276	239	239
Number of groups	80	80	80	80	80	80

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A8

Exploring how the scale of the green interventions relates to their impact on perceived levels of stress.

VARIABLES	SMALL		MEDIUM		LARGE	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Interventions	-0.528** (0.222)	-0.845*** (0.125)	-0.945*** (0.270)	-0.969*** (0.273)	-1.187*** (0.287)	-1.212*** (0.287)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	3.802*** (0.255)	-48.390 (69.70)	4.922*** (0.283)	-101.000 (98.27)	4.436*** (0.294)	9.442 (96.02)
Observations	320	959	277	277	239	239
Number of groups	80	80	80	80	80	80

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Table A9

Exploring how the scale of the green interventions relates to their impact on perceptions of safety.

VARIABLES	SMALL		MEDIUM		LARGE	
	(1)	(2)	(3)	(4)	(5)	(6)
Green Interventions	0.622*** (0.238)	0.638*** (0.238)	0.700** (0.275)	0.701** (0.273)	0.994*** (0.282)	1.111*** (0.278)
CONTROLS	NO	YES	NO	YES	NO	YES
Constant	6.056*** (0.305)	33.560 (47.66)	6.046*** (0.294)	26.580 (47.14)	5.882*** (0.305)	76.980* (46.57)
Observations	315	311	271	267	240	237
Number of groups	79	78	80	79	82	81

Robust standard errors in parentheses.

**p < .05.

***p < .01.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2019.103618>.

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