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Research Paper

Green Enough? A dose-response curve of the impact of street greenery levels and types on perceived happiness

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HIGHLIGHTS

- We assess the impact of levels and types of street-greenery on people's perceptions of happiness.
- A photo-simulation experiment is proposed as a method.
- A positive and concave relationship exist between green coverage and perceived happiness.
- People report the highest levels of perceived happiness at 35% and 45% of green coverage.
- Vertical greenery is more effective to increase perceived happiness.

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ABSTRACT

Although research shows that individuals report higher levels of happiness when viewing green environments, the dose curve describing the impact of greenery on happiness remains undefined. Current literature only presents dose curves representing the associations between stress recovery and tree coverage, and does not explore how this fluctuates for different types of green infrastructure. Using an image-based randomised control trial with 401 participants, this study assesses the impact of levels and types of street greenery on people's perceptions of happiness. Participants were randomly assigned to rate one of six images representing proportional increments of street greenery coverage (from 0% to 45%) across three greenery configurations – ground level, between buildings, and vertical (on building façades). The results suggest that the highest levels of perceived happiness are obtained from green coverage of between 35% and 45%, at which point the effect levels off. Vertical greenery coverage has a larger impact on perceived happiness than the other two tested configurations, and has a positive linear rather than concave relationship. The study indicates that viewing greater amounts of greenery significantly enhances communities' perceived happiness, and shows that the relationship is dependent on the type of green infrastructure configuration used.

1. Introduction

Implementing greenery in urban areas, in an effort to enhance the wellbeing of all residents, is a primary concern for urban planners in towns and cities across the world. Green infrastructure is moreover commonly recognised as an important strategy to improve individuals' wellbeing, in terms of both physical and mental health. Furthermore, Bikomeye et al. (2021) propose that targeted green infrastructure investment in deprived urban areas has the potential to promote greater reductions in spatial racial inequalities, improve community resilience, combat climate change and promote health equity in cities. Indeed, research shows that green spaces make a significant contribution to improving urban water and air quality, regulating the urban climate and fostering biodiversity in cities (Li, Tam, Tai, & Lau, 2021; Threlfall, Williams, Hahs, & Livesley, 2016; Feng et al., 2023). Green infrastructure has also been shown to have a positive impact on citizens' physical and mental health. For instance, residents living close to green spaces have lower incidences of obesity (Lachowycz & Jones, 2011) and mortality (Van den Berg et al., 2015). However, as the world urbanises, people's access to and contact with nature becomes more restricted,

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particularly for those of lower socio-economic status and living in higher-density city areas (Rigolon, 2016, 2018; WHO, 2017).

An expanding body of literature demonstrates the impact of green infrastructure on emotional subjective wellbeing, and therefore on mental health (Maas et al., 2009; Du et al., 2021; Moreira et al., 2021; Nieuwenhuijsen, 2021; Wu et al., 2022). Residents of neighbourhoods lacking green spaces have higher levels of negative affects and moods, including increased fear of crime (Blöbaum & Hunecke, 2005; Ratnayake, 2013), anxiety, stress, and depression (De Vries et al. 2003; Van den Berg et al. 2010), and lower levels of perceived happiness and life satisfaction (Ambrey et al., 2014; Gómez-Ospina et al., 2024; Krekel et al., 2016; MacKerron & Mourato, 2013; White et al., 2013). Similarly, studies have also shown that exposure to green spaces may promote mental health and reduce the impact of stressful life events (McCormick, 2017; Astell-Burt & Feng, 2019).

These benefits for urban residents' wellbeing are at the heart of initiatives to increase access to greenery and develop a more egalitarian spatial distribution of green areas. The aforementioned body of studies has largely concentrated on large-scale green spaces, and has demonstrated their significant impact on emotional wellbeing (Ambrey et al., 2013; Hazer et al., 2018; White et al., 2013), however in more concrete terms, the implementation of these results has not been a simple process. Traditional large green infrastructure, such as squares, playing fields, parks, and other large open green spaces, requires significant availability of public land – land that is often not available where is most needed, in areas such as consolidated city centres, dense low-income neighbourhoods and informally urbanised neighbourhoods. Moreover, the larger the green infrastructure area, the more expensive land and maintenance costs become, often surpassing the budgetary capacities of municipalities (Picon Meleda et al., 2023). Thus the development of large-scale green infrastructure might not present a viable option for increasing citizens' emotional wellbeing in many urban areas, whether in the Global North or the Global South. Moving beyond these large green spaces, existing literature shows that disparities in access to green space extend also to smaller-scale green elements, such as street-level green coverage and back gardens (Gerrish & Watkins, 2018; Pedlowski, Da Silva, Adell, & Heynen, 2002). Micro-scale greenery strategies may therefore provide a low-land and low-cost strategy to reach these same goals (Navarrete-Hernandez & Laffan, 2019). Although recent research has shown the effectiveness of this small-scale greening strategy (Tzoulas et al., 2007), we still need to better understand the types and amounts of green coverage that are able to maximise gains for emotional wellbeing, while also minimising investment and maintenance costs to untap the potential for greening the single largest available public space: streets (UN-Habitat, 2013).

This study therefore evaluates the impact of different types and coverage levels of street-level greening on perceived happiness, while addressing some of the confounding factors of previous green infrastructure studies[1]. To do this, we performed an online image-based randomised controlled trial (RCT) in the city centre of Piacenza (northern Italy) in 2021, a dense urban area with low green-space provision and low land availability, and thus typical context for many city centres in Italy and Europe. A total of 401 participants stated their perceived happiness in response to street-level images simulating six levels of vegetation coverage (between 0 and 45 %), and three types of green infrastructure configuration: ground level; in between (i.e. between buildings); and vertical (i.e. on building façades). From the experimental data, we are able to produce reliable estimates of how perceived happiness varies with coverage levels and configuration types, and whether differences exist for relevant socio-economic covariates.[1]

The contributions of our paper are threefold. Firstly, we test the relationship between different amounts of street-level green coverage and perceived happiness in the public space. Secondly, we analyse whether this relationship is dependent on the types of green infrastructure configuration used. Finally, we explicitly analyse whether this impact is dependent on the attitudes or socio-economic and cultural characteristics of participants, adding intersectional evidence to our understanding of the wellbeing-green infrastructure relationship.

In the next section we review theory and evidence regarding the relationship between emotional wellbeing, green infrastructure and the built environment. We then present the methodology used in the experiment, and cover the main results found in the study. Finally, we discuss the results and consider their wider implications for urban policy.

2. Emotional wellbeing and the green environment

Wellbeing is a multifaceted concept that encompasses how people are doing in their life on material, social, health, and subjective level (Dolan & Metcalfe, 2012; Dolan, Peasgood, & White, 2008). Currently, there is debate revolving around whether we can best quantify wellbeing through objective or subjective measures (Estes & Sirgy, 2017). Objective wellbeing measures focus on tangible aspects linked to an individual's capacity to satisfy preferences – such as income – or their possession of objectively 'good' characteristics – such as high education or health. Instead, proponents of subjective wellbeing (henceforth referred to as SWB) state that wellbeing is a mental state relying on each individual's self perception. SWB is thus defined as an individual's own reports of their emotions, and of how they think about their lives. Metcalfe and Dolan (2012, p. 508) propose that public policies should be based on SWB impacts, as these provide a true measure of people's experiences (unlike an objective approach, which effectively uses proxies). Indeed, it is increasingly accepted that SWB should at the very least be incorporated as a relevant complement to traditional (i.e. objective) accounts of wellbeing (Helliwell & Barrington-Leigh, 2010). SWB itself is commonly further broken into two components: cognitive (or eudaemonic) and affective (or hedonic) SWB (Diener & Suh, 2003). Cognitive SWB is generally measured through reported personal satisfaction with distinct aspects of one's life (e.g. five-item questionnaires) on specific temporal bases (past, present, and future) (Margolis et al., 2018). Affective SWB, instead, reports on positive and/or negative emotions such as sadness, happiness, fear, or joy (Scherer, 2005).

Accordingly, a growing body of literature is moving beyond the perceived restrictions of objective preference-based measures of wellbeing, using SWB as a means of examining the benefits of green environments (Krefis et al., 2018). Measurements of SWB have gained prominence as a valuable source of public policy information used to determine the actions necessary to improve people's lives as they perceive them. This has been especially pronounced in the fields of economy and psychology, and now forms a common element of national statistical agencies' reports (e.g. in France, the UK, New Zealand, and Australia) (Stone & Mackie, 2013). Such information is used for guidance on non-market goods (like green spaces) through cost-benefit analysis (Fujiwara & Campbell, 2011). Within the methodologies used, one of the most common measurement strategies used is self-reports of happiness ((Su et al., 2022; Wren-Lewis, 2014; Rodogno, 2014; Weimann et al., 2015). Here, happiness is defined as a positive emotion associated with feeling good, enjoying life, and increased

[1] For example, unobservable variables such as an individual's personality traits might influence their perception of happiness in a public space. In contrast, an image-based RCT technique balances observable and unobservable covariables of individuals rating control and treatment images, making groups comparable.

wellbeing (Cooper & Layard, 2005). Happiness has been underlined as a particularly relevant emotion, as people tend to place a higher importance on it than they do on other relevant aspects of life, such as intelligence, success, and even health (Ballas, 2013; Smith & Reid, 2018).

2.1. Impact of green infrastructure on emotional wellbeing and happiness

Research has looked into the effects of green space on emotional wellbeing and subjective health, and has shown, for instance, that living in a greener environment is connected to higher levels of happiness and life satisfaction (Hazer et al., 2018; MacKerron & Mourato, 2013; White et al., 2013; Pfeiffer et al., 2020), as well as decreased levels of stress, depression and anxiety (Van den Berg et al., 2010; Van den Berg et al., 2015; Fong et al., 2018; Kondo et al., 2018; Kong et al., 2022; Lachowycz & Jones, 2011; Thompson et al., 2012). For instance, White et al. (2013), using longitudinal data of a representative sample of UK residents, show that individuals reported higher life satisfaction and lower mental distress when living in urban areas with a higher quantity of green spaces. Similar outcomes have been found in other locations, such urban areas of Germany, where presence of green spaces had a particularly large positive effect on older residents (Krekel et al., 2016). Positive results have also been found regarding the effect of green infrastructure in indoor spaces on mental wellbeing (Beukeboom et al., 2012; Larsen et al., 1998).

Among the literature, the impact of green spaces on stress levels is particularly well researched. Several studies have shown that the presence of green spaces is associated with lower perceived stressed as well as lower physiological expression (Hedblom et al., 2019; Jiang et al., 2016; 2014; (Laumann et al., 2003). This relationship with stress has also been explored by a series of laboratory experiments. Jiang et al. (2016), in an experiment involving video recordings of street foliage, showed a positive linear relationship between perceived stress and green coverage. Similar results were found by Jiang, et al. (2015)Jiang et al. (2015) when measuring the effect of tree coverage using panoramic photographs and satellite images, ultimately finding optimal stress reduction at green coverage levels of no less than 41 % when measured from panoramic views, and 20 % from satellite images. Furthermore, Jiang et al. (2014) found significant gendered differences: while women showed no relationship between green coverage and stress reduction, a U-shaped relationship was found for men, with significant reduction between around 2 % and 24 % coverage. Evidence has also shown that increases in green spaces are associated with reduced stress in disadvantaged urban populations, and that green space can function as a safeguard for stressful life events (Thompson et al., 2016; Van den Berg et al., 2010). This suggests that green spaces might play an important and specific social function of reducing stress for more vulnerable members of society in particular.

While this research does suggest that green spaces have a clear effect on emotions, and that there is a strong relationship between green coverage and stress, there exists less empirical evidence to provide guidance on exactly what levels or types of such infrastructure will maximise potential subjective wellbeing outcomes, and how these relate to positive emotions such as happiness. Kim et al., (2010), in an experiment using functional magnetic resonance imaging, showed that the presence of urban areas with low to no provision of green spaces activates the amygdala, a brain area associated with the negative emotions of fear and anger, while rural and natural landscapes activate the putamen, an area associated with positive emotions such as happiness. Navarrete-Hernandez and Laffan's (2019) study using photo simulations found correlational evidence of higher perceived happiness with increased street-level green infrastructure (across small, medium and large scales). These studies do provide a useful starting point, however a more fine-grained analysis of the exact types and levels of urban green infrastructure necessary to maximise positive wellbeing outcomes, such as happiness, has not been undertaken. Providing empirical evidence of this type is thus the central aim of this work here.

2.2. Photo simulation techniques

A photo simulation (PS) approach refers to the adaptation of photographs of a given location to change the visual environment in some way. PS relies on the widely recognised capability of images to trigger emotions, and has frequently been used to study the impact of different spatial interventions on people. These techniques have also found wide use in research in urban planning and environmental psychology (Jorgensen et al., 2002; Kuo et al. 1998; Navarrete-Hernandez & Afarin, 2023; Rodiek & Fried, 2005). For example, Sullivan and Lovell (2006) used PS to study residents' preferences regarding local commercial strips, changing elements such as car parks and nature coverage (trees and flowers), while Juncker and Buchecker (2008) used PS to explore the various impacts of river restoration on people. Along similar lines, Cerina et al. (2016) drew on PS to study the preferences of older adults for different architecture designs of residential facilities, and their feelings of broken home attachment.

Studies in environmental psychology have shown that viewing images or videos of green spaces can lead to physiological changes associated with the emotional activation of the parasympathetic autonomous system (Kreibig, 2010; Chirico et al., 2017), such as lower heart rates, decreased sweating, and hormonal changes including reduced cortisol levels (Hedblom et al., 2019; Yu et al., 2018). Further to this, and as mentioned earlier, Kim et al. (2010) were able to demonstrate the link between viewing urban and rural images and the activation of parts of the brain representing responses of fear and happiness respectively. There is therefore robust evidence demonstrating the capacity of images to evoke emotion, leading to a rising number of empirical urban studies of happiness using photography and PS techniques.

When considering research specifically related to green infrastructure, PS and videos have been used (Chang & Chen, 2005; Parsons et al., 1998; Ulrich et al., 1991) to explore the impact of the addition of green elements into physical environments on people's perceptions of these areas. In an early study, Kuo et al. (1998) used PS to examine the impact of various greening strategies on Chicago residents' preferences and sense of safety in their local area, finding that increased tree density and grass maintenance both positively impacted the outcomes in question. A more recent study by Jiang et al. (2017) used PS to investigate the impact of green interventions on people's perceptions of the safety of alleyways, and found that the use of geometric vegetation increased safety perception to a greater extent than naturalistic vegetation. Finally, Nejati et al.(2016) used PS to demonstrate how the addition of natural elements to break areas for hospital staff positively impacted the workers' perceptions of the restorative nature of these areas.

This body of literature demonstrates that PS techniques can inform our understanding of individuals' perceptions of, as well as their preferences for, particular sites. PS has been shown to effectively trigger emotional responses, and can produce insights which inform the design and maintenance of both indoor and outdoor green infrastructure. Therefore, in the present study, through careful manipulation of PS techniques in a randomised control trial setting, we are able to generate insights on the emotional changes elicited by differences in the amount and type of vegetation coverage in an area, and so can comparatively examine the benefits of different types of urban green interventions.

3. Methodology

3.1. Study design

To understand the impact of different levels of greenery on perceived happiness, we designed an experiment to compare participants' ratings of computer-simulated images of street spaces. For this, we used the online platform Urban Experiment (https://www.urban-experiment.com) to collect data from 401 participants, each of whom rated a series of three randomly assigned images according to how happy they

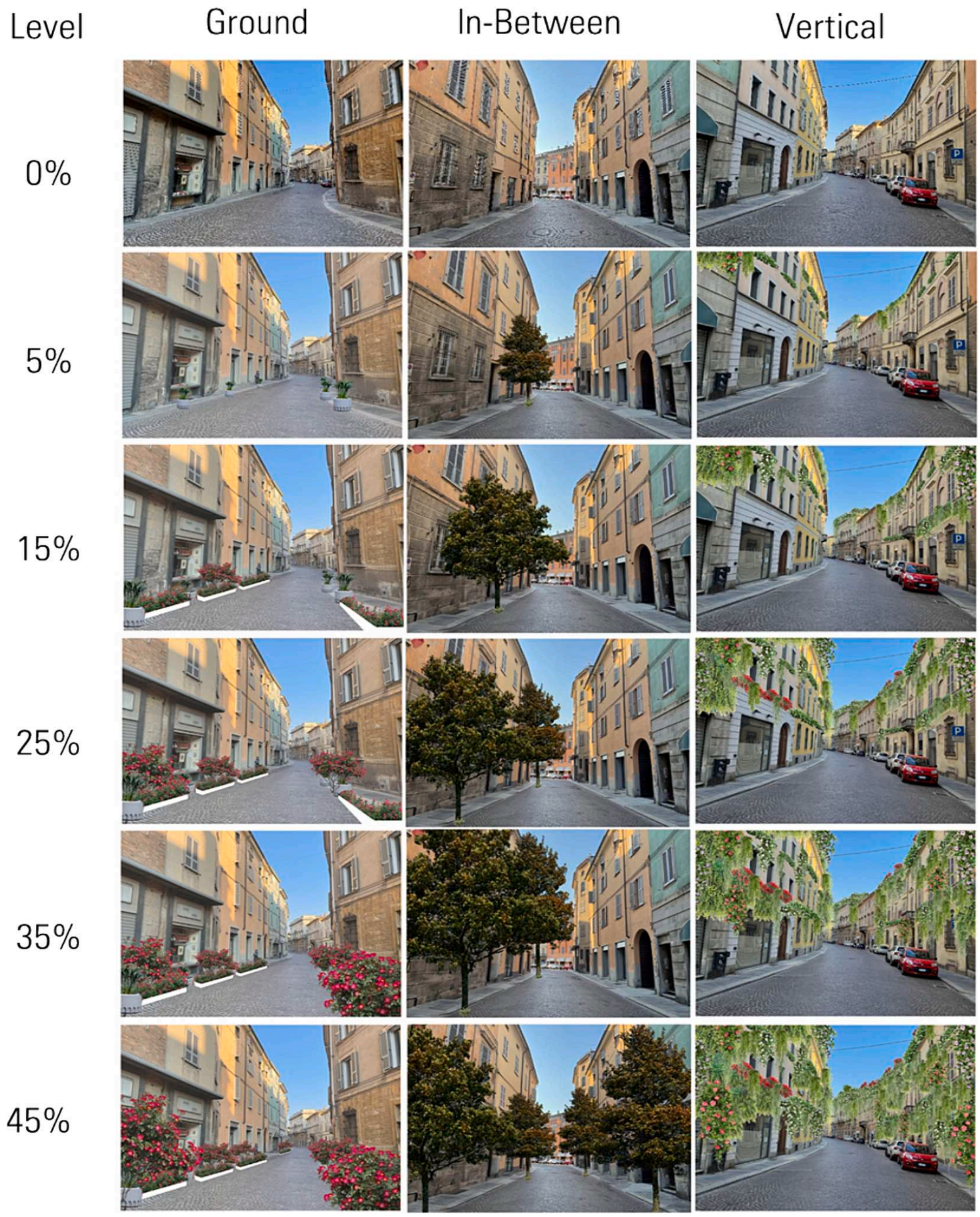

Fig. 1. Photographic simulations of green coverage.

would feel walking alone in the presented public space.

Three different typical types of street greenery were tested using the street images: 1) "ground level", representing low-height greenery interventions such as flower boxes and bushes; 2) "in between" greenery, mainly comprising greenery at height and covering the spaces between buildings using trees; and, 3) "vertical" greenery, interventions in which building walls were covered with flower pots or climbing plants (e.g. ivy). For each category, an image with no greenery was used as a baseline (control image with 0 % green coverage), on top of which digital editing was used to create photo simulations of five incremental increases in greenery (green coverage treatments at 5 %, 15 %, 25 %, 35 %, and 45 % levels). We set 45 % as the maximum limit for greenery coverage in order to maintain the perception of a realistic intervention. In total, we simulated eighteen images comparable in all elements, save for the different levels and types of greenery present (see Fig. 1).

To obtain comparable images for different greenery levels, the relevant background features of the baseline image were kept constant (few cars, no people, and sunny weather). To generate reasonably comparable baseline images across the three categories of greenery, we used photographs taken a short distance apart from one another along Garibaldi Avenue (Corso Garibaldi) in Piacenza (northern Italy) as baseline images. This street was selected as it contains no green coverage and maintains similar spatial configuration and building types along its length.

3.2. Sampling method

We collected data online using social media over the period June 19–25, 2021. Advertisements were posted on social media asking potential participants to take part in a five-minute experiment to measure

Table 1
Descriptive Statistics.

	Variable	N	Percentage	Min	Max
A. Gender				0	2
	Female	727	66.33 %		
	Male	369	33.67 %		
B. Age				≤30	>64
	≤30	764	69.71 %		
	31–40	155	14.14 %		
	41–50	118	10.77 %		
	51–64	44	4.01 %		
	>64	15	1.37 %		
C. Frequency of visiting a park or square				0	3
	At least once a week	540	49.27 %		
	Less than once a week	222	20.26 %		
	Once a month	163	14.87 %		
	Once every two weeks	171	15.60 %		
D. Allergic to plants or insects				0	1
	No	834	76.09 %		
	Yes	262	23.91 %		
E. Country/Continent				0	5
	Europe	616	56.36 %		
	Asia	235	21.50 %		
	Africa	69	6.31 %		
	North America	33	3.02 %		
	South America	144	12.81 %		
F. Live in urban/rural setting				0	2
	Rural	92	8.39 %		
	Urban	983	89.69 %		
	Other	21	1.92 %		
G. Type of Greenery					
	Ground	365	33.30%		
	In-Between	366	33.39%		
	Vertical	365	33.30%		
H. Response by green coverage %				0 %	45 %
	0 %	159	14.51 %		
	5 %	183	16.70 %		
	15 %	173	15.78 %		
	25 %	200	18.25 %		
	35 %	192	17.52 %		
	45 %	189	17.24 %		

their levels of happiness in different street spaces. Participants read and signed an informed consent form and then completed a registration questionnaire regarding their habits in using green spaces and their socio-demographic characteristics. They were then instructed to imagine themselves walking in the presented street and state their level of happiness on a scale from 1 (not at all happy) to 10 (extremely happy). This question was adapted from the Positive and Negative Affect Schedule (PANAS) – a standardised psychometric scale with robust validity and reliability – as a proxy to capture positive hedonic sentiments in the presented street spaces. Each participant saw the images in full-screen and rated three randomly allocated images using their preferred personal device.

We selected this online experimental approach for two reasons. First, for its feasibility, since local COVID-19 restrictions at the time prevented in-the-field data collection, and moreover many participants in this context would likely be reluctant to touch screens due to concerns around infection. Second, we wanted to capture people's responses to greenery across different geographies to enable us to analyse whether culture can play a role in shaping perceptions – an objective that, given our resources, was attainable through online participation.

We used an automated, dual-randomisation process to ensure that participants' covariates were balanced among control and treatment groups. First, we randomised the order of appearance of each intervention category (ground, in-between, or vertical). This allowed us to avoid bias from the potential spillover of participants' ratings from one image to the next. Second, for each type of green intervention, we selected only one image (of a randomised coverage level) to be rated by each participant. In doing so, we were able to balance the covariates of participants that rated images across each of the six levels of intervention (Navarrete-Hernandez & Zegras, 2023). To test the success of our randomisation strategy, we ran balance tests for each level and type of intervention to observe whether any systematic differences existed between the baseline image and altered images for participant covariates. Across 60 tests, only one was significant at the 5 % level, reflecting successful randomisation (balance test tables available on request).

3.3. Data set

In our analysis, three sources of data were used: 1) participants' socio-demographic and personal characteristics; 2) experimental condition measurements; and 3) participants' perceptions of happiness. The first of these corresponds to participants' gender identity, age,[2] country of residence, typical frequency of visiting public parks, presence of allergies to insects, pollen or plants, and whether the participant lives in a rural or urban area. Experimental conditions correspond to the ID of each image, treatment status, order of appearance, and the test date. The participants' declared perception of happiness is the dependent variable in the study, corresponding to a number from 1 to 10 for each image. Descriptive statistics are presented in Table 1.

3.4. Empirical strategy

To conduct our analysis, we run random intercept models with fixed effects at the image and country level. Random intercepts are used to account for the fact that each individual might have a different starting level of happiness. We then include fixed effects to control for each image's average happiness rating, the order of appearance of each image, and cultural distinctions between countries. The models then take the following form:

$$Happiness_{ij} = \beta_1 GreenLevel_i + \beta_2 X_i + U_j + E_{ij} \quad (1)$$

where $Happiness_{ij}$ is the declared perception of happiness of participant j for image i. $GreenLevel$ is a categorical variable from one to five if the ith image contains a green space intervention (treatment) and 0 otherwise (control). β_1 is the coefficient of interest that captures the impact of the green intervention on participants' reported happiness. X_i is the fixed effects of image ID, order of appearance, and respondent country for the ith image rated. U_j is the random intercept associated with the jth individual. E_{ij} is the error term.

We analyse the effect of greening streets in the following ways. First, we run Eq. (1) at an aggregate level to estimate the overall impact of different levels of green space coverage on participants' perceived happiness. We then run Eq. (1) on the three green space types to test the impact of each intervention option. Finally, we run Eq. (1) on socio-

[2] *As described in Table A1 in the Appendix, we collected gender identity based on three categories: male, female and other. In our sample, however, no participant self-identified in the other gender category.*

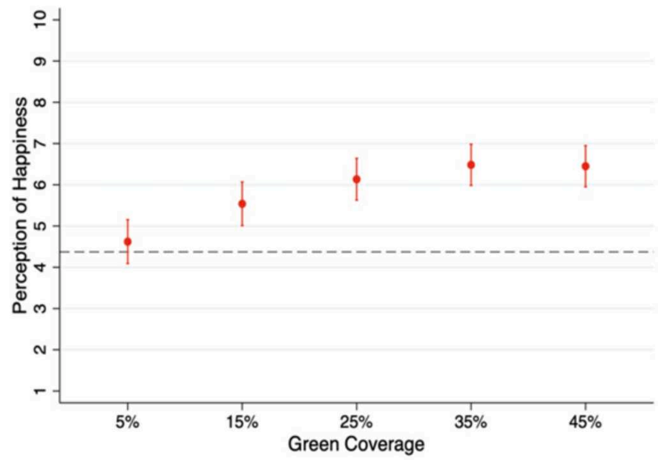

Fig. 2. Impact of Green Interventions on Perceived Happiness by Level of Greenery (All Interventions). Note: Each point represents the average treatment effect compared with images with no interventions. Capped spikes represent 95 % confidence intervals. *** p < 0.01, ** p < 0.05, * p < 0.1, n.s. not significant.

demographic data to understand how happiness perceptions vary across different participant characteristics.

3.5. Robustness checks

We conduct a robustness analysis of results by running Eq. (1) with and without control variables (Eq. (2)). Control variables correspond to all socio-demographic characteristics (variables A to F in Table 1) and the time and day of the response. The objective of this is to examine the RCT hypothesis that, with the random assignment of control and treatment conditions, changes in perceived happiness can only be attributed to the photo-simulations. Therefore, we expect that including relevant observable control variables should not significantly alter the estimates. The model follows the form:

$$Perception_{ij} = \beta_1 Treatment_i + \beta_2 \mathrm{Image}_i + \beta_3 X_{ij} + U_j + E_{ij} \quad (2)$$

This is the same as Eq. (1) with the addition of X_{ij}, which contains the socio-demographic variables for participant j and response condition measures for image i.

4. Results

Here, we present the results of the three analyses performed, with the aim of understanding: 1) how levels of green coverage affect perceived happiness; 2) which of the three explored green infrastructure configurations is most effective at increasing perceived happiness; and 3) which participant background characteristics, if any, are relevant in defining the relationship between perceived happiness and green coverage.

4.1. General findings for all participants

4.1.1. How does green coverage affect perceived happiness?

Fig. 2 describes the impact of different levels of green coverage on perceived happiness for all three types of greenery taken together. Overall, from levels of 15 % green coverage and up, participants' perceived happiness significantly increases, with the impact stabilising at around 35 % coverage. As shown in Table A2 (see Appendix), when compared to 0 % green coverage, 35 % coverage increases perceived

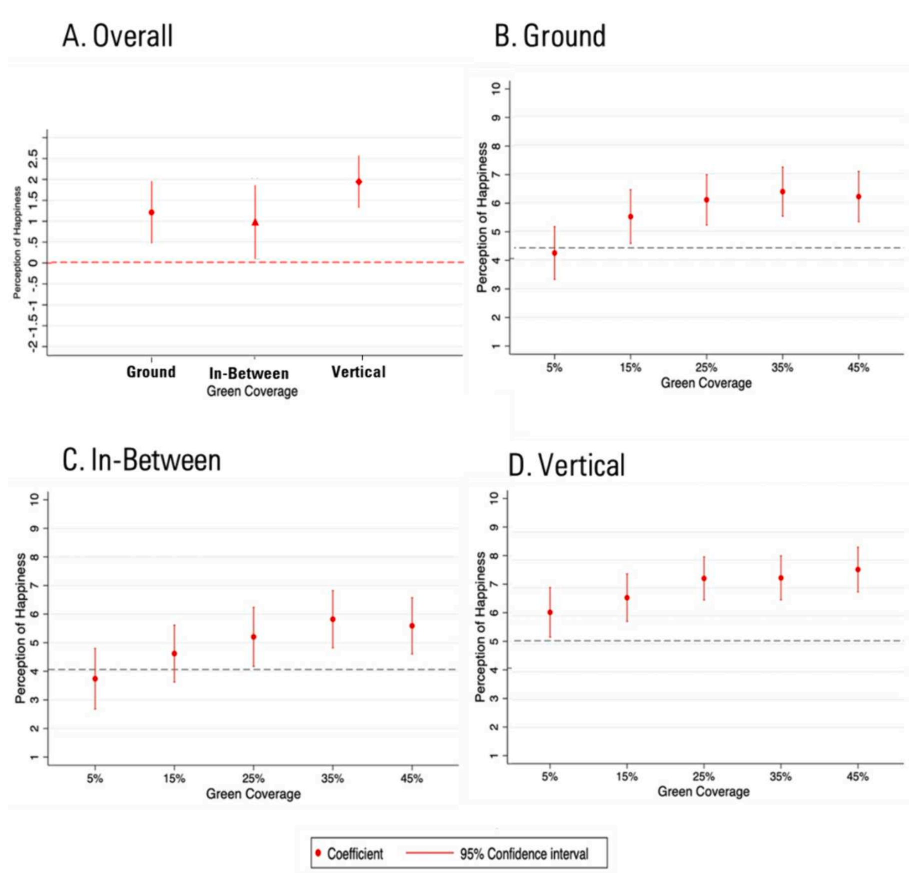

Fig. 3. Impact of Green Interventions on Perceived Happiness by Intervention Type. Note: Each point represents the average treatment effect compared with images with no interventions. Capped spikes represent 95 % confidence intervals. *** p < 0.01, ** p < 0.05, * p < 0.1, n.s. not significant.

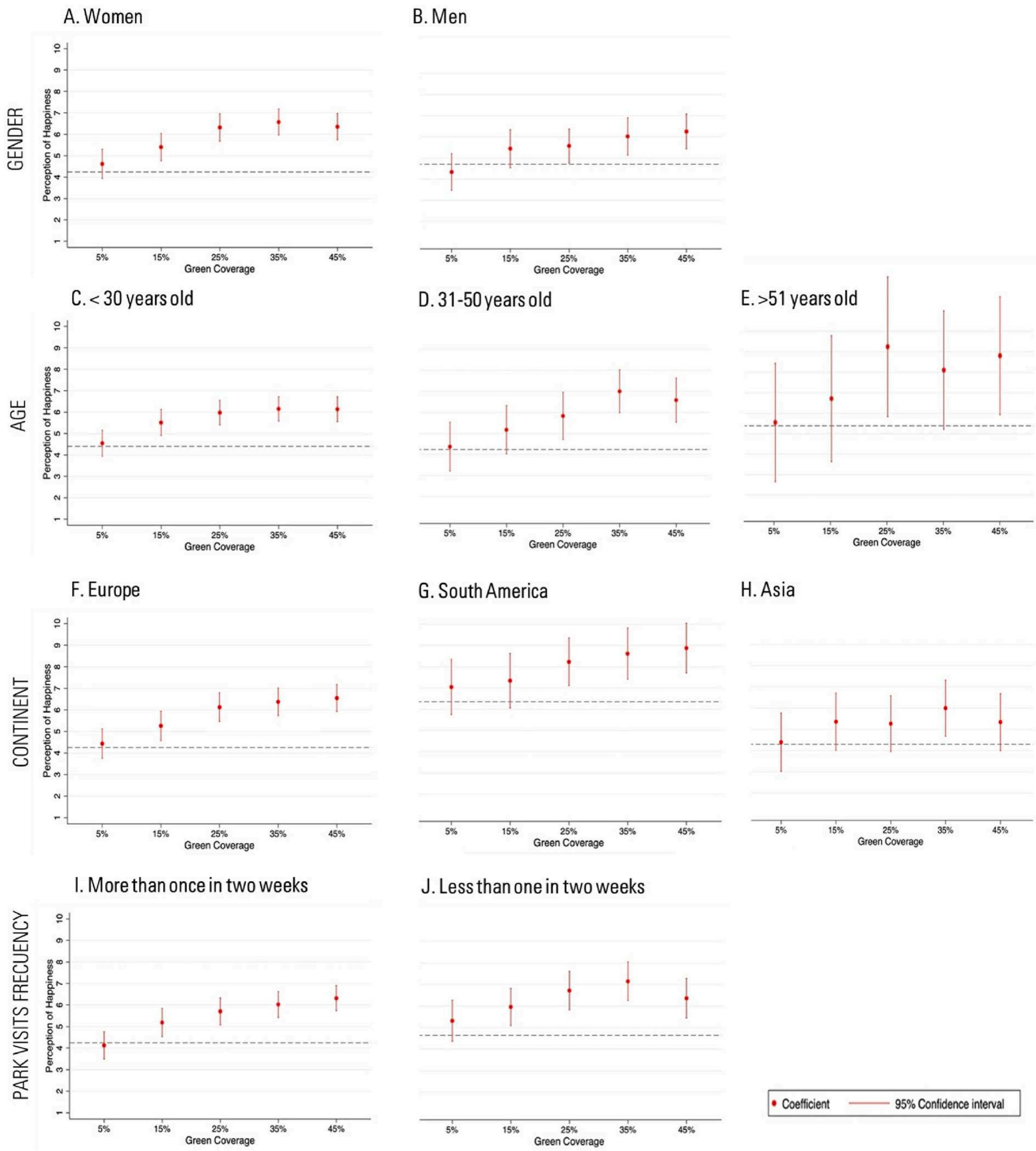

Fig. 4. Impact of Green Interventions on Perceived Happiness by Demographics and Behaviour. Note: Regression results are plotted with and without controls. Each point represents the average treatment effect compared with images with no interventions. Capped spikes represent 95 % confidence intervals. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, n.s not significant.

happiness by around 48.28 % (estimate = 2.12, S.D. = 0.25, $p < 0.01$). Column 2 shows that these results are robust to the addition of controls.

4.1.2. Which greenery intervention type is most effective for enhancing perceived happiness?

The results show that each of the three types of intervention taken alone increases participants' perceived happiness. In Fig. 3 (panel A), for each intervention type, all levels of greenery coverage (from 5 % to 45 %) are combined, allowing us to compare the effectiveness by intervention. Table A3 (see Appendix) indicates that the vertical greenery interventions (estimate = 1.94, S.D. = 0.31, p = 0.001) produce the largest change, followed by ground-level greenery (estimate = 1.21, S.D. = 0.37, $p < 0.001$) and finally in-between greenery coverage (estimate = 0.98, S.D. = 0.45, p = 0.030).

Fig. 3 (panels B through D) illustrates the relationship between levels of green coverage and perceived happiness for each of three intervention types. Table A4 (columns 1, 3, and 5; see Appendix) shows that this relationship follows a similar pattern, where regardless of the type of coverage, increases in greenery yield higher perceived happiness. However, some nuances do exist. For ground-level interventions, significant increases in perceived happiness start at 15 % green coverage (estimate = -1.09, S.D. = 0.48, p = 0.024) and peak at 35 % (estimate = 1.96, S.D. = 0.44, $p < 0.001$). Similarly, for 'in-between' interventions, significant increases begin at 25 % green coverage (estimate = 1.14, S.D. = 0.53, p = 0.048), and also peak at 35 % (estimate = 1.76, S.D. = 0.51, p = 0.001). The results then suggest a concave relationship for

Table A1
Description of Variables.

Variable	Definition
Score	Continuous variable showing a respondent's rating of perceived happiness when viewing the image on a scale of 1–10.
Green infrastructure configurations	Categorical variable representing green infrastructure interventions with: 1 – "ground-level greenery"; 2 – "in-between greenery"; and 3 – "vertical greenery".
Response by green coverage %	Categorical variable indicating 5 incremental levels of percentage of greenery in the simulated image: 0 % for 0 % green coverage, 5 % for 5 % green coverage, 15 % for 15 % green coverage, 25 % for 25 % green coverage, 35 % for 35 % green coverage and 45 % for 45 % green coverage.
Question	Introduction states: "Imagine you are walking in the presented street." The question is a categorical variable where 0 equals the question "How happy do you feel in this public space?" on a scale of 1 "not at all happy" to 10 "extremely happy".
Gender	Categorical variable where a respondent is identified as either 0 "female", 1 "male", or 2 "other".
Age	Categorical variable showing the respondent's age group in years when the experiment was conducted, with 0 = "≤30″, 1 = "31-50″, or 2 = ">50″.
Frequency of visiting a park or square	Categorical variable showing how often the respondent visit a green public space, where 0 is "At least once a week", 1 is "Less than once a month", 2 is "Once a month", and 3 is "Once every two weeks".
Allergic to plants or insects	Categorical variable indicating if a person has any plant or insect allergies as 0 "No"or 1 "Yes".
Country/Continent	Categorical variable indicating if a respondent is currently lives in 0 "Europe", 1 "Asia", 2 "America" or 3 "Other".
Living in urban/rural setting	Categorical variable indicating if a respondent currently lives in 0 "Rural area", 1 "Urban area"or 2 "Other".

Table A2
Impact of Happiness Enhancement Interventions with Different Green Coverages (All Interventions).

		How Often Do You Visit a Public Park			
		More than once in two week		Less than once in two week	
VARIABLES		1	2	3	4
Baseline (0 % Greenery)					
	5 %	−0.12	−0.11	0.68	0.65
		(0.32)	(0.32)	(0.49)	(0.49)
	15 %	0.94***	0.99***	1.32***	1.36***
		(0.33)	(0.34)	(0.44)	(0.45)
	25 %	1.46***	1.54***	2.08***	2.08***
		(0.32)	(0.32)	(0.46)	(0.44)
	35 %	1.78***	1.86***	2.51***	2.56***
		(0.30)	(0.31)	(0.46)	(0.45)
	45 %	2.07***	2.13***	1.72***	1.70***
		(0.30)	(0.30)	(0.47)	(0.48)
Controls		No	Yes	No	Yes
Constant		4.25***	4.55***	4.64***	4.01***
		(0.39)	(0.52)	(0.63)	(0.71)
Observations		708	708	385	385
R-squared		0.13	0.17	0.17	0.22

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

these two intervention types, reaching a maximum perceived happiness at 35 % green coverage. For the case of vertical greenery, significant increases in happiness begin at just 5 % coverage (estimate = 1.02, S.D. = 0.45, p = 0.032), however at the 45 % level (estimate = 2.55, S.D. = 0.41, p < 0.001) we continue to see an upward trend. This shows a positive linear relationship, raising the possibility that the optimal point coverage could be even higher. As shown in columns 2, 4 and 6 in Table A4 (see Appendix), these results remain stable with the addition of controls. Overall, the stronger impact and positive linear relationship suggest that vertical greenery may have a stronger impact on perceived happiness than greenery located at ground level and between buildings.

4.2. General findings for socioeconomic characteristics

The following subsection analyses how participants' socioeconomic characteristics and attitudes affect the relationship between green coverage and perceived happiness. Here, we concentrate on four factors: gender, age, location (by continent, as a broad proxy for cultural differences) and frequency of visiting parks (as a proxy for regular contact with nature in an urban setting).

4.2.1. How do gender differences affect perceived happiness?

Fig. 4 (panels A and B) shows changes in perceived happiness by gender at different levels of greenery coverage. The results for women follow a concave relationship, with perceived happiness significantly increasing from 15 % coverage and peaking at 35 % (estimate = 2.33, S.D. = 0.31, p < 0.001). For male participants, this growth of perceived happiness has a smaller overall effect, but follows a more linear trajectory, with significant effects beginning only at 25 % green coverage but reaching a peak at 45 % coverage (estimate = 1.55, S.D. = 0.42, p < 0.001). Overall, the general finding is that green street coverage increases perceived happiness for both genders, but has a larger effect for female than for male participants (Table A5, columns 1 and 3; see Appendix).

4.2.2. How do age differences affect perceived happiness?

Fig. 4 (panels C to E) illustrates the results by three age groups: participants aged 30 and under, participants aged 31 to 50 years, and participants over 50. For the two lower age brackets, the relationship has a similar concave trend: higher levels of green coverage significantly increase perceived happiness, with a peak at 35 % (estimate [<31] = 1.75, S.D. = 0.29, p < 0.001; estimate [31–50] = 2.77, S.D. = 0.52, p < 0.001). For participants over 50 years of age, green coverage significantly increases perceived happiness from 25 % coverage (estimate = 3.87, S.D. = 1.74, p = 0.049) and seems to follow a similar concave pattern, though this is less clear given the large standard errors resulting from having fewer overall participants in this category. Overall, the results suggest that the effect of green coverage follows a similar concave pattern across all ages (Table A6, columns 1, 3 and 5; see Appendix).

4.2.3. How do different locations and cultures affect perceived happiness?

Fig. 4 (panels F to H) shows how participant location (divided by continent into Europe, Asia, and South America) affects the results (Table A7, columns 1, 3 and 5; see Appendix). Our analysis shows that participants residing in Europe and South America show a positive linear relationship of increasing perceived happiness, peaking at around 45 % (estimate [Europe] = 2.29, S.D. = 0.32, p < 0.001; estimate [South America] = 2.53, S.D. = 0.60, p < 0.001). For residents in Asia, the relationship is less clear, with the results showing an overall positive effect but obtaining only a significant increase in perceived happiness at 35 % coverage (estimate = 1.70, S.D. = 0.68, p = 0.020). Overall, these results suggest that, while green coverage does increase perceived happiness regardless of location, cultural differences might impact the magnitude and shape of this effect. This therefore is an essential consideration when planning green infrastructure developments across different geographies.

4.2.4. How does the frequency of visits to parks affect perceived happiness?

Fig. 4 (panels I and J) shows the results according to how often

Table A3
Impact of Happiness Enhancement by Intervention Types.

	Ground		In Between		Vertical	
VARIABLES	1	2	3	4	5	6
GreenIntervention	1.21***	1.18***	0.98**	0.86*	1.94***	1.96***
	(0.37)	(0.38)	(0.45)	(0.45)	(0.31)	(0.32)
Controls	No	Yes	No	Yes	No	Yes
Constant	4.26***	4.32***	4.06***	3.50***	5.27***	5.42***
	(0.58)	(0.70)	(0.63)	(0.80)	(0.49)	(0.63)
Observations	364	364	365	365	364	364
R-squared	0.09	0.10	0.07	0.09	0.11	0.13

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A4
Impact of Happiness Enhancement Interventions with Different Green Coverages (By Intervention Types).

		Ground		In Between		Vertical	
VARIABLES		1	2	3	4	5	6
Baseline (0 % Greenery)							
	5 %	−0.18	−0.25	−0.32	−0.46	1.02**	0.97**
		(0.47)	(0.47)	(0.54)	(0.54)	(0.45)	(0.45)
	15 %	1.09**	1.09**	0.56	0.43	1.54***	1.57***
		(0.48)	(0.49)	(0.51)	(0.51)	(0.43)	(0.44)
	25 %	1.67***	1.63***	1.14**	1.05**	2.23***	2.33***
		(0.45)	(0.45)	(0.53)	(0.53)	(0.39)	(0.41)
	35 %	1.96***	1.90***	1.76***	1.67***	2.25***	2.29***
		(0.44)	(0.44)	(0.51)	(0.51)	(0.40)	(0.41)
	45 %	1.78***	1.80***	1.53***	1.39***	2.55***	2.58***
		(0.45)	(0.46)	(0.50)	(0.51)	(0.41)	(0.42)
Controls		No	Yes	No	Yes	No	Yes
Constant		4.42***	4.33***	4.06***	3.45***	5.11***	5.42***
		(0.58)	(0.68)	(0.64)	(0.81)	(0.49)	(0.64)
Observations		364	364	365	365	364	364
R-squared		0.17	0.18	0.15	0.17	0.16	0.18

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

participants visit a public park, divided into high-frequency (more than once every two weeks) and low-frequency (less than once every two weeks) visitors (Table A8, columns 1 and 3, see Appendix). We use this as a proxy to account for personal preferences for green urban spaces, reflected through concrete individual behaviour. The results for both types of participants show that significant increases of perceived happiness occur with at least 15 % of green coverage. The low-frequency park visitors follow a concave positive relationship, reaching a maximum perceived happiness at 35 % coverage (estimate = 2.51, S.D. = 0.46, $p < 0.001$). In contrast, for high-frequency visitors, the results show a linear relationship, reaching a peak at 45 % (estimate = 2.07, S. D. = 0.30, $p < 0.001$), which again suggests that for this group optimal levels of street greenery might lie beyond this point.

5. Discussion and conclusion

Our study explores the relationship between street-level green infrastructure coverage and perceived happiness, working at different scales and with different typologies. While previous studies have established differing impacts on subjective wellbeing for urban versus natural environments (McMahan & Estes, 2015), this work contributes to the growing body of literature interested in a similar effect as it occurs within urban settings (Feng & Astell-Burt, 2018; Navarrete-Hernandez & Laffan, 2019; Zhu et al., 2021; Abdul Aziz et al., 2021; Ta et al., 2021). One of our primary contributions here is to show that changes in the greenery-happiness relationship are always positive, but that the details of this relationship and optimal greenery levels vary with the type of infrastructure developed and the personal characteristics of those exposed to it. In doing so, this work expands on the existing literature, which has commonly focused only on large-scale greenery (Kweon et al., 2010; White et al., 2013) and on measures of stress (Campagnaro et al., 2020; Jones et al., 2021; Maury-Mora et al., 2022), helping us to understand more precisely the impact of street-level nature on happiness and, therefore, subjective wellbeing.

By gradually increasing the coverage levels of different types of green interventions, we found that people report higher levels of happiness when exposed to levels of between 15 % and 35 % green coverage in photo simulations. These results align with Navarrete-Hernandez and Laffan's (2019) work, which indicates that small-scale greenery positively correlates with perceived happiness. Our study, moving beyond this, is able to provide evidence on the impact of different levels and types of street-level green infrastructure on perceived happiness, and adds intersectional considerations to this relationship.

Our analysis separated green interventions into three main categories: ground level, between buildings, and vertical. We found a

Table A5
Impact of Happiness Enhancement Interventions with Different Green Coverages (By Gender Difference).

		What is Your Gender			
		Female		Male	
VARIABLES		1	2	3	4
Baseline (0 % Greenery)					
	5 %	0.38	0.40	−0.37	−0.28
		(0.35)	(0.35)	(0.44)	(0.43)
	15 %	1.16***	1.30***	0.73	0.81*
		(0.33)	(0.33)	(0.46)	(0.46)
	25 %	2.08***	2.18***	0.86**	0.92**
		(0.33)	(0.33)	(0.41)	(0.41)
	35 %	2.33***	2.40***	1.31***	1.41***
		(0.31)	(0.31)	(0.45)	(0.46)
	45 %	2.12***	2.20***	1.55***	1.64***
		(0.32)	(0.32)	(0.42)	(0.43)
Controls		No	Yes	No	Yes
Constant		4.24***	4.37***	4.71***	3.88***
		(0.44)	(0.55)	(0.48)	(0.59)
Observations		727	727	366	366
R-squared		0.14	0.17	0.19	0.21

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

difference in the impact on perceived happiness amongst these categories, showing that vertical green interventions were the most effective intervention type to increase perceived happiness, suggesting that the type of green interventions that we incorporate into cities is an important consideration. We went further to find some evidence that these impacts vary across sociodemographics, with the exact shape and particulars of the greenery-happiness relationship being influenced by gender, culture and preference for nature. This presents us with the hypothesis that street-level green interventions may indeed work across different geographies, but should be fine-tuned to each context. Furthermore, the analysis techniques that we have presented here might be able to provide practical support to urban planners working across diverse geographies to fine-tune street-level infrastructure to maximise the happiness of their target population.

The study is not without limitations, which indeed present opportunities for further experimental research. First, the sample size includes participants only belonging to binary genders. As a result, we cannot draw any conclusions around the impact of greenery types and amounts for the wide variety of gender identities, which might be different to those presented. Further studies could continue to explore the non-binary interaction of street greenery and perceived happiness.

Although we do comply with the three causality conditions of temporal precedence (the green infrastructure treatment precedes changes in happiness perception), covariance (changes in greening levels relate to changes in happiness perceptions), and ruling out alternative hypotheses (randomisation of participants, along with applying different photo-simulations to the same image, rule out alternative explanations due to individual participant characteristics and image content), we do not make causal claims since, given the quality of photo-simulations, it is likely that participants were able to identify the treatments. Future studies could work on achieving truly photo-realistic simulations in which participants cannot identify the treatment, allowing causal claims to be made. Moreover, the results cannot be extrapolated to other populations due to the nature and size of the sample.

Another consideration is the possibility that green interventions, while having a positive impact on happiness, may also negatively affect other aspects of subjective wellbeing. Studies on environmental psychology, for instance, mention that encounters with nature and green spaces are not always positive (Lyytimäki and Sipilä, 2009). Examples of this include discomfort in nature compared to facilities provided by modern life or due to allergies (Bixler & Floyd, 1997), or fear caused from encounters with insects, animals and people in urban environments (Van den Berg & Ter Heijne, 2005; see also Sreetheran & van den Bosch, 2014, for a full review of fear of crime), although the authors do tend to concentrate on specific demographics. That being said, Navarrete-Hernandez and Laffan (2023) recently demonstrated that street-level green spaces increase overall affective wellbeing by augmenting a wide range of positive emotions and reducing negative emotions for a wide variety of demographics. Experiments in the field could further investigate the impact that different street greening intervention types can yield across a wide variety of affective wellbeing measures to grant net gains.

This study also employs photo simulations and thus draws from visual stimuli, rather than immersive technologies that incorporate more of our senses. It is likely that this enhanced immersive experience would

Table A6
Impact of Happiness Enhancement Interventions with Different Green Coverages (By Age Group).

How Old Are You							
		≤30		31–50		>50	
VARIABLES		1	2	3	4	5	6
Baseline (0 % Greenery)							
	5 %	0.15	0.19	0.14	0.19	0.17	−0.66
		−0.31	−0.31	(0.59)	(0.60)	(1.48)	(1.21)
	15 %	1.11***	1.14***	0.94	0.95	1.33	1.62
		−0.31	−0.31	(0.59)	(0.58)	(1.57)	(1.38)
	25 %	1.58***	1.64***	1.60***	1.79***	3.87**	3.08**
		−0.29	−0.29	(0.57)	(0.58)	(1.74)	(1.50)
	35 %	1.75***	1.80***	2.77***	2.77***	2.73*	3.13**
		−0.29	−0.29	(0.52)	(0.52)	(1.48)	(1.38)
	45 %	1.74***	1.82***	2.35***	2.48***	3.43**	2.33*
		−0.3	−0.3	(0.54)	(0.54)	(1.47)	(1.25)
Controls		No	Yes	No	Yes	No	Yes
Constant		4.40***	4.09***	4.23***	5.13***	5.38**	4.26**
		(0.37)	(0.47)	(0.74)	(0.96)	(2.06)	(1.88)
Observations		761	761	273	273	59	59
R-squared		0.12	0.15	0.18	0.22	0.45	0.64

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A7
Impact of Happiness Enhancement Interventions with Different Green Coverages (By Continent).

Where Do You Live									
		Europe		Asia		America		Others	
VARIABLES		1	2	3	4	5	6	7	8
Baseline (0 % Greenery)									
	5 %	0.18	0.25	0.10	0.03	0.69	0.30	−2.13**	−0.97
		(0.35)	(0.35)	(0.70)	(0.71)	(0.66)	(0.70)	(0.96)	(1.01)
	15 %	1.00***	1.07***	1.06	1.10	0.99	0.84	1.15	1.41*
		(0.35)	(0.35)	(0.69)	(0.67)	(0.66)	(0.67)	(0.89)	(0.80)
	25 %	1.87***	1.95***	0.97	1.10*	1.88***	1.73***	0.73	1.72*
		(0.34)	(0.34)	(0.67)	(0.64)	(0.57)	(0.57)	(1.00)	(0.88)
	35 %	2.12***	2.30***	1.70**	1.59**	2.26***	2.03***	1.48*	1.96**
		(0.33)	(0.33)	(0.68)	(0.68)	(0.62)	(0.58)	(0.77)	(0.85)
	45 %	2.29***	2.40***	1.04	1.00	2.53***	2.05***	0.71	1.69*
		(0.32)	(0.32)	(0.69)	(0.68)	(0.60)	(0.62)	(0.95)	(0.95)
Controls		No	Yes	No	Yes	No	Yes	No	Yes
Constant		4.25***	4.07***	4.30***	4.86***	6.35***	4.96***	5.51***	7.82***
		(0.43)	(0.58)	(0.76)	(0.89)	(0.78)	(0.97)	(0.88)	(1.24)
Observations		616	616	235	235	173	173	69	69
R-squared		0.15	0.20	0.10	0.16	0.19	0.28	0.36	0.54

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

Table A8
Impact of Happiness Enhancement Interventions with Different Green Coverages (By Frequency of Park Visiting).

		How Often Do You Visit a Public Park			
		More than once in two week		Less than once in two week	
VARIABLES		1	2	3	4
Baseline (0 % Greenery)					
	5 %	−0.12	−0.11	0.68	0.65
		(0.32)	(0.32)	(0.49)	(0.49)
	15 %	0.94***	0.99***	1.32***	1.36***
		(0.33)	(0.34)	(0.44)	(0.45)
	25 %	1.46***	1.54***	2.08***	2.08***
		(0.32)	(0.32)	(0.46)	(0.44)
	35 %	1.78***	1.86***	2.51***	2.56***
		(0.30)	(0.31)	(0.46)	(0.45)
	45 %	2.07***	2.13***	1.72***	1.70***
		(0.30)	(0.30)	(0.47)	(0.48)
Controls		No	Yes	No	Yes
Constant		4.25***	4.55***	4.64***	4.01***
		(0.39)	(0.52)	(0.63)	(0.71)
Observations		708	708	385	385
R-squared		0.13	0.17	0.17	0.22

Robust standard errors in parentheses.
*** p < 0.01, ** p < 0.05, * p < 0.1.

lead to more accurate results. Our primary reason for opting for photo simulation techniques is due to their offering a low-cost strategy for simulating green interventions, and thus presenting an accessible technique for planners hoping to develop green infrastructure proposals in cities across the world. Regardless of the lower accuracy, this method arguably provides a conservative estimate of perceived happiness, since studies have shown that immersive technologies with aligned stimuli should not change the direction of results, but should rather only increase their magnitude (Rossetti & Hurtubia, 2020).

Overall, this experiment has shown that street-level green coverage at levels of around 35 % has the potential to make a positive change on people's perceptions of happiness in urban locations. Furthermore, we have shown that vertical-style green interventions yield the highest positive impact on perceived happiness, with significant changes beginning at 5 % coverage, and still continuing to trend upwards at 45 % coverage. This suggests that further incorporation of vertical vegetation should be considered in urban planning proposals, helping us to increase the subjective wellbeing of all people in an urbanising world.

CRediT authorship contribution statement

Pablo Navarrete-Hernandez: Conceptualization, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Niloufar Kiarostami:** . **Dicheng Yang:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Alp Ozcakir:** .

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.

Appendix 1

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