forests

MDPI

Article

Socio-Ecological Dimensions Linking Campus Forest Ecosystems and Students' Restorative Perception: Quantile Regression Evidence from Street-Level PPGIS

Jiachen Yin [1], Ruiying Jia [2] and Lei Peng [1,3,*]

[1] School of Architecture and Urban Planning, Huazhong University of Science and Technology, 1037 Luoyu Road, Hongshan District, Wuhan 430074, China; m202273970@hust.edu.cn
[2] College of Architecture and Urban Planning, Tongji University, 1239 Siping Road, Yangpu District, Shanghai 200092, China; 2410359@tongji.edu.cn
[3] Hubei Engineering and Technology Research Center of Urbanization, Wuhan 430074, China
* Correspondence: penglei@hust.edu.cn

Abstract

University students face rising mental health pressures, making restorative environmental perception (REP) in campus forests critical for psychological recovery. While environmental factors are recognized contributors, Socio-Ecological Systems (SES) theory emphasizes that environmental and social processes are interdependent. Within this context, informal social interaction (ISI)—low-effort encounters such as greetings or small talk—represent a key social dimension that may complement environmental restoration by fostering comfort and embedded affordances. However, most studies examine these factors separately, often using coarse measures that overlook heterogeneity in restorative mechanisms. This study investigates how environmental-exposure and social–environmental context dimensions jointly shape REP in campus forests, focusing on distributional patterns beyond average effects. Using a Public Participation Geographic Information Systems (PPGIS) approach, 30 students photographed 1294 tree-dominant scenes on a forest-rich campus. Environmental features were quantified via semantic segmentation, and ISI was rated alongside REP. Quantile regression estimated effects across the REP distribution. Three distributional patterns emerged. First, blue exposure and ISI acted as reliable resources, consistently enhancing REP with distinct profiles. Second, green exposure functioned as a threshold-dependent resource, with mid-quantile attenuation but amplified contributions in highly restorative scenes. Third, anthropogenic and demographic factors created conditional barriers with distribution-specific effects. Findings demonstrate that campus forest restoration operates through differentiated socio-ecological mechanisms rather than uniform pathways, informing strategies for equitable, restoration-optimized management. More broadly, the distributional framework offers transferable insights for urban forests as socio-ecological infrastructures supporting both human well-being and ecological resilience.

Keywords: urban campus forestry; blue–green infrastructure; psychological restoration; socio-ecological systems; informal social interaction; quantile regression; street-level visual analytics

check for updates

Academic Editor: Remus Creţan

Received: 23 September 2025
Revised: 24 October 2025
Accepted: 28 October 2025
Published: 31 October 2025

Citation: Yin, J.; Jia, R.; Peng, L. Socio-Ecological Dimensions Linking Campus Forest Ecosystems and Students' Restorative Perception: Quantile Regression Evidence from Street-Level PPGIS. *Forests* **2025**, *16*, 1668. https://doi.org/10.3390/f16111668

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

University students worldwide are experiencing escalating mental health pressures driven by academic overload, social isolation, and urbanized living environments, increasingly recognized as a global public health concern [1–4]. In increasingly urbanized

settings, blue–green infrastructure (BGI) provides essential opportunities for psychological recovery through accessible restorative resources within the built environment [5,6]. Understanding how everyday environments can support mental restoration has thus become a pressing issue for both research and campus planning [7,8]. Nature exposure facilitates restorative functions by reducing stress and enabling attentional recovery, with restorative environmental perception (REP) reflecting individuals' subjective evaluation of the extent to which a given environment affords such experiences [9–11]. University campuses, particularly their forested landscapes, function as micro-scale urban forest ecosystems embedded within broader BGI networks [12], providing accessible and recurrent opportunities for daily nature contact [13–15]. However, despite extensive research on restorative environments in urban forestry contexts, whether environmental and social dimensions operate through differentiated mechanisms across varying levels of perceived restoration remains inadequately understood.

Research on restorative environments provides the theoretical and empirical foundations for this inquiry. Attention Restoration Theory (ART) posits that natural environments support recovery from directed attention fatigue through perceptual qualities such as soft fascination, being away, extent, and compatibility [16], while Stress Recovery Theory (SRT) emphasizes that low-arousal natural scenes trigger rapid psychophysiological down-regulation [17]. Empirical evidence extends these frameworks: forest therapy studies document physiological benefits such as reduced cortisol, improved autonomic balance, and enhanced immune function [18,19], while urban forestry research links proximity to and daily exposure to urban forests—conceptualized as components of BGI—with reduced stress, improved mood, and better overall mental health outcomes [7,20].

Building on these theoretical foundations, research on urban forests and BGI has identified specific environmental characteristics that support restorative experiences. Tree canopy cover and vegetation density are structural features associated with cooler microclimates, reduced noise, and heightened naturalness [21,22]. Visual openness, measured through sky visibility and view depth, balances prospect and refuge and supports exploration and restoration [23–25]. Water features contribute via acoustic masking, visual motion, and evaporative cooling [26–28]. Methodologically, this body of work spans approaches from city-scale remote sensing (Normalized Difference Vegetation Index (NDVI), land-use classification), to street-view imagery and computer vision for fine-grained feature extraction [29–31], to experimental designs isolating environmental attributes. Within this broader urban forestry context, campus forests represent micro-scale ecosystems in which environmental features align with students' daily movement patterns to shape restoration [32,33].

However, understanding restoration solely through environmental characteristics overlooks the social processes co-existing within these settings. Social-Ecological Systems (SESs) theory emphasizes that restoration is shaped by the co-presence of human and environmental processes rather than by environmental features alone [34–36]. Within campus contexts, environmental exposure co-occurs with frequent social activity, creating settings where biophysical elements and social processes operate in parallel to influence restorative outcomes [32,37]. Informal social interaction (ISI)—brief, low-effort encounters such as greetings or small talk—represents a relevant yet underexplored social dimension that may complement environmental restoration by fostering comfort and social connection [38–40]. Studies suggest that even minimal social acknowledgment in natural settings can contribute to restoration experiences through pathways distinct from, yet parallel to, direct environmental contact [41–43]. As everyday environments embedded in students' routines, campus forests may buffer against academic stress and social isolation through environmental and social pathways considered analytically distinct dimensions [42,44]. Nevertheless,

these dimensions are often examined separately, leaving their parallel contributions to restorative experiences insufficiently understood.

Existing research thus faces three critical limitations. First, most studies rely on coarse-grained environmental measures, such as NDVI or broad land-use categories [45,46], or employ standardized street-view imagery that lacks place-based context and personal relevance [47,48], rather than participatory approaches that capture the specific visual environments users actually encounter and evaluate in their everyday experiences [49,50]. Second, environmental and social factors are often examined in isolation [15,51,52], overlooking the socio-ecological settings in which biophysical elements—operationalized here as scene-level proxies of BGI components (e.g., sky visibility, water features, vegetation) and anthropogenic stressors—co-occur with social processes such as ISI as parallel dimensions shaping restoration [42,53]. Third, analytical approaches typically emphasize the mean effects through ordinary least squares regression [14,54], potentially masking distributional heterogeneity across varying restoration levels and user contexts [55,56].

To address these gaps, this study develops a dual-dimension socio-ecological framework grounded in SES theory [34,35]. The framework distinguishes two complementary dimensions: (i) an environmental-exposure dimension encompassing scene-level blue–green elements (operationalized as human-scale BGI components) and anthropogenic stressors, and (ii) a social–environmental context dimension capturing ISI and environmental affordances. The study integrates participatory perception data with computer-vision-based semantic segmentation of street-level imagery, generating a spatially explicit dataset linking human evaluation with environmental composition. Quantile regression is then applied to examine how restorative mechanisms vary across the distribution of perceived restoration, moving beyond average-effect interpretations to reveal threshold-dependent, compensatory, and vulnerability patterns.

This study makes threefold contributions. Theoretically, it demonstrates that restorative resources operate through distinct distributional profiles—foundational, optimizing, and conditional—advancing understanding of socio-ecological restoration mechanisms. Methodologically, it integrates participatory mapping, computer vision, and distributional regression within a unified framework for fine-scale socio-ecological analysis. Practically, it provides evidence-based strategies for campus forest management within the broader urban forestry and BGI context, illustrating how blue-infrastructure features, vegetative structure, and social affordances can be strategically configured to enhance equitable access to restorative environments. Building on these contributions, Section 2 introduces the conceptual framework that connects these theoretical and empirical foundations.

2. Conceptual Framework

Building on the theoretical foundations and research gaps outlined in the Introduction, this section develops the conceptual framework guiding the empirical analysis. The framework integrates insights from SES theory, environmental psychology, and ecological affordance perspectives to articulate a dual-dimension socio-ecological model for understanding restorative perception in campus forest environments (CFE).

2.1. A Socio-Ecological Dimensions Perspective on Campus Forest Environments

SES theory conceptualizes human–nature relations as coupled systems in which biophysical structures and social processes co-produce outcomes across scales, rather than as separable ecological backdrops and human uses [34–36]. In campus contexts, this perspective applies to campus green spaces (CGS)—encompassing trees, shrubs, hedges, lawns/groundcovers, and water features [32,57]—with particular relevance to CFE, understood as tree-dominant scenes (e.g., wooded areas, tree-lined paths, forest-edge pockets) [33,57]. Foundational SES work emphasizes multi-subsystem, nested and interacting structures, providing conceptual tools to identify diverse determinants across complex environmental settings [35].

CFE exemplify everyday socio-ecological settings where blue–green biophysical structures co-occur with anthropogenic stressors (e.g., built surfaces, internal roads, vehicles) and with dense social activity [32,57,58]. Unlike remote natural areas accessed occasionally, CFE are embedded within students' routine navigation patterns, creating repeated-exposure contexts in which ecological and social determinants are encountered together [32]. Accordingly, restorative appraisals in campus contexts are understood as shaped by co-occurring socio-ecological processes rather than isolated environmental or social factors.

While recognizing the coupled nature of socio-ecological systems, analytical tractability benefits from distinguishing two conceptual dimensions for research purposes: an environmental-exposure dimension that aggregates blue–green exposure and anthropogenic stressors, and a social–environmental context dimension that emphasizes informal social presence and environmental affordances. These dimensions reflect different analytical perspectives rather than ontologically separate systems, allowing systematic examination of how environmental and social factors relate to restoration outcomes. This dual-dimension framework structures the subsequent sections (Sections 2.2 and 2.3); operational definitions and measurement approaches are detailed in the Methods (Section 3.3).

2.2. Environmental Exposure Dimension: Scene-Level Blue–Green Exposure and Anthropogenic Stressors

Building on this dual-dimension framing, the first dimension focuses on environmental exposure mechanisms. Within environmental psychology, two robust lenses explain why contact with nature supports restoration. ART links "soft fascination," being away, extent, and compatibility to attentional recovery [16]; SRT emphasizes low-arousal, nonthreatening scenes that facilitate rapid psychophysiological down-regulation [17]. In everyday campus settings—especially in tree-dominant scenes—these mechanisms point to the relevance of blue–green features for restorative appraisals [9].

Empirical evidence consistently associates blue–green exposure with better mental health and perceived restoration across experiments, clinical protocols, and large observational cohorts [7,20,51,59]. Reviews and meta-reviews further consolidate benefits of nature contact, including established blue-space contributions from water features (e.g., visual motion, acoustic masking) [26–28]. Crucially, in dense settings like forests, this concept extends to open sky visibility, which provides spatial openness and natural light exposure [23,24], complementing vegetation-based cues. In campus forest contexts, blue exposure encompasses both water elements (ponds, streams, fountains) and sky visibility through forest canopies [20,51], with the latter providing critical visual relief and perceived spaciousness in tree-dominant scenes [25]. Forest-focused physiology (*Shinrin-yoku* and related studies) corroborates effects on autonomic activity and cortisol [60–63]. Taken together, these strands justify treating blue exposure (water and sky elements) and green exposure as core components of the environmental-exposure dimension.

Countervailing influences arise from anthropogenic stressors that co-occur with blue–green elements in campus forest scenes. Built surfaces and hard geometries reduce per-

ceived naturalness and increase vigilance; road infrastructures fragment spatial continuity and constrain movement; vehicle presence adds noise, exhaust, visual dominance, and safety concerns [64–67]. These elements are therefore treated as negative exposure components within the same dimension, complementing the positive blue–green components rather than forming a separate construct.

The environmental-exposure dimension adopts a location-specific approach through Public Participation Geographic Information Systems (PPGIS), enabling examination of environmental composition at fine spatial scales and capturing the immediate visual environment that individuals encounter at specific locations [49,50]. This approach enables examination of environmental variation within highly green campuses, where aggregate measures may obscure meaningful differences in local environmental composition. This location-specific approach, by revealing fine-grained environmental heterogeneity, necessitates an analytical strategy sensitive to distributional effects. It therefore demands moving beyond mean-based associations to examine how blue-green exposure, anthropogenic stressors, and REP relate across the entire perceptual spectrum. Operational details are reported in the methods section (Section 3.3).

2.3. Social–Environmental Dimension: Social Context and Environmental Affordances

Beyond biophysical contact, restoration in green settings is shaped by social processes. Public-health and SES scholarship consolidates the role of social buffering and co-regulation—where social cohesion, perceived support, and low-demand encounters help modulate stress and affect [53,68–70]. Greener environments are frequently associated with greater opportunities for informal contact and a stronger sense of belonging, which, in turn, relate to better mental health outcomes [69–72]. In forested contexts, the combination of visual shelter, acoustical dampening, and perceived safety can further support short, low-intensity exchanges that align with restorative appraisals [69,73].

Environmental affordances provide the bridge between setting and social process. Following ecological psychology, affordances denote action possibilities offered by environments to typical users [74,75]. In CFE, micro-features such as benches, shaded edges, path junctions, and small clearings afford sitting, lingering, and brief conversations [76,77]; edge conditions and visual permeability balance privacy with prospect, enabling low-effort social engagement without eroding perceived naturalness [25,78]. These design-relevant properties clarify how tree-dominant scenes can enable social use that supports restorative appraisals.

Campus settings intensify the salience of this social–environmental dimension. Daily class schedules, walking routes, and recurring gatherings embed social activity within highly green spaces [79,80]. Empirical studies on university grounds link accessible, comfortable, and legible green spaces with more frequent informal encounters and higher perceived restoration, while noting variation across landscape typologies and times of day [20,32,51,81–83].

ISI emerges as a particularly relevant construct in campus forest settings. Unlike formal social engagement, informal interactions—brief conversations, casual encounters, shared presence—require minimal effort while providing social connection that can buffer stress and enhance positive affect [38–40]. In green campus environments, the combination of frequent pedestrian flow and comfortable microclimates creates repeated opportunities for such low-demand social contact [80,84]. Research suggests that even minimal social acknowledgment in natural settings can contribute to restoration experiences, operating through pathways distinct from but complementary to direct environmental contact [42,43,85].

A location-specific perspective is therefore pertinent for the social–environmental context dimension. What users encounter in a given scene—alongside the potential for ISI supported by nearby features—conditions restorative appraisals in parallel with blue–green exposure. This approach captures the social environment characteristics experienced by individuals at specific locations, complementing the location-specific environmental measures. In subsequent analyses, ISI propensity serves as the primary indicator of this social–environmental dimension, reflecting individuals' perceived likelihood of engaging in casual social contact given the environmental affordances present at each location. Together with environmental exposure, ISI forms the dual-dimension framework elaborated below; operational details for measuring ISI and recreational affordances are reported in the Methods (Section 3.2).

2.4. Dual-Dimension Socio-Ecological Framework and Analytical Expectations

Drawing on the preceding review, a dual-dimension socio-ecological framework is articulated for understanding REP in CFE. Grounded in SES theory, the framework treats restoration as an outcome of environmental and social factors operating across two conceptual dimensions [35,36,86].

The environmental-exposure dimension encompasses biophysical contact—both positive (blue and green exposure) and negative (anthropogenic stressors)—that conditions restorative appraisals in line with ART and SRT [16,17]. The social–environmental context dimension captures embedded social processes (ISIs) and environmental affordances that operate as correlates of restoration, drawing on social buffering and ecological psychology [68,74]. These dimensions represent different conceptual dimensions rather than ontologically separate systems, reflecting the integrated nature of socio-ecological settings in which biophysical and social elements are encountered together during everyday campus navigation.

Based on the dual-dimension framework and the literature reviewed above, the empirical analysis proceeds with the following research hypotheses:

H1 (Environmental exposure). *Blue exposure and green exposure are expected to show positive effects with REP, while anthropogenic stressors show negative effects.*

H2 (Social–environmental context). *ISI and recreational affordances are expected to relate positively to REP, consistent with social buffering and affordance perspectives.*

H3 (Joint contribution). *When modeled together, both dimensions are expected to contribute independently to REP variance, supporting the dual-dimension conceptualization.*

Detailed operationalization of these concepts, including variable definitions, measurement protocols, and analytical specifications, are provided in the methods section (Section 3, and see Figure 1). Although situated in campus contexts, this framework contributes to broader forest-environment research by highlighting how tree-dominant scenes support psychological restoration through both environmental exposure and ISI.

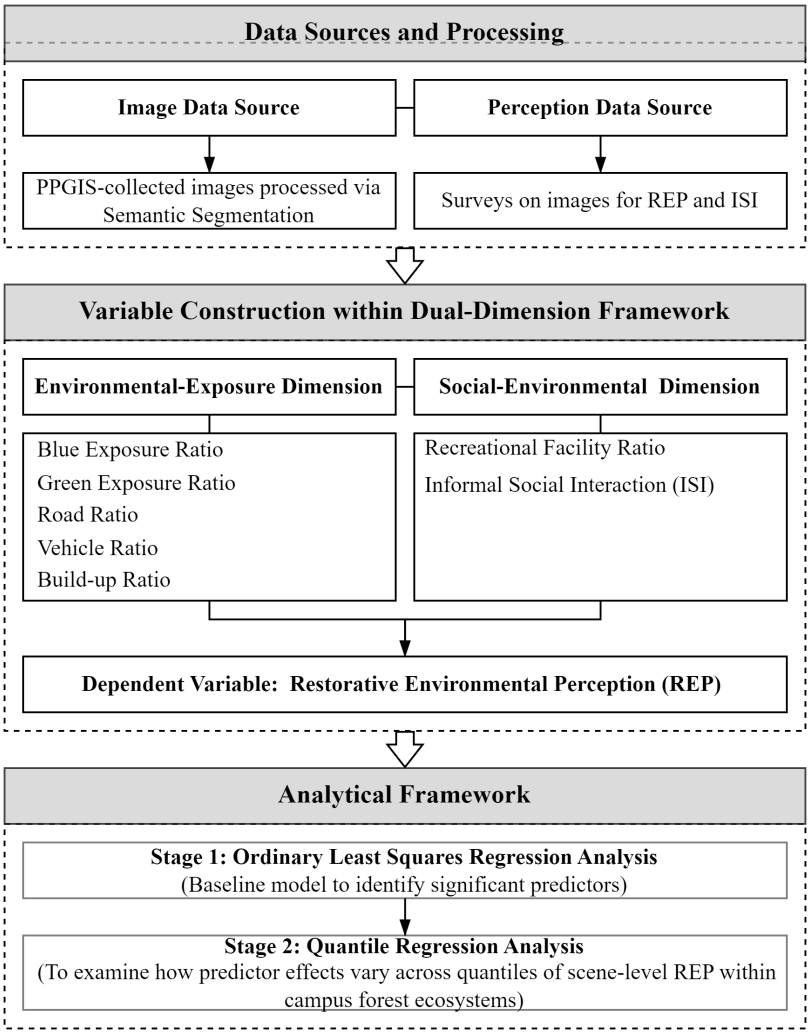

Figure 1. Methodological framework for scene-level REP analysis in CFE.

3. Materials and Methods

3.1. Study Area

The study was conducted at Huazhong University of Science and Technology (HUST), located in Wuhan, a central Chinese metropolis characterized by its abundant water resources and extensive urban greenery [87] (see Figure 2). The main campus of HUST occupies approximately 467 hectares, with a vegetation coverage of about 72%, earning it the reputation of a "forest-like university" [88]. The campus landscape integrates diverse ecological components, including mature deciduous and evergreen canopies, layered shrub zones, managed lawns, and water features such as lakes and streams, forming a heterogeneous setting representative of urban forest ecosystems [88,89].

The spatial organization of the campus combines dense tree cover with clusters of academic buildings, recreational facilities, and extensive pedestrian pathways. With an enrolled student population of nearly 58,000, the campus sustains continuous pedestrian flows, creating a natural laboratory where exposure to blue–green environments and opportunities for informal social encounters are embedded in students' daily routines [90]. This unique socio-ecological setting, with its blend of ecological richness and social dynamism, provides an ideal living laboratory for investigating the restorative processes of CFE.

(a) Wuhan City in Hubei Province, China (b) Satellite view of the main campus (c) Aerial view of the campus landscape

Figure 2. Study area: from city to campus scale. (**a**) Location of Wuhan City, Hubei Province, China; (**b**) satellite view of the main campus; (**c**) aerial view of the campus environment (image source: Huazhong University of Science and Technology official website, https://www.hust.edu.cn/zjhkd/xyfg/gyhzd.htm, accessed on 14 October 2025).

3.2. Data Collection Framework

3.2.1. Sampling Strategy in Campus Forest Environments

To operationalize the dual-dimension socio-ecological framework, sampling targeted tree-dominant scenes on the HUST campus. Transects followed major pedestrian flows to secure routine exposure contexts and to cover diverse forest typologies (see Figure 3), including canopy-enclosed paths, forest–edge interfaces, open woodland clearings, and areas where tree cover adjoins water bodies. This forest-centric design yielded heterogeneous scene compositions necessary for distribution-sensitive analysis of restorative perception.

(a) Survey Route 1 (primarily along East–West roads) (b) Survey Route 2 (primarily along North–South roads)

Figure 3. Two alternative survey routes and sampling points within the main campus. White dashed lines indicate the study boundary, and white arrows show typical movement directions. (**a**) Survey Route 1, primarily following East–West roads. (**b**) Survey Route 2, primarily following North–South roads. The routes are schematic representations: participants generally followed the designated frameworks but were allowed limited flexibility for local exploration.

3.2.2. Image Acquisition and Scene Feature Processing

Fieldwork was conducted in June–August 2024 with 30 trained student volunteers (17 female, 13 male) under informed consent. Using a PPGIS-based mobile workflow [91], volunteers photographed campus forest scenes along predefined survey routes. This participant sample size aligns with established PPGIS-based environmental perception studies in urban parks and campus settings, where 30–50 participants are typically recruited to balance logistical feasibility with coverage of diverse user perspectives and spatial sampling density [8,92].

Participant recruitment and training. Volunteers were recruited via the university's internal online platform through an open call circulated among enrolled students. Participation was voluntary and based on informed consent. Interested students contacted the research team directly and were provided with a study information sheet and consent

form prior to inclusion. To ensure participants were familiar with the study site, only students who had studied and lived on campus for at least one academic year were eligible. Familiarity was further verified through brief pre-training interviews in which participants described frequently visited campus areas and daily movement patterns. The final sample included students from diverse academic backgrounds. Although the recruitment aimed for gender balance (15 male and 15 female), the final ratio reflected practical constraints related to summer-term availability. Gender and disciplinary background were both controlled for in the regression analysis to mitigate potential bias.

Photography protocol and data validation. Each participant was instructed to photograph up to 45 campus forest scenes following predefined routes that ensured comprehensive spatial coverage across the 467-ha campus. A flexible upper limit was applied to avoid repetitive or purposeless images. Participants received standardized guidance regarding camera orientation, exposure, and scene composition to maintain visual consistency. A total of 1332 photographs were collected. After screening for clarity (exposure, focus, lighting) and contextual validity (absence of private or irrelevant spaces), 1294 photographs were retained. Image filtering was based solely on technical and contextual criteria, not on perceived scene quality, thereby minimizing subjective bias. These images constitute the analytical dataset (N = 1294), each representing an independent environmental-perceptual observation rather than a participant-level datum, providing sufficient statistical power for subsequent quantile regression analysis.

Environmental features were then derived from these photographs via a Mask2Former semantic-segmentation model pre-trained on ADE20K. The model was selected for its strong performance on complex, non-panoramic scenes typical of campus environments [93]. Segmentation outputs were converted into pixel-share indicators summarizing the relative presence of major spatial elements within each image (see Figure 4); construction of analysis variables from these indicators is detailed in Section 3.3.

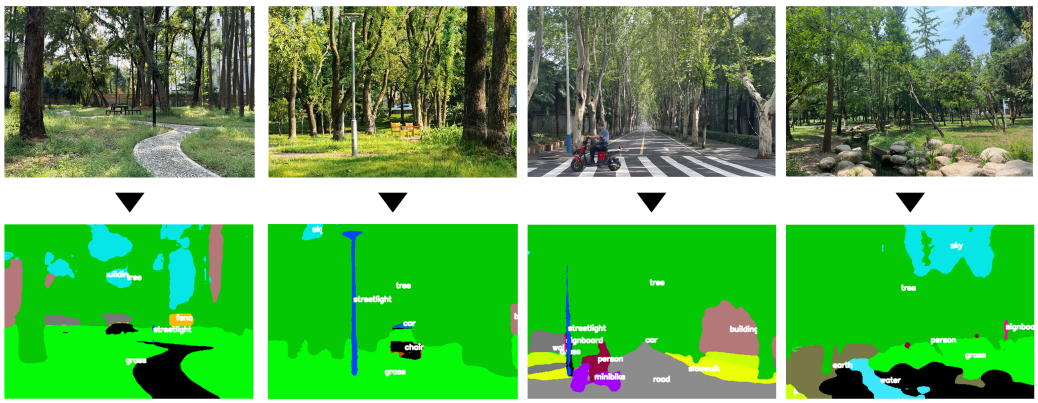

Figure 4. Examples of campus forest scenes (top) and corresponding semantic segmentation results (bottom). The segmentation was derived from Mask2Former pre-trained on ADE20K, with color-coded pixel classes indicating vegetation, built structures, circulation infrastructure, vehicles, and other scene elements.

3.2.3. Perceptual Evaluation Procedure

Perceptual responses were collected through a web-based interface that linked each participant to their own photographs. For every image, participants provided ratings on a seven-point Likert scale (see Table 1), covering (i) REP—drawing on established dimensions such as being away, coherence, extent, and fascination—and (ii) ISI propensity. To reduce recall decay and maintain ecological validity, evaluations were completed within 24 h of image capture. This protocol generated paired environmental–perceptual observa-

tions that underpin the distribution-sensitive models reported below. (Item sources and operationalization continue in Section 3.3.)

Table 1. Operationalization of questionnaire items for REP and ISI.

Code	Construct	Item (7-Point Likert Scale)
REP1	Being Away	"This place helps me escape daily demands."
REP2	Coherence	"The spatial layout feels coherent and orderly."
REP3	Extent	"This environment offers room for exploration."
REP4	Fascination	"This setting captures attention with varied features."
ISI1	Informal Social Interaction	"I would linger here and engage in casual conversations."

Notes: All items used a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The REP index was computed as the mean of four items (REP1–REP4). ISI was measured as a single-item indicator of willingness for informal encounters in campus spaces. REP items are rephrased from the Chinese version of the Perceived Restorativeness Scale (PRS) [94].

3.3. Variables

Building on Section 3.2, the imagery and perceptual responses were converted into analysis-ready indicators aligned with the dual-dimension socio-ecological framework (Definitions are summarized in Appendix A). Unless otherwise noted, continuous predictors were z-standardized (mean = 0, SD = 1) to aid effect-size interpretation; binary indicators were left unscaled.

3.3.1. Outcome: Restorative Environmental Perception

For each scene, participants provided seven-point ratings of restorative qualities drawing on the established facets of being away, coherence, extent, and fascination (see Table 1). Facet scores were averaged to form a composite REP index (higher values indicate stronger perceived restoration).

3.3.2. Predictors: Environmental-Exposure Dimension

Scene composition indicators were derived from the Mask2Former segmentation outputs (Section 3.2.2) via feature engineering: (i) converting per-class masks to pixel-share ratios (class pixels/total pixels), and (ii) aggregating semantically related classes into conceptually coherent groups to align with the dual-dimension theoretical framework (see Table 2). From ADE20K's 150+ categories, the analysis retained 27 semantically relevant classes frequently occurring in campus forest scenes, then aggregated them into theoretically meaningful composites to reduce multicollinearity and enhance interpretability. The resulting scene-level predictors are:

- Blue exposure ratio (BS): sky and water elements.
- Green exposure ratio (GS): vegetation elements (e.g., trees, shrubs/groundcover).
- Built-up ratio: built surfaces (e.g., façades, walls/structures).
- Road ratio: circulation and linear hard surfaces (e.g., roadway, paved path/sidewalk, curbs).
- Vehicle ratio: visible vehicles (e.g., cars, buses, motorcycles; bicycles where present).

Expected association signs follow the theoretical hypotheses in Section 2.4 (H1): BS/GS positive, anthropogenic components negative. Table 2 provides detailed operationalization of these scene-level predictors.

Table 2. Operationalization of scene-level predictors from semantic segmentation.

Predictor Variable	ADE20K Labels	Description and Role
Positive Exposure Components		
Blue Exposure (BS)	Sky; Water	Pixel-share of sky and water; positive exposure for openness and visual relief.
Green Exposure (GS)	Tree; Grass; Plant; Shrub	Pixel-share of vegetation; positive exposure for nature-based restoration.
Anthropogenic Stressor Components		
Built-up Ratio	Building; Wall; Fence; Window; Glass; Railing	Pixel-share of built structures; stressors reducing naturalness.
Road Ratio	Road; Sidewalk; Path; Pavement; Curb	Pixel-share of circulation infrastructure; stressors from fragmentation.
Vehicle Ratio	Car; Bus; Motorcycle; Bicycle; Minibike	Pixel-share of vehicles; stressors from noise and safety concerns.
Affordance Component		
Recreational Facility Ratio	Bench; Seat; Chair; Table; Desk	Pixel-share of social fixtures; proxy for ISI affordances.

Note: Predictors aggregate pixel shares from ADE20K labels (https://github.com/CSAILVision/ADE20K, accessed on 27 October 2025). Categories align with the dual-dimension framework.

3.3.3. Predictors: Social–Environmental Context

ISI: a single-item, seven-point scene-level rating of the likelihood of brief (see Table 1), low-demand encounters (greetings, small talk, lingering with peers). Higher values denote stronger social affordance (see Section 2.4 (H2)).

Additional social–environmental indicators were initially screened, including recreational-facility ratio (an affordance proxy based on pixel share of social-use fixtures such as benches and shelters). These indicators were not retained in the main specification due to parsimony and coefficient stability considerations (see Section 4.1).

3.3.4. Controls and Data Quality

Controls include gender (indicator), academic background (architecture-related vs. other), and survey route choice (east–west vs. north–south transects, reflecting the campus grid structure and ensuring coverage of diverse forest scene typologies). Images failing clarity or contextual validity screening were excluded a priori; the survey interface enforced complete responses, so no imputation was required.

3.4. Analytical Framework

3.4.1. Statistical Approach

Analysis proceeded in two complementary stages to capture both mean associations and distributional heterogeneity anticipated by the SES framework (see Section 2.4: H1–H3).

Stage 1: OLS baseline and variable screening [95]. Ordinary least squares (OLS) regression was first estimated using the full, theory-driven set of predictors (BS, GS, Built, Road, Vehicle, ISI, plus controls; see Section 3.3). All continuous variables—including the outcome (REP) and continuous predictors—were z-standardized (mean $= 0$, SD $= 1$) prior to estimation; binary indicators were left unscaled. Thus, coefficients can be interpreted as fully standardized effects (change in REP, in SD units, per one-SD increase in a predictor). A parsimonious subset of predictors $\mathcal{S}^*$ was then determined via backward elimination based on $p < 0.05$ and AICc improvement [96,97] (see Section 4.1).

Stage 2: Quantile regression on the retained subset [98,99]. To examine how effects vary across the REP distribution, quantile regressions were fitted at key quantiles, $\tau \in \{0.05, 0.25, 0.50, 0.75, 0.95, 0.99\}$, using only the predictors retained in $\mathcal{S}^*$ from Stage 1. In this framework, each scene's position along the REP distribution (quantile level τ) serves as an analytical proxy for its relative restorative quality: lower quantiles ($\tau = 0.05, 0.25$)

represent scenes with lower-quality restorative conditions, the median ($\tau = 0.50$) represents moderate-quality contexts, the third quartile ($\tau = 0.75$) captures moderately high-quality contexts, and upper quantiles ($\tau = 0.95, 0.99$) represent higher-quality and highest-quality contexts, respectively. This operationalization of "scene quality" or "environmental quality" derives from the distributional ranking of perceived restoration rather than from separate quality ratings or objective physical measures. This strategy reveals whether mechanisms differ across lower vs. higher restoration levels, identifying compensation (stronger at lower quantiles), leverage (stronger at upper quantiles), and ceiling effects that may be masked by mean-based analysis. Full specification follows in Section 3.4.2; variable definitions are in Section 3.3.

3.4.2. Model Specification

Let $\tilde{Y}_i$ denote the standardized REP for scene i. Define the standardized environmental-exposure vector for the full set $\tilde{\mathbf{X}}_i^{(0)} = (\widetilde{BS}_i, \widetilde{GS}_i, \widetilde{Built}_i, \widetilde{Road}_i, \widetilde{Vehicle}_i, \widetilde{Facility}_i)$, the (standardized) social–environmental predictor $\tilde{Z}_i = \widetilde{ISI}_i$, and controls $\mathbf{C}_i$ (gender, academic background, route choice; see Section 3.3). Backward elimination in Stage 1 yields the retained subset $\tilde{\mathbf{X}}_i^* \subseteq \tilde{\mathbf{X}}_i^{(0)}$ and, where applicable, $\tilde{Z}_i$.

OLS (Baseline)

$$\tilde{Y}_i = \alpha + \left(\tilde{\mathbf{X}}_i^{(0)}\right)^\top \boldsymbol{\beta} + \gamma \tilde{Z}_i + \mathbf{C}_i^\top \boldsymbol{\delta} + \varepsilon_i,$$

with the reported parsimonious OLS using $\tilde{\mathbf{X}}_i^*$ and the same controls (see Section 4.1).

Quantile Regression

For each $\tau \in \{0.05, 0.25, 0.50, 0.75, 0.95, 0.99\}$,

$$\tilde{Y}_i = \alpha(\tau) + \left(\tilde{\mathbf{X}}_i^*\right)^\top \boldsymbol{\beta}(\tau) + \gamma(\tau)\tilde{Z}_i + \mathbf{C}_i^\top \boldsymbol{\delta}(\tau) + u_i(\tau),$$

where parameters are estimated by minimizing the check (pinball) loss ρ_τ. Because both outcome and continuous predictors are standardized, β_j and $\beta_j(\tau)$ are fully standardized coefficients: they represent the SD change in REP associated with a one SD increase in predictor j (at quantile τ for QR). Allowing parameters to vary across τ enables identification of compensation, leverage and ceiling patterns.

4. Results

4.1. Baseline OLS Results Under the Dual-Dimension Framework

Stage 1: Variable screening. Starting from the theory-driven predictor set (BS, GS, road ratio, vehicle ratio, built-up ratio, recreational facility ratio, ISI, plus controls), backward elimination based on $p < 0.05$ and AICc improvement retained $\mathcal{S}^* = \{BS, GS, \text{road ratio}, \text{vehicle ratio}, ISI, \text{gender}\}$. Built-up and recreational facility ratios were excluded owing to statistical non-significance and marginal explanatory contribution. Among control variables, academic background and route choice were also excluded due to non-significance, retaining only gender. Multicollinearity was low for all retained predictors (max VIF $\approx 1.397 < 5$).

Baseline OLS results. With variables fully standardized (outcome and continuous predictors), the parsimonious OLS explained substantial variance in REP (Adj. $R^2 = 0.636$; Table 3). Within the environmental-exposure dimension, blue ($\beta = 0.177$, $p < 0.001$) and green ($\beta = 0.116$, $p < 0.001$) were positively associated with REP, whereas road ($\beta = -0.059$, $p = 0.003$) and vehicle ($\beta = -0.099$, $p < 0.001$) were negatively associated. Within the social–environmental dimension, ISI showed a strong positive association ($\beta = 0.628$, $p < 0.001$). Gender displayed a negative coefficient ($\beta = -0.267$, $p < 0.001$). All coefficients are fully standardized (SD change in REP per one–SD change in the predictor).

Table 3. OLS Baseline for REP.

Dependent Variable	Independent Variable	Beta	Std. Error	Sig.	VIF
REP	Blue exposure ratio (BS)	0.177	0.576	0.000 ***	1.234
	Green exposure ratio (GS)	0.116	0.293	0.000 ***	1.397
	Road ratio	−0.059	0.781	0.003 **	1.366
	Vehicle ratio	−0.099	5.808	0.000 ***	1.077
	Gender	−0.267	0.253	0.000 ***	1.056
	ISI (Informal Social Interaction)	0.628	0.042	0.000 ***	1.072
				Model fit (Adj. R^2)	0.636

Notes. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, indicating statistical significance. Std. Error denotes the adjusted standard error; Sig. indicates significance level; Adj. R^2 represents the adjusted coefficient of determination. Excluded predictors include: blue–green synergy, built-up ratio, recreational facility ratio, academic background, and route choice.

4.2. Quantile Regression Results: Distribution-Sensitive Estimates by Dimension

Stage 2: Quantile regression on the retained subset. Quantile regressions (QRs) are estimated conditional on the OLS-based screening in Stage 1; only predictors in $\mathcal{S}^*$ enter the QR models. Coefficients are fully standardized. Results are summarized in Figure 5 and Table 4 for $\tau \in \{0.05, 0.25, 0.50, 0.75, 0.95, 0.99\}$.

Table 4. Quantile regression results for restorative environmental perception (REP).

Variable	5%	25%	50%	75%	95%	99%
Constant	**−0.898** ***	**−0.313** ***	**0.118** ***	**0.504** ***	**1.092** ***	**1.356** ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
BS	**0.171** ***	**0.145** ***	**0.171** ***	**0.160** ***	**0.154** ***	**0.141** ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GS	**0.105** *	**0.139** ***	**0.077** **	**0.104** **	**0.185** ***	**0.107** *
	(0.021)	(0.000)	(0.006)	(0.002)	(0.000)	(0.023)
Road ratio	−0.083	−0.054	−0.045	−0.060	−0.076	−0.046
	(0.089)	(0.076)	(0.115)	(0.085)	(0.073)	(0.202)
Vehicle ratio	−0.051	**−0.068** *	**−0.078** **	−0.073	−0.110	−0.117
	(0.201)	(0.026)	(0.008)	(0.062)	(0.070)	(0.064)
Gender (female = 0)	**−0.309** ***	**−0.324** ***	**−0.294** ***	**−0.194** **	−0.090	0.085
	(0.000)	(0.000)	(0.000)	(0.000)	(0.203)	(0.266)
ISI (Informal Social Interaction)	**0.576** ***	**0.590** ***	**0.601** ***	**0.602** ***	**0.540** ***	**0.483** ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Pseudo R^2	0.369	0.346	0.313	0.291	0.306	0.271

Notes. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$, indicating statistical significance. Numbers in parentheses are p-values. Pseudo R^2 is reported for each quantile regression.

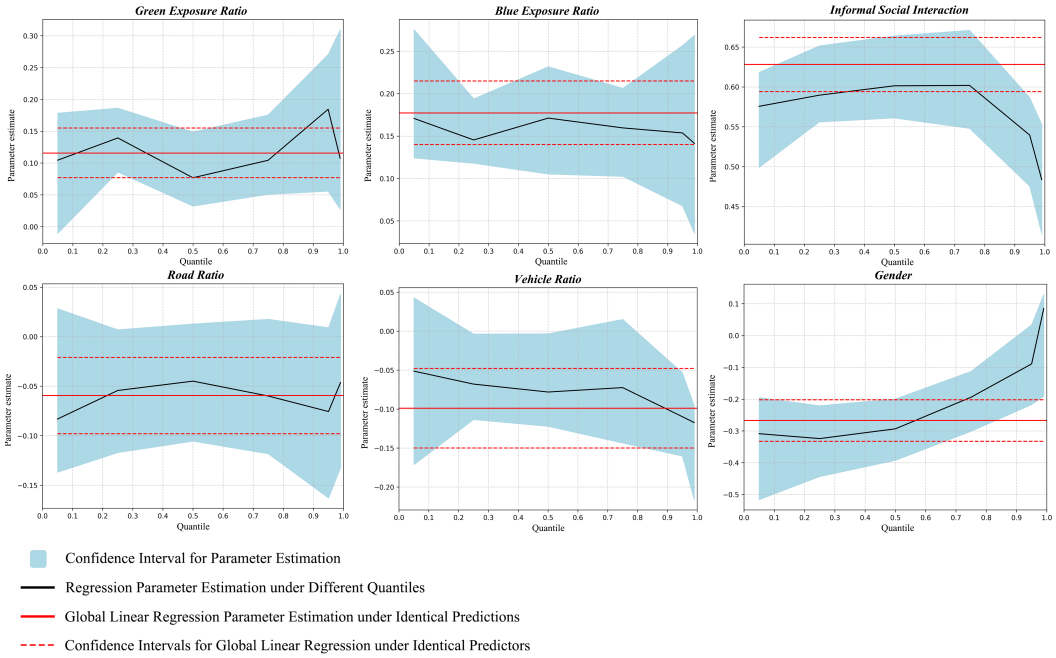

Figure 5. Effect Heterogeneity across Quantiles of Scene-level REP.

4.2.1. Environmental Exposure Dimension: Blue–Green and Anthropogenic Effects

Blue exposure. Estimates are universally positive and relatively stable across the distribution: $\hat{\beta}_{0.05} = 0.171\,^{***}$, $\hat{\beta}_{0.25} = 0.145\,^{***}$, $\hat{\beta}_{0.50} = 0.171\,^{***}$, $\hat{\beta}_{0.75} = 0.160\,^{***}$, $\hat{\beta}_{0.95} = 0.154\,^{***}$, $\hat{\beta}_{0.99} = 0.141\,^{***}$. This indicates robust blue-space benefits, with slight attenuation at the extreme upper tail.

Green exposure. Effects display a mid-quantile dip with upper-tail amplification followed by extreme-tail moderation: estimates are weakest around the median ($\hat{\beta}_{0.50} = 0.077\,^{**}$), higher at the lower tail ($\hat{\beta}_{0.05} = 0.105\,^{*}$, $\hat{\beta}_{0.25} = 0.139\,^{***}$), peak at the 0.95 quantile ($\hat{\beta}_{0.95} = 0.185\,^{***}$), and then moderate at the extreme upper tail ($\hat{\beta}_{0.99} = 0.107\,^{*}$), indicating an upper-tail amplification with a ceiling effect.

Road ratio. Coefficients are consistently negative but small and non-significant across quantiles (-0.083, -0.054, -0.045, -0.060, -0.076, -0.046 across $\tau = 0.05$–0.99), suggesting a diffuse constraint rather than concentrated distributional effects.

Vehicle ratio. The negative impact is statistically detectable primarily around the median: $\hat{\beta}_{0.25} = -0.068\,^{*}$ ($p = 0.026$), $\hat{\beta}_{0.50} = -0.078\,^{**}$ ($p = 0.008$); at upper quantiles, coefficients are larger in magnitude but remain not significant ($\hat{\beta}_{0.95} = -0.110$, $p = 0.070$; $\hat{\beta}_{0.99} = -0.117$, $p = 0.064$).

Across quantiles, the pseudo R^2 ranges from 0.369 (at $\tau = 0.05$) to 0.271 (at $\tau = 0.99$).

4.2.2. Social–Environmental Dimension: Embedded Social Process Effects

ISI. Effects are stable and positive across the distribution (range $0.483\,^{***}$–$0.602\,^{***}$), peaking near the median ($\hat{\beta}_{0.50} = 0.601\,^{***}$, $\hat{\beta}_{0.75} = 0.602\,^{***}$). This full-distribution robustness underscores ISI as a reliable restorative pathway in campus forest settings.

Gender. Coefficients indicate lower-tail vulnerability: large negative gaps at the 5th and 25th percentiles ($\hat{\beta}_{0.05} = -0.309\,^{***}$, $\hat{\beta}_{0.25} = -0.324\,^{***}$) that diminish and become non-significant at higher quantiles ($\hat{\beta}_{0.95} = -0.090$, $p = 0.203$; $\hat{\beta}_{0.99} = 0.085$, $p = 0.266$).

4.3. Summary of Dual-Dimension Restoration Patterns

Three recurrent distributional patterns emerge within the SES-informed framework:

1. Consistent positive effects with distinct distributional profiles. Blue exposure, green exposure, and ISI all remain statistically significant across quantiles but display distinct distributional shapes. Blue exposure shows relative stability with slight upper-tail attenuation ($\hat{\beta}_\tau$ range 0.141–0.171), ISI displays an inverted-U pattern peaking near the median, and green exposure demonstrates pronounced mid-quantile attenuation with upper-tail amplification.
2. Threshold-dependent green exposure effects. Green exposure exhibits the strongest distributional heterogeneity, with the weakest effects at the median ($\hat{\beta}_{0.50} = 0.077$ **) and strongest at the 95th percentile ($\hat{\beta}_{0.95} = 0.185$ ***), followed by a decline at the extreme upper tail ($\hat{\beta}_{0.99} = 0.107$ *).
3. Distribution-specific negative effects. Road and vehicle exposures have negative effects with distinct profiles. The negative coefficients for road exposure are diffuse across quantiles, whereas those for vehicle presence are concentrated at the median. For gender, negative coefficients are most pronounced at the lower tail and attenuate toward higher quantiles. Notably, road ratio has a significant negative effect in the OLS baseline ($\beta = -0.059$, $p = 0.003$) but becomes non-significant across quantiles in the QR models.

5. Discussion

This study employed a dual-dimension socio-ecological framework and quantile regression to examine how scene-level environmental and social factors shape perceived restoration. The analysis reveals three core distributional patterns: the complementary roles of foundational (blue exposure) and optimizing (ISI) resources; the conditional, threshold-dependent nature of green exposure; and the distribution-specific impacts of anthropogenic barriers. These patterns provide substantial support for the study's guiding hypotheses regarding environmental exposure (H1), social context (H2), and their joint contribution (H3) (see Section 2.4), confirmed by the model's high explanatory power (Adj. $R^2 = 0.636$). This section now interprets these findings in detail, connecting them to established theories (ART, SRT, SES) to articulate their theoretical and practical implications for campus forest management and scene-based BGI design.

5.1. Foundational and Optimizing Resources: Blue Exposure and ISI

The results distinguish between two types of reliable positive resources. Blue exposure—comprising sky visibility and water features—functions as a foundational resource, demonstrating remarkable stability across the restoration distribution. This suggests its capacity to engage evolutionarily prepared perceptual systems that promote restoration regardless of overall scene quality [16,24,82]. The stronger effects observed at lower and mid-quantiles point to a compensation mechanism, where blue elements offer crucial visual relief and stress-buffering when other restorative cues are scarce [9,25,28,100]. The slight attenuation at the extreme upper tail likely reflects a ceiling effect, where additional blue elements yield diminishing marginal benefits in already exceptional scenes, aligning with optimal stimulation perspectives that favor balanced environmental exposure [25,26,59,101].

In contrast, ISI acts as an optimizing resource, with its positive effects following a distinct inverted-U shape that peaks in moderately to highly restorative contexts [102–104]. This pattern suggests a socio-ecological synergy: ISI's benefits are not merely additive but are maximized when the environment itself affords positive social encounters [68,69,105]. The peak in the mid-to-upper quantiles represents a 'sweet spot' where the scene's qual-

ity provides an ideal backdrop for restorative social connection [102,106]. Conversely, the attenuation at both the lower and upper extremes suggests that social benefits are diminished in low-quality settings (which may fail to support positive interactions) and in exceptional scenes (where the environment's restorative power may overshadow social contributions) [7,105,106]. This nuanced dynamic, mediated by low-effort connections that buffer stress [107,108], reveals that social contributions are highly context-dependent.

5.2. Green Exposure as a Conditional, Threshold-Dependent Resource

Unlike the consistent effects of blue exposure, green exposure—the composite of trees, shrubs, and groundcover—operates as a conditional resource, exhibiting a pattern of mid-quantile attenuation and upper-tail amplification. This non-linear profile indicates that the restorative function of vegetation is not universal but threshold-dependent, challenging simple "more green is better" assumptions [7,109,110]. The weak effects in moderately restorative contexts suggest that sheer quantity of vegetation is less important than its qualitative organization and contextual fit [58,109,111]. This aligns with ART's emphasis on compatibility and fascination, where vegetation's ability to restore attention is greatest when it forms a coherent and engaging spatial structure [16,112–114], a view supported by research on visual complexity and preference [115,116].

The pronounced amplification at the upper tail reveals a quality-enhancement mechanism: in already high-quality scenes, well-structured vegetation (e.g., mature canopies, layered understory) delivers exceptional restorative benefits. This synergy likely arises when greenery is combined with other favorable qualities like clear spatial organization and supportive microclimates [117–120]. Such multilayered, diverse vegetation structures are known to amplify physiological benefits like parasympathetic activation [62,121,122]. The subsequent decline at the extreme upper quantile ($\tau = 0.99$) points to a ceiling effect, where in truly top-tier environments, other factors may become more decisive than marginal gains in vegetation [9,122,123].

5.3. Distribution-Specific Barriers: Roads, Vehicles, and Gender-Based Vulnerability

The analysis further identifies anthropogenic and demographic factors as conditional barriers with distinct distributional profiles, demonstrating that restoration is not only driven by positive inputs but also constrained by structural disruptions and inequities. Road exposure, representing hardscape fragmentation, acts as a diffuse constraint, imposing a subtle but broadly distributed negative influence that reduces perceived naturalness [124–126]. In contrast, active vehicle presence operates as a median-concentrated disruption, with its negative impact being most statistically detectable in moderately restorative contexts where environmental buffers are neither overwhelmingly strong nor absent [9,67,127].

Most critically, gender disparities reveal a lower-tail vulnerability pattern, with the restoration gap being largest in low-quality scenes and diminishing in high-quality ones. This finding strongly suggests that high-quality green infrastructure can play an equity-enhancing role by buffering gender-based disparities, potentially by improving perceptions of safety and reducing environmental stress [128,129]. This concentration of vulnerability in lower-quantile environments aligns with environmental justice principles, highlighting that the burdens of poor-quality environments are not borne equally [130,131].

5.4. Theoretical Implications

This study makes several theoretical contributions by integrating a dual-dimension socio-ecological framework [34,35] with a distributional perspective [98,99]. First, it operationalizes SES constructs and refines their application to restorative environments by empirically distinguishing between foundational (stable, compensatory), optimizing (syner-

gistic, context-dependent), and conditional (threshold-dependent) resources. This typology moves beyond treating environmental and social factors as equivalent inputs, revealing the distinct roles they play in shaping restorative experiences [9,16,102,132]. It reframes "greenness" not as a simple quantity but as a structural property, and social interaction not as a universal positive but as a context-sensitive amplifier [133,134].

Second, the findings extend ART and SRT by showing evidence consistent with non-linear, distribution-dependent mechanisms [7,109]. The threshold effects of green exposure and the inverted-U profile of social interaction suggest that concepts like "soft fascination" and "stress reduction" are not static processes but are contingent on the overall quality of the socio-ecological setting [9,17]. This highlights the need for restorative theories to more explicitly account for contextual synergies and saturation effects [7,110,111].

Third, by identifying lower-tail vulnerability patterns related to gender, the research pushes restorative environment theory toward a more justice-oriented framework. It demonstrates that the benefits of BGI are not distributed uniformly and that improving baseline environmental quality can be a direct mechanism for enhancing equity. This integrates principles of environmental justice into the core of restoration science, urging a focus not just on average benefits but on outcomes for the most vulnerable [129,131,135].

5.5. Planning and Policy Implications

The distributional patterns identified in this study translate directly into a multi-pronged, evidence-based strategy for campus forest planning and BGI design. This study proposes a synergistic approach that moves beyond one-size-fits-all solutions:

Establish a Foundational Blue–Green Network: Given the stable, compensatory benefits of blue exposure, planning should prioritize the creation and protection of a baseline network of visible sky and water features [10,26,136]. This network acts as a "restorative safety net," providing reliable support, particularly in underperforming areas. For green exposure, the focus should be on ensuring coherent, legible baseline tree coverage along pedestrian corridors rather than simply maximizing density [78,109,134].

Develop Synergistic "Premium" Nodes: The findings on optimizing and conditional resources call for targeted investments in high-potential areas. Planners should identify locations with existing foundational qualities and develop them into "premium" restorative nodes. This involves creating immersive forest experiences with complex canopy layering and high plant diversity to trigger the upper-tail amplification of green exposure [120–122]. Simultaneously, integrating social affordances (e.g., well-placed seating, inviting clearings) into these high-quality settings will create "social-environmental synergy zones" that maximize the context-sensitive benefits of ISI [39,137,138].

Implement Equity-Oriented Barrier Mitigation: Addressing anthropogenic and demographic barriers requires targeted interventions. Diffuse road impacts can be softened with vegetation buffers and naturalized edges [139,140]. Median-focused vehicle disruption can be managed temporally (e.g., restricted access) [67]. Most importantly, the concentration of gender disparities in low-quality environments demands an equity-first approach to upgrading baseline conditions [130,131]. Interventions such as improved lighting, clear sightlines, and high-maintenance standards in these vulnerable zones are not just environmental improvements—they are critical measures for promoting restorative justice [130,141].

6. Conclusions

This study examined REP in campus forests conceptualized as BGI, integrating environmental-exposure and social–environmental context dimensions and estimating distributional effects via quantile regression. Through analyzing student-photographed

and student-evaluated tree-dominant scenes across a forest-rich campus, three distributional patterns emerged: (i) consistently positive yet distributionally varying contributions of sky openings and water features (blue exposure) alongside ISI, (ii) threshold-dependent effects of vegetative structures—e.g., tree canopies, shrubs, and groundcover (green exposure)—with mid-quantile attenuation and upper-tail amplification, and (iii) conditional barriers stemming from paved paths and vehicle presence (anthropogenic stressors) as well as demographic vulnerabilities. These patterns indicate that restoration processes in vegetation-rich and water-integrated campus landscapes vary systematically across scene-quality levels as perceived by students, rather than operating uniformly.

Theoretically, the findings articulate a resource-differentiated view within an SES perspective, grounded in students' everyday encounters with campus forest scenes integrating vegetation, water, and social activity: sky visibility through canopy openings and campus ponds/streams function as foundational resources providing compensatory benefits in lower-quality contexts; ISI operates as an optimizing resource with peak effects under favorable conditions; and mature tree canopies, layered understory vegetation, and well-maintained groundcover act as conditional resources requiring structural integration to yield amplified benefits. Methodologically, the integration of participatory mapping (PPGIS), semantic segmentation, and quantile regression enables fine-grained analysis of how environmental and social mechanisms jointly shape restoration across perceptual distributions as experienced and rated by student users, extending insight beyond mean-based perspectives. These distributional patterns are likely transferable to broader urban-forest and municipal BGI settings, where foundational, optimizing, and conditional components must be balanced against distribution-sensitive barriers to support equitable restoration outcomes.

Practically, campus BGI design should align with these student-perceived mechanisms through differentiated strategies: secure sky openings (through canopy management) and accessible water features as baseline infrastructure that provide compensatory support in underperforming areas; implement a dual-track vegetation strategy that combines coherent tree coverage along pedestrian corridors with premium immersive forest nodes featuring complex canopy layering, diverse understory, and shaded clearings; concentrate social infrastructure (benches, path junctions) in "synergy zones" where favorable tree–water–light configurations optimize informal encounters; and deploy multi-level interventions to address hardscape fragmentation and vehicle intrusion through spatial buffers, temporal management, and equity-oriented baseline upgrades targeting lower-tail gender vulnerabilities. Embedding restorative performance indicators—e.g., perceived restoration scores, exposure-diversity indices, ISI density, and gender-disaggregated equity assessments—into campus and municipal BGI policies can institutionalize distribution-sensitive planning informed by user-perceived landscape qualities, helping campus forests function as multifunctional restorative infrastructure that supports mental health, social cohesion, environmental equity, and climate adaptation.

7. Limitations and Future Directions

Several limitations warrant acknowledgment. First, the cross-sectional design limits causal inference; longitudinal or experimental studies would enable more robust testing of causal pathways. Second, the single-campus focus may constrain generalizability; cross-site work across different forest densities, climatic zones, cultural contexts, and student populations would clarify boundary conditions for the foundational/optimizing/conditional typology. Third, the composite-indicator approach, while addressing multicollinearity, precludes fine-grained estimation of individual landscape elements (e.g., tree canopy vs. shrubs; sky vs. water); alternative methods such as conjoint analysis, discrete-choice ex-

periments, or virtual-reality simulations could isolate component-specific effects. Fourth, PPGIS-based imagery may not fully capture temporal dynamics (seasonal change, diurnal variation) or three-dimensional qualities (canopy layering, understory complexity); multi-season data collection and immersive technologies (e.g., LiDAR, 360° photography) could enrich environmental characterization. Finally, the single-item ISI measure captures perceived propensity for informal encounters but not actual interactions or their affective valence; ecological momentary assessment, GPS-linked observation, or social-network approaches could provide direct evidence of ISI occurrence and experience.

Despite these limitations, the study establishes a dual-dimension socio-ecological framework demonstrating that environmental and social processes operate through differentiated distributional mechanisms. By integrating PPGIS, semantic segmentation, and quantile regression, it offers a methodological template for fine-scale analysis and actionable guidance for equitable campus-forest management, and it lays foundations for understanding urban-forest ecosystems as integrated socio-ecological infrastructure that supports human well-being.

Author Contributions: Conceptualization, J.Y., R.J. and L.P.; methodology, J.Y. and R.J.; software, J.Y.; validation, J.Y.; formal analysis, J.Y.; investigation, J.Y. and R.J.; resources, J.Y. and L.P.; data curation, J.Y.; writing—original draft preparation, J.Y.; writing—review and editing, J.Y., R.J. and L.P.; visualization, J.Y.; supervision, R.J. and L.P.; project administration, L.P.; funding acquisition, L.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (No. 51978294) and the Hubei Provincial Social Science Foundation (No. HBSXK2024103). The funders had no role in study design, data collection, analysis and interpretation, writing of the article, or the decision to submit the article for publication.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Tongji Medical College, Huazhong University of Science and Technology (protocol code 2025S096).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are not publicly available due to ethical restrictions and institutional policies but are available from the corresponding author on reasonable request.

Acknowledgments: During the preparation of this work the authors used ChatGPT 5 (OpenAI) in order to improve language clarity and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of 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.

Appendix A. Glossary of Key Terms

Blue–Green Infrastructure (BGI)

An integrated network of natural and semi-natural systems—including vegetation, water bodies, and soil structures—designed to deliver ecosystem services and psychological benefits in urban settings. BGI combines both blue (water-related) and green (vegetation-related) components and provides the planning context for understanding campus forest environments.

Green Infrastructure (GI)
The vegetative component of BGI, including trees, shrubs, and grasslands that offer ecological (e.g., cooling, air purification) and social (e.g., recreation, restoration) benefits.

Blue Exposure (BS)
A scene-level measure of visible blue-space elements—sky openness and water features—derived from semantic segmentation (see Section 3.3.2). Serves as a perceptual proxy for the blue component of BGI.

Green Exposure (GS)
A scene-level measure of visible vegetation (tree canopy, shrubs, grass, groundcover), representing the GI dimension within the environmental-exposure pathway (see Section 3.3.2). Functions as aperceptual proxy for GI.

Campus Forest Environments (CFE)
Tree-dominant campus landscapes—wooded areas, tree-lined paths, and forest-edge spaces—that serve as localized urban forest ecosystems and everyday sites for nature contact.

Informal Social Interaction (ISI)
Low-effort, spontaneous social encounters (e.g., greetings, brief conversations) in public green spaces that promote comfort, connectedness, and stress buffering. Measured as scene-level perceived propensity for casual social contact.

Restorative Environmental Perception (REP)
Individuals' subjective assessment of an environment's restorative potential, reflecting attention restoration theory and stress recovery theory dimensions. Computed as a composite index of four perceptual factors.

Anthropogenic Stressors
Built or human-induced elements—roads, vehicles, hard edges, visual clutter—that reduce naturalness, coherence, or perceived safety in campus forest scenes.

Dual-Dimension Socio-Ecological Framework
A conceptual model based on Social–Ecological Systems (SES) theory distinguishing two analytical dimensions: (i) environmental exposure (blue–green elements and stressors) and (ii) social–environmental context (ISI and affordances).

Environmental Quality (Scene Quality)
An analytical construct representing the relative restorative quality of each campus forest scene, operationalized through its position along the distribution of Restorative Environmental Perception (REP) scores. In the quantile regression framework (Section 3.4.1), scenes at lower quantiles ($\tau = 0.05, 0.25$) represent lower-quality restorative contexts, median quantiles ($\tau = 0.50$) represent moderate-quality contexts, and upper quantiles ($\tau = 0.95, 0.99$) represent higher-quality contexts. This construct reflects distributional variation in perceived restoration across different scene compositions, NOT participants' subjective judgments of "quality" as a separate rating dimension or objective physical measures (e.g., NDVI, air quality index).

Note on Terminology: BGI and GI denote planning-scale infrastructure concepts, while blue exposure and green exposure refer to scene-level perceptual proxies. BS and GS denote the analytical notation used in statistical models (see Section 3.3.2). This distinction clarifies the link between user-experienced perception and the broader BGI/GI planning discourse.

References

1. Duffy, M.E.; Twenge, J.M.; Joiner, T.E. Trends in Mood and Anxiety Symptoms and Suicide-Related Outcomes Among U.S. Undergraduates, 2007–2018: Evidence From Two National Surveys. *J. Adolesc. Health Off. Publ. Soc. Adolesc. Med.* **2019**, *65*, 590–598. [CrossRef]
2. Zhang, Y.; Zhang, H.; Ma, X.; Di, Q. Mental Health Problems during the COVID-19 Pandemics and the Mitigation Effects of Exercise: A Longitudinal Study of College Students in China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3722. [CrossRef]
3. Busch, C.A.; Wiesenthal, N.J.; Gin, L.E.; Cooper, K.M. Behind the Graduate Mental Health Crisis in Science. *Nat. Biotechnol.* **2024**, *42*, 1749–1753. [CrossRef]
4. Mason, A.; Rapsey, C.; Sampson, N.; Lee, S.; Albor, Y.; Al-Hadi, A.N.; Alonso, J.; Al-Saud, N.; Altwaijri, Y.; Andersson, C.; et al. Prevalence, Age-of-Onset, and Course of Mental Disorders among 72,288 First-Year University Students from 18 Countries in the World Mental Health International College Student (WMH-ICS) Initiative. *J. Psychiatr. Res.* **2025**, *183*, 225–236. [CrossRef] [PubMed]
5. Polo-Martín, B. The Potential of Blue–Green Infrastructures (BGIs) to Boost Urban Resilience: Examples from Spain. *Urban Sci.* **2025**, *9*, 102. [CrossRef]
6. Wang, J.; Foley, K. Preference and Perception of Individuals for Blue-Green Infrastructure in the Promotion of Climate-Resilient Cities: A Visual Experiment in Ireland and China. *Urban For. Urban Green.* **2025**, *106*, 128730. [CrossRef]
7. Jiang, B.; Li, J.; Gong, P.; Webster, C.; Schumann, G.; Liu, X.; Suppakittpaisarn, P. A Generalized Relationship between Dose of Greenness and Mental Health Response. *Nat. Cities* **2025**, *2*, 739–748. [CrossRef]
8. Ma, H.; Xu, Q.; Zhang, Y. High or Low? Exploring the Restorative Effects of Visual Levels on Campus Spaces Using Machine Learning and Street View Imagery. *Urban For. Urban Green.* **2023**, *88*, 128087. [CrossRef]
9. Hartig, T.; Mitchell, R.; de Vries, S.; Frumkin, H. Nature and Health. *Annu. Rev. Public Health* **2014**, *35*, 207–228. [CrossRef]
10. Hunter, R.F.; Nieuwenhuijsen, M.; Fabian, C.; Murphy, N.; O'Hara, K.; Rappe, E.; Sallis, J.F.; Lambert, E.V.; Duenas, O.L.S.; Sugiyama, T.; et al. Advancing Urban Green and Blue Space Contributions to Public Health. *Lancet Public Health* **2023**, *8*, e735–e742. [CrossRef]
11. Shi, H.; Luo, H.; Wei, Y.; Shin, W.S. The Influence of Different Forest Landscapes on Physiological and Psychological Recovery. *Forests* **2024**, *15*, 498. [CrossRef]
12. Dhyani, S.; Krishnaswamy, J. Integration of Blue, Green, and Grey Infrastructure in Urban Campuses as a Nature-Based Solution for Resilience and Harnessing Co-Benefits. In Proceedings of the EGU General Assembly 2025, Vienna, Austria, 27 April–2 May 2025; EGU25-16048. [CrossRef]
13. Ribeiro, H.; Santana, K.V.d.S.; Oliver, S.L. Natural Environments in University Campuses and Students' Well-Being. *Int. J. Environ. Res. Public Health* **2024**, *21*, 413. [CrossRef] [PubMed]
14. Nie, X.; Wang, Y.; Zhang, C.; Zhao, Y.; Kirkwood, N. The Varied Restorative Values of Campus Landscapes to Students' Well-Being: Evidence from a Chinese University. *BMC Public Health* **2024**, *24*, 487. [CrossRef]
15. Aghabozorgi, K.; van der Jagt, A.; Bell, S.; Smith, H. The Role of University Campus Landscape Characteristics in Students' Mental Health. *Urban For. Urban Green.* **2025**, *111*, 128863. [CrossRef]
16. Kaplan, S. The Restorative Benefits of Nature: Toward an Integrative Framework. *J. Environ. Psychol.* **1995**, *15*, 169–182. [CrossRef]
17. Ulrich, R.S.; Simons, R.F.; Losito, B.D.; Fiorito, E.; Zelson, M. Stress Recovery During Exposure to Natural and Urban Environments. *J. Environ. Psychol.* **1991**, *11*, 201–230. [CrossRef]
18. Wen, Y.; Yan, Q.; Pan, Y.; Gu, X.; Liu, Y. Medical Empirical Research on Forest Bathing (Shinrin-yoku): A Systematic Review. *Environ. Health Prev. Med.* **2019**, *24*, 70. [CrossRef]
19. Siah, C.J.R.; Goh, Y.S.; Lee, J.; Poon, S.N.; Ow Yong, J.Q.Y.; Tam, W.S.W. The Effects of Forest Bathing on Psychological Well-Being: A Systematic Review and Meta-Analysis. *Int. J. Ment. Health Nurs.* **2023**, *32*, 1038–1054. [CrossRef]
20. Li, H.; Du, J.; Chow, D. Perceived Environmental Factors and Students' Mental Wellbeing in Outdoor Public Spaces of University Campuses: A Systematic Scoping Review. *Build. Environ.* **2024**, *265*, 112023. [CrossRef]
21. Kumar, P.; Debele, S.E.; Khalili, S.; Halios, C.H.; Sahani, J.; Aghamohammadi, N.; Andrade, M.d.F.; Athanassiadou, M.; Bhui, K.; Calvillo, N.; et al. Urban Heat Mitigation by Green and Blue Infrastructure: Drivers, Effectiveness, and Future Needs. *Innov.* **2024**, *5*, 100588. [CrossRef] [PubMed]
22. Wang, J.; Wang, Z.; Li, C.; Yao, Z.; Cui, S.; Huang, Q.; Liu, Y.; Wang, T. An Exploratory Framework for Mapping, Mechanism, and Management of Urban Soundscape Quality: From Quietness to Naturalness. *Environ. Int.* **2024**, *187*, 108699. [CrossRef]
23. Sztuka, I.M.; Örken, A.; Sudimac, S.; Kühn, S. The Other Blue: Role of Sky in the Perception of Nature. *Front. Psychol.* **2022**, *13*, 932507. [CrossRef]
24. Sztuka, I.M.; Kühn, S. Blue Skies: Does the Visual Composition of Sky Guide Subjective Judgments of Naturalness in the Environment? *Environ. Res.* **2024**, *262*, 119845. [CrossRef]
25. Yao, T.; Lin, W.; Bao, Z.; Zeng, C. Natural or Balanced? The Physiological and Psychological Benefits of Window Views with Different Proportions of Sky, Green Space, and Buildings. *Sustain. Cities Soc.* **2024**, *104*, 105293. [CrossRef]

26. White, M.P.; Elliott, L.R.; Gascon, M.; Roberts, B.; Fleming, L.E. Blue Space, Health and Well-Being: A Narrative Overview and Synthesis of Potential Benefits. *Environ. Res.* **2020**, *191*, 110169. [CrossRef]
27. Poulsen, M.N.; Nordberg, C.M.; Fiedler, A.; DeWalle, J.; Mercer, D.; Schwartz, B.S. Factors Associated with Visiting Freshwater Blue Space: The Role of Restoration and Relations with Mental Health and Well-Being. *Landsc. Urban Plan.* **2022**, *217*, 104282. [CrossRef]
28. Luo, S.; Xie, J.; Wang, H.; Wang, Q.; Chen, J.; Yang, Z.; Furuya, K. Natural Dose of Blue Restoration: A Field Experiment on Mental Restoration of Urban Blue Spaces. *Land* **2023**, *12*, 1834. [CrossRef]
29. James, P.; Hart, J.E.; Banay, R.F.; Laden, F. Exposure to Greenness and Mortality in a Nationwide Prospective Cohort Study of Women. *Environ. Health Perspect.* **2016**, *124*, 1344–1352. [CrossRef] [PubMed]
30. Gascon, M.; Sánchez-Benavides, G.; Dadvand, P.; Martínez, D.; Gramunt, N.; Gotsens, X.; Cirach, M.; Vert, C.; Molinuevo, J.L.; Crous-Bou, M.; et al. Long-Term Exposure to Residential Green and Blue Spaces and Anxiety and Depression in Adults: A Cross-Sectional Study. *Environ. Res.* **2018**, *162*, 231–239. [CrossRef] [PubMed]
31. Larkin, A.; Huang, T.; Chen, L.; Lin, P.I.D.; Hart, J.E.; Zhang, W.; Coull, B.A.; Yi, L.; Suel, E.; Hankey, S.; et al. Developing Nationwide Estimates of Built Environment Quality Characteristics Using Street-View Imagery and Computer Vision. *Environ. Sci. Technol.* **2025**, *59*, 13638–13646. [CrossRef] [PubMed]
32. Liu, Q.; Luo, S.; Shen, Y.; Zhu, Z.; Yao, X.; Li, Q.; Tarin, M.W.K.; Zheng, J.; Zhuo, Z. Relationships between Students' Demographic Characteristics, Perceived Naturalness and Patterns of Use Associated with Campus Green Space, and Self-Rated Restoration and Health. *Urban For. Urban Green.* **2022**, *68*, 127474. [CrossRef]
33. Gulwadi, G.B.; Mishchenko, E.D.; Hallowell, G.; Alves, S.; Kennedy, M. The Restorative Potential of a University Campus: Objective Greenness and Student Perceptions in Turkey and the United States. *Landsc. Urban Plan.* **2019**, *187*, 36–46. [CrossRef]
34. Berkes, F.; Folke, C.; Colding, J. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience*; Cambridge University Press: Cambridge, UK, 2000.
35. Ostrom, E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* **2009**, *325*, 419–422. [CrossRef]
36. Ferraro, P.J.; Sanchirico, J.N.; Smith, M.D. Causal Inference in Coupled Human and Natural Systems. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 5311–5318. [CrossRef]
37. Sugiyama, T.; Leslie, E.; Giles-Corti, B.; Owen, N. Associations of Neighbourhood Greenness with Physical and Mental Health: Do Walking, Social Coherence and Local Social Interaction Explain the Relationships? *J. Epidemiol. Community Health* **2008**, *62*, e9. [CrossRef]
38. Simões Aelbrecht, P. 'Fourth Places': The Contemporary Public Settings for Informal Social Interaction among Strangers. *J. Urban Des.* **2016**, *21*, 124–152. [CrossRef]
39. Jansz, S.N.; Van Dijk, T.; Mobach, M.P. Facilitating Campus Interactions – Critical Success Factors According to University Facility Directors. *Facilities* **2021**, *39*, 585–600. [CrossRef]
40. Alves, S.; Betrabet Gulwadi, G.; Nilsson, P. An Exploration of How Biophilic Attributes on Campuses Might Support Student Connectedness to Nature, Others, and Self. *Front. Psychol.* **2022**, *12*, 793175. [CrossRef] [PubMed]
41. Sandstrom, G.M.; Dunn, E.W. Social Interactions and Well-Being: The Surprising Power of Weak Ties. *Personal. Soc. Psychol. Bull.* **2014**, *40*, 910–922. [CrossRef]
42. Hartig, T. Restoration in Nature: Beyond the Conventional Narrative. In *Nature and Psychology: Biological, Cognitive, Developmental, and Social Pathways to Well-Being*; Schutte, A.R., Torquati, J.C., Stevens, J.R., Eds.; Springer International Publishing: Cham, Switzerland, 2021; pp. 89–151. [CrossRef]
43. Pasanen, T.P.; White, M.P.; Elliott, L.R.; van den Bosch, M.; Bratman, G.N.; Ojala, A.; Korpela, K.; Fleming, L.E. Urban Green Space and Mental Health among People Living Alone: The Mediating Roles of Relational and Collective Restoration in an 18-Country Sample. *Environ. Res.* **2023**, *232*, 116324. [CrossRef] [PubMed]
44. Foellmer, J.; Kistemann, T.; Anthonj, C. Academic Greenspace and Well-Being—Can Campus Landscape Be Therapeutic? Evidence from a German University. *Wellbeing Space Soc.* **2021**, *2*, 100003. [CrossRef]
45. Diao, W.; Li, S.; Zhao, B.; Zhang, F. Estimation of Mediators in the Associations between Campus Green Spaces and Students' Anxiety: A Case Study in Nanjing. *Front. Psychol.* **2024**, *15*, 1396548. [CrossRef]
46. Cetin, M.; Aksoy, T.; Cabuk, S.N.; Kurkcuoglu, M.A.S.; Cabuk, A. Employing Remote Sensing Technique to Monitor the Influence of Newly Established Universities in Creating an Urban Development Process on the Respective Cities. *Land Use Policy* **2021**, *109*, 105705. [CrossRef]
47. Meng, Y.; Li, Q.; Ji, X.; Yu, Y.; Yue, D.; Gan, M.; Wang, S.; Niu, J.; Fukuda, H. Research on Campus Space Features and Visual Quality Based on Street View Images: A Case Study on the Chongshan Campus of Liaoning University. *Buildings* **2023**, *13*, 1332. [CrossRef]
48. Wu, T.; Lin, D.; Chen, Y.; Wu, J. Integrating Street View Images, Deep Learning, and sDNA for Evaluating University Campus Outdoor Public Spaces: A Focus on Restorative Benefits and Accessibility. *Land* **2025**, *14*, 610. [CrossRef]

49. Laatikainen, T.; Tenkanen, H.; Kyttä, M.; Toivonen, T. Comparing Conventional and PPGIS Approaches in Measuring Equality of Access to Urban Aquatic Environments. *Landsc. Urban Plan.* **2015**, *144*, 22–33. [CrossRef]
50. Garcia, X.; Gottwald, S.; Benages-Albert, M.; Pavón, D.; Ribas, A.; Vall-Casas, P. Evaluating a Web-Based PPGIS for the Rehabilitation of Urban Riparian Corridors. *Appl. Geogr.* **2020**, *125*, 102341. [CrossRef]
51. Aghabozorgi, K.; van der Jagt, A.; Bell, S.; Smith, H. How University Blue and Green Space Affect Students' Mental Health: A Scoping Review. *Urban For. Urban Green.* **2024**, *97*, 128394. [CrossRef]
52. Sotaquirá, L.; Backhaus, I.; Sotaquirá, P.; Pinilla-Roncancio, M.; González-Uribe, C.; Bernal, R.; Galeano, J.J.; Mejia, N.; La Torre, G.; Trujillo-Maza, E.M.; et al. Social Capital and Lifestyle Impacts on Mental Health in University Students in Colombia: An Observational Study. *Front. Public Health* **2022**, *10*, 840292. [CrossRef] [PubMed]
53. Jennings, V.; Bamkole, O. The Relationship between Social Cohesion and Urban Green Space: An Avenue for Health Promotion. *Int. J. Environ. Res. Public Health* **2019**, *16*, 452. [CrossRef] [PubMed]
54. Colley, K.; Brown, C.; Montarzino, A. Understanding Knowledge Workers' Interactions With Workplace Greenspace. *Environ. Behav.* **2017**, *49*, 314–338. [CrossRef]
55. Tomao, A.; Secondi, L.; Carrus, G.; Corona, P.; Portoghesi, L.; Agrimi, M. Restorative Urban Forests: Exploring the Relationships between Forest Stand Structure, Perceived Restorativeness and Benefits Gained by Visitors to Coastal Pinus Pinea Forests. *Ecol. Indic.* **2018**, *90*, 594–605. [CrossRef]
56. Wang, R.; Cleland, C.L.; Weir, R.; McManus, S.; Martire, A.; Grekousis, G.; Bryan, D.; Hunter, R.F. Rethinking the Association between Green Space and Crime Using Spatial Quantile Regression Modelling: Do Vegetation Type, Crime Type, and Crime Rates Matter? *Urban For. Urban Green.* **2024**, *101*, 128523. [CrossRef]
57. Xu, X.; Sun, X.; Xie, H. Passive Long-Term Acoustic Sampling Reveals Multiscale Temporal Ecological Pattern and Anthropogenic Disturbance of Campus Forests in a High Density City. *Forests* **2025**, *16*, 1289. [CrossRef]
58. Shin, W.S.; Seong, I.K.; Kim, J.G. Psychological Benefits of Self-Guided Forest Healing Program Using Campus Forests. *Forests* **2023**, *14*, 336. [CrossRef]
59. Gascon, M.; Zijlema, W.; Vert, C.; White, M.P.; Nieuwenhuijsen, M.J. Outdoor Blue Spaces, Human Health and Well-Being: A Systematic Review of Quantitative Studies. *Int. J. Hyg. Environ. Health* **2017**, *220*, 1207–1221. [CrossRef]
60. Park, B.J.; Tsunetsugu, Y.; Kasetani, T.; Kagawa, T.; Miyazaki, Y. The Physiological Effects of *Shinrin-yoku* (Taking in the Forest Atmosphere or Forest Bathing): Evidence from Field Experiments in 24 Forests across Japan. *Environ. Health Prev. Med.* **2010**, *15*, 18–26. [CrossRef]
61. Rajoo, K.S.; Karam, D.S.; Abdullah, M.Z. The Physiological and Psychosocial Effects of Forest Therapy: A Systematic Review. *Urban For. Urban Green.* **2020**, *54*, 126744. [CrossRef]
62. Chun, H.r.; Choi, Y.Y.; Cho, I.; Nam, H.k.; Kim, G.; Park, S.; Cho, S.i. Indicators of the Psychosocial and Physiological Effects of Forest Therapy: A Systematic Review. *Forests* **2023**, *14*, 1407. [CrossRef]
63. Zhang, Z.; Ye, B. Forest Therapy in Germany, Japan, and China: Proposal, Development Status, and Future Prospects. *Forests* **2022**, *13*, 1289. [CrossRef]
64. Asim, F.; Chani, P.S.; Shree, V.; Rai, S. Restoring the Mind: A Neuropsychological Investigation of University Campus Built Environment Aspects for Student Well-Being. *Build. Environ.* **2023**, *244*, 110810. [CrossRef]
65. Park, K.; Ergan, S. Quantification of the Impact of Street Design Features on Restorative Quality in Urban Settings. *Sustain. Cities Soc.* **2025**, *121*, 106216. [CrossRef]
66. Ding, Y.; Lee, C.; Chen, X.; Song, Y.; Newman, G.; Lee, R.; Lee, S.; Li, D.; Sohn, W. Exploring the Association between Campus Environment of Higher Education and Student Health: A Systematic Review of Findings and Measures. *Urban For. Urban Green.* **2024**, *91*, 128168. [CrossRef]
67. Miner, P.; Smith, B.M.; Jani, A.; McNeill, G.; Gathorne-Hardy, A. Car Harm: A Global Review of Automobility's Harm to People and the Environment. *J. Transp. Geogr.* **2024**, *115*, 103817. [CrossRef]
68. Maas, J.; van Dillen, S.M.E.; Verheij, R.A.; Groenewegen, P.P. Social Contacts as a Possible Mechanism behind the Relation between Green Space and Health. *Health Place* **2009**, *15*, 586–595. [CrossRef]
69. Peters, K.; Elands, B.; Buijs, A. Social Interactions in Urban Parks: Stimulating Social Cohesion? *Urban For. Urban Green.* **2010**, *9*, 93–100. [CrossRef]
70. Liu, Y.; Wang, R.; Lu, Y.; Li, Z.; Chen, H.; Cao, M.; Zhang, Y.; Song, Y. Natural Outdoor Environment, Neighbourhood Social Cohesion and Mental Health: Using Multilevel Structural Equation Modelling, Streetscape and Remote-Sensing Metrics. *Urban For. Urban Green.* **2020**, *48*, 126576. [CrossRef]
71. Krellenberg, K.; Welz, J.; Reyes-Päcke, S. Urban Green Areas and Their Potential for Social Interaction - A Case Study of a Socio-Economically Mixed Neighbourhood in Santiago de Chile. *Habitat Int.* **2014**, *44*, 11–21. [CrossRef]
72. Chen, S.; Sleipness, O.; Christensen, K.; Yang, B.; Park, K.; Knowles, R.; Yang, Z.; Wang, H. Exploring Associations between Social Interaction and Urban Park Attributes: Design Guideline for Both Overall and Separate Park Quality Enhancement. *Cities* **2024**, *145*, 104714. [CrossRef]

73. Yu, C.P.; Chen, H.T.; Chao, P.H.; Yin, J.; Tsai, M.J. The Role of Social Context in Physiological and Psychological Restoration in a Forest: Case Study of a Guided Forest Therapy Program in Taiwan. *Int. J. Environ. Res. Public Health* **2021**, *18*, 10076. [CrossRef]
74. Gibson, J.J. *The Ecological Approach to Visual Perception: Classic Edition*; Psychology Press: New York, NY, USA, 2014. [CrossRef]
75. Heft, H. *Ecological Psychology in Context: James Gibson, Roger Barker, and the Legacy of William James's Radical Empiricism*; Psychology Press: New York, NY, USA, 2001. [CrossRef]
76. Small, M.L.; Adler, L. The Role of Space in the Formation of Social Ties. *Annu. Rev. Sociol.* **2019**, *45*, 111–132. [CrossRef]
77. Rout, A.; Galpern, P. Benches, Fountains and Trees: Using Mixed-Methods with Questionnaire and Smartphone Data to Design Urban Green Spaces. *Urban For. Urban Green.* **2022**, *67*, 127335. [CrossRef]
78. Zhao, W.; Li, X.; Zhu, X.; Ye, H.; Xu, H. Restorative Properties of Green Sheltered Spaces and Their Morphological Characteristics in Urban Parks. *Urban For. Urban Green.* **2023**, *86*, 127986. [CrossRef]
79. Dalton, L.C.; Hajrasouliha, A.H.; Riggs, W.W. State of the Art in Planning for College and University Campuses: Site Planning and Beyond. *J. Am. Plan. Assoc.* **2018**, *84*, 145–161. [CrossRef]
80. Soares, I.; Weitkamp, G.; Yamu, C. Public Spaces as Knowledgescapes: Understanding the Relationship between the Built Environment and Creative Encounters at Dutch University Campuses and Science Parks. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7421. [CrossRef]
81. Jansz, S.N.; Mobach, M.; Van Dijk, T.; De Vries, E.; Van Hout, R. On Serendipitous Campus Meetings: A User Survey. *Int. J. Environ. Res. Public Health* **2022**, *19*, 14504. [CrossRef]
82. Zhao, J.; Hu, X.; Huang, Y. Mental Restoration, Preference and Safety of Waterscapes: The Effects of Viewing Distance, Type and Movement of Water. *Landsc. Ecol. Eng.* **2024**, *20*, 559–569. [CrossRef]
83. Zhou, Y.; Yang, L.; Yu, J.; Guo, S. Do Seasons Matter? Exploring the Dynamic Link between Blue-Green Space and Mental Restoration. *Urban For. Urban Green.* **2022**, *73*, 127612. [CrossRef]
84. Sara, R.; Albans, A.; Rice, L. The 15-MinuteCampus: Exploring the Potential Impacts on Biodiversity, Health and Wellbeing of Co-Creating 15-Minute City Design Principles on University Campuses. *Architecture* **2025**, *5*, 82. [CrossRef]
85. von Lindern, E.; Lymeus, F.; Hartig, T. The Restorative Environment: A Complementary Concept for Salutogenesis Studies. In *The Handbook of Salutogenesis*; Mittelmark, M.B., Sagy, S., Eriksson, M., Bauer, G.F., Pelikan, J.M., Lindström, B., Espnes, G.A., Eds.; Springer: Cham, Switzerland, 2017; pp. 181–195. [CrossRef]
86. Rapport, D.J.; Gaudet, C.; Karr, J.R.; Baron, J.S.; Bohlen, C.; Jackson, W.; Jones, B.; Naiman, R.J.; Norton, B.; Pollock, M.M. Evaluating Landscape Health: Integrating Societal Goals and Biophysical Process. *J. Environ. Manag.* **1998**, *53*, 1–15. [CrossRef]
87. Wuhan Municipal People's Government. Geography of Wuhan. 2021. Available online: https://english.wuhan.gov.cn/overview4of4wuhan/geography/202110/t20211026_1819195.shtml (accessed on 8 July 2025).
88. Huazhong University of Science and Technology. University Profile. 2025. Available online: https://www.hust.edu.cn/xxgk/xxjj.htm (accessed on 8 July 2025). (In Chinese).
89. Wuhan Water Authority. Infrastructure Construction News Release. 2023. Available online: https://swj.wuhan.gov.cn/tzdt/jcss/202303/t20230316_2170864.html (accessed on 8 July 2025). (In Chinese)
90. Times Higher Education. Huazhong University of Science and Technology: World University Rankings. 2025. Available online: https://www.timeshighereducation.com/world-university-rankings/huazhong-university-science-and-technology (accessed on 8 July 2025).
91. Fooooooot. Fooooooot: Campus and City Walking Activity Platform. 2024. Available online: https://www.fooooooot.com/ (accessed on 2 July 2025).
92. Li, X.; Shang, W.L.; Liu, Q.; Liu, X.; Lyu, Z.; Ochieng, W. Towards a Sustainable City: Deciphering the Determinants of Restorative Park and Spatial Patterns. *Sustain. Cities Soc.* **2024**, *104*, 105292. [CrossRef]
93. facebookresearch. GitHub—Facebookresearch/Mask2Former: Code Release for "Masked-Attention Mask Transformer for Universal Image Segmentation". Available online: https://github.com/facebookresearch/Mask2Former (accessed on 8 July 2025).
94. Li, Y.; Du, X.; Wu, J. Revision of the Chinese Version of the Perceived Restorativeness Scale. *Chin. J. Health Psychol.* **2024**, *32*, 1883–1889.
95. Wooldridge, J.M. *Econometric Analysis of Cross Section and Panel Data*, 2nd ed.; MIT Press: Cambridge, MA, USA, 2010.
96. Derksen, S.; Keselman, H.J. Backward, forward and stepwise automated subset selection algorithms: Frequency of obtaining authentic and noise variables. *Br. J. Math. Stat. Psychol.* **1992**, *45*, 265–282. [CrossRef]
97. Draper, N.R.; Smith, H. *Applied Regression Analysis*, 3rd ed.; John Wiley & Sons: New York, NY, USA, 1998.
98. Koenker, R.; Bassett, G. Regression Quantiles. *Econometrica* **1978**, *46*, 33–50. [CrossRef]
99. Koenker, R. *Quantile Regression*; Cambridge University Press: Cambridge, UK, 2005.
100. White, M.P.; Elliott, L.R.; Gascon, M.; Roberts, B.; Fleming, L.E. Potential Benefits of Blue Space for Human Health and Well-Being. In *Urban Blue Spaces*, 1st ed.; Routledge: London, UK, 2021; pp. 38–58. [CrossRef]

101. Wyles, K.J.; White, M.P.; Hattam, C.; Pahl, S.; King, H.; Austen, M. Are Some Natural Environments More Psychologically Beneficial Than Others? The Importance of Type and Quality on Connectedness to Nature and Psychological Restoration. *Environ. Behav.* **2019**, *51*, 111–143. [CrossRef]
102. Staats, H.; Hartig, T. Alone or with a Friend: A Social Context for Psychological Restoration and Environmental Preferences. *J. Environ. Psychol.* **2004**, *24*, 199–211. [CrossRef]
103. Korpela, K.M.; Ylén, M.; Tyrväinen, L.; Silvennoinen, H. Determinants of Restorative Experiences in Everyday Favorite Places. *Health Place* **2008**, *14*, 636–652. [CrossRef]
104. Huang, W.; Lin, G. The Relationship between Urban Green Space and Social Health of Individuals: A Scoping Review. *Urban For. Urban Green.* **2023**, *85*, 127969. [CrossRef]
105. Ren, D.; Stavrova, O.; Loh, W.W. Nonlinear Effect of Social Interaction Quantity on Psychological Well-Being: Diminishing Returns or Inverted U? *J. Personal. Soc. Psychol.* **2022**, *122*, 1056–1074. [CrossRef] [PubMed]
106. Luo, M.; Macdonald, B.; Hülür, G. Not "The More The Merrier": Diminishing Returns to Daily Face-To-Face Social Interaction Frequency for Well-Being in Older Age. *Journals Gerontol. Ser. B Psychol. Sci. Soc. Sci.* **2022**, *77*, 1431–1441. [CrossRef]
107. Kikusui, T.; Winslow, J.T.; Mori, Y. Social Buffering: Relief from Stress and Anxiety. *Philos. Trans. R. Soc. B Biol. Sci.* **2006**, *361*, 2215–2228. [CrossRef]
108. Ditzen, B.; Heinrichs, M. Psychobiology of Social Support: The Social Dimension of Stress Buffering. *Restor. Neurol. Neurosci.* **2014**, *32*, 149–162. [CrossRef]
109. Mao, Y.; Xia, T.; Hu, F.; Hu, J.; He, Y.; Yan, J.; Wang, L.; Xu, H.; Zhang, J.; Chen, D. Greener Is Not Always Better: Exploring the Non-Linear Relationships between Three-Dimensional Green and Gray Spaces Exposure and Various Physical Activities. *Build. Environ.* **2025**, *272*, 112654. [CrossRef]
110. Markevych, I.; Schoierer, J.; Hartig, T.; Chudnovsky, A.; Hystad, P.; Dzhambov, A.M.; De Vries, S.; Triguero-Mas, M.; Brauer, M.; Nieuwenhuijsen, M.J.; et al. Exploring Pathways Linking Greenspace to Health: Theoretical and Methodological Guidance. *Environ. Res.* **2017**, *158*, 301–317. [CrossRef]
111. Barton, J.; Pretty, J. What Is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis. *Environ. Sci. Technol.* **2010**, *44*, 3947–3955. [CrossRef]
112. Turner, M.G. Landscape Ecology: The Effect of Pattern on Process. *Annu. Rev. Ecol. Syst.* **1989**, *20*, 171–197. [CrossRef]
113. Baskent, E.Z.; Jordan, G.A. Designing Forest Management to Control Spatial Structure of Landscapes. *Landsc. Urban Plan.* **1996**, *34*, 55–74. [CrossRef]
114. Lu, M.; Fu, J. Attention Restoration Space on a University Campus: Exploring Restorative Campus Design Based on Environmental Preferences of Students. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2629. [CrossRef]
115. Dober, R.P. *Campus Landscape: Functions, Forms, Features*; John Wiley & Sons: New York, NY, USA, 2000.
116. Twedt, E.; Rainey, R.M.; Proffitt, D.R. Beyond Nature: The Roles of Visual Appeal and Individual Differences in Perceived Restorative Potential. *J. Environ. Psychol.* **2019**, *65*, 101322. [CrossRef]
117. Kaplan, R.; Kaplan, S. *The Experience of Nature: A Psychological Perspective*; Cambridge University Press: Cambridge, UK, 1989.
118. Nassauer, J.I. Messy Ecosystems, Orderly Frames. *Landsc. J.* **1995**, *14*, 161–170. [CrossRef]
119. Luo, H.; Deng, L.; Song, C.; Jiang, S.; Huang, Y.; Wang, W.; Liu, X.; Li, S.; Guo, B.; Peng, L.; et al. Which Characteristics and Integrations between Characteristics in Blue–Green Spaces Influence the Nature Experience? *J. Environ. Plan. Manag.* **2023**, *66*, 1253–1279. [CrossRef]
120. Liu, S.; Zhao, D.J.; Xu, M.; Ahmadian, E. Effects of Landscape Patterns on the Summer Microclimate and Human Comfort in Urban Squares in China. *Sustain. Cities Soc.* **2021**, *73*, 103099. [CrossRef]
121. Antonelli, M.; Barbieri, G.; Donelli, D. Effects of Forest Bathing (Shinrin-Yoku) on Levels of Cortisol as a Stress Biomarker: A Systematic Review and Meta-Analysis. *Int. J. Biometeorol.* **2019**, *63*, 1117–1134. [CrossRef]
122. Peng, L.; Cao, S.; Chen, Y.; Zeng, B.; Lin, D.; Xie, C.; Li, X.; Ma, J. The Restorative Effect of Urban Forest Vegetation Types and Slope Positions on Human Physical and Mental Health. *Forests* **2025**, *16*, 653. [CrossRef]
123. Hao, J.; Li, Y.; Hu, T.; Ma, Y.; Wang, X.; Liu, J.; Gao, T.; Qiu, L. Vegetation Diversity in Structure, Species or Colour: Coupling Effects of the Different Characteristics of Urban Green Spaces on Preference and Perceived Restoration. *Ecol. Indic.* **2024**, *169*, 112897. [CrossRef]
124. Forman, R.T.T.; Alexander, L.E. Roads and Their Major Ecological Effects. *Annu. Rev. Ecol. Evol. Syst.* **1998**, *29*, 207–231. [CrossRef]
125. Forman, R.T.T. Estimate of the Area Affected Ecologically by the Road System in the United States. *Conserv. Biol.* **2000**, *14*, 31–35. [CrossRef]
126. Laurance, W.F.; Goosem, M.; Laurance, S.G. Impacts of Roads and Linear Clearings on Tropical Forests. *Trends Ecol. Evol.* **2009**, *24*, 659–669. [CrossRef]
127. Appleyard, D.; Gerson, M.S.; Lintell, M. *Livable Streets*; University of California Press: Berkeley, CA, USA, 1981.

128. Blomquist, E. *Revitalising Urban Public Green Space : Exploring Lived Experiences of Teenage Girls in Socio-Economically Challenged Neighbourhoods in Stockholm, Sweden, Using Google Maps*; School of Natural Sciences, Technology and Environmental Studies: Stockholm, Sweden, 2021.
129. Wu, S.; Chen, B.; Webster, C.; Xu, B.; Gong, P. Improved Human Greenspace Exposure Equality during 21st Century Urbanization. *Nat. Commun.* **2023**, *14*, 6460. [CrossRef]
130. Bornioli, A.; Hopkins-Doyle, A.; Fasoli, F.; Faccenda, G.; Subiza-Pérez, M.; Ratcliffe, E.; Beyazit, E. Sex and the City Park: The Role of Gender and Sex in Psychological Restoration in Urban Greenspaces. *J. Environ. Psychol.* **2024**, *100*, 102476. [CrossRef]
131. Nazmul Haque, M.; Sharifi, A. Justice in Access to Urban Ecosystem Services: A Critical Review of the Literature. *Ecosyst. Serv.* **2024**, *67*, 101617. [CrossRef]
132. Gifford, R. Environmental Psychology Matters. *Annu. Rev. Psychol.* **2014**, *65*, 541–579. [CrossRef]
133. Zhang, X.; Lin, E.S.; Tan, P.Y.; Qi, J.; Ho, R.; Sia, A.; Waykool, R.; Song, X.P.; Olszewska-Guizzo, A.; Meng, L.; et al. Beyond Just Green: Explaining and Predicting Restorative Potential of Urban Landscapes Using Panorama-Based Metrics. *Landsc. Urban Plan.* **2024**, *247*, 105044. [CrossRef]
134. Wang, H.; Gholami, S.; Xu, W.; Samavatekbatan, A.; Sleipness, O.; Tassinary, L.G. Where and How to Invest in Greenspace for Optimal Health Benefits: A Systematic Review of Greenspace Morphology and Human Health Relationships. *Lancet Planet. Health* **2024**, *8*, e574–e587. [CrossRef]
135. Nguyen, P.Y.; Astell-Burt, T.; Rahimi-Ardabili, H.; Feng, X. Green Space Quality and Health: A Systematic Review. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11028. [CrossRef]
136. Fan, P.Y.; Chun, K.P.; Mijic, A.; Tan, M.L.; Liu, M.S.; Yetemen, O. A Framework to Evaluate the Accessibility, Visibility, and Intelligibility of Green-Blue Spaces (GBSs) Related to Pedestrian Movement. *Urban For. Urban Green.* **2022**, *69*, 127494. [CrossRef]
137. Garrett, J.; White, M.; Huang, J.; Ng, S.; Hui, Z.; Leung, C.; Tse, L.; Fung, F.; Elliott, L.; Depledge, M.; et al. Urban Blue Space and Health and Wellbeing in Hong Kong: Results from a Survey of Older Adults. *Health Place* **2019**, *55*, 100–110. [CrossRef] [PubMed]
138. Wan, J.; Wu, H.; Collins, R.; Deng, K.; Zhu, W.; Xiao, H.; Tang, X.; Tian, C.; Zhang, C.; Zhang, L. Integrative Analysis of Health Restoration in Urban Blue-Green Spaces: A Multiscale Approach to Community Park. *J. Clean. Prod.* **2024**, *435*, 140178. [CrossRef]
139. Neher, D.A.; Williams, K.M.; Lovell, S.T. Environmental Indicators Reflective of Road Design in a Forested Landscape. *Ecosphere* **2017**, *8*, e01734. [CrossRef]
140. Gregory, A.; Spence, E.; Beier, P.; Garding, E. Toward Best Management Practices for Ecological Corridors. *Land* **2021**, *10*, 140. [CrossRef]
141. Bornioli, A.; Gatersleben, B. Man or Bear? How Gender Affects Experiences of Natural Environments with Varying Levels of Vegetation Density and Different Danger Threats. *J. Environ. Psychol.* **2025**, *106*, 102722. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.