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The restorative value of urban environments: A systematic review of quantitative evidence, methods and data

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ABSTRACT

Amidst ongoing urbanisation, understanding how various urban elements contribute to stress reduction and well-being is increasingly crucial. However, existing research has prioritized natural elements, reinforcing a nature-urban dichotomy that overlooks the restorative potential of the built environment itself. This systematic review examines the restorative value of urban environments through quantitative studies from 2010 to 2024, exploring the effects on cognitive, affective, and physiological outcomes. Following the Synthesis Without Meta-analysis (SWiM) reporting guideline, it narratively synthesises findings from 50 quantitative human studies, identified through PRISMA-referenced screening of peer-reviewed articles that report associations between urban environmental characteristics and restorative outcomes. Results indicate urban spaces with integrated greenery are more often linked to higher perceived restorativeness and short-term psychological benefits than predominantly grey comparators. Several built environment characteristics, including architectural façade design, design quality, service facilities, and street-scale vegetation, were positively associated with restoration. Psycho-environmental characteristics (e.g., serenity, prospect, refuge) and person–place relationships further shape restorative experiences. Future research should focus more on various urban settings—high-density neighbourhoods, historical districts, and waterfronts—and compare similarities and differences in their restorative mechanisms. The review identifies emerging neuro-urbanism and big-data approaches as transformative tools; despite current methodological limitations, they radically expand the potential to clarify mechanisms and enhance generalisability. Based on the evidence extracted from the 50 studies, an evidence-informed, hypothesis-generating conceptual framework is proposed to map the observed associations between urban environment attributes, restorative value, and health and well-being. The framework organises current associational evidence and identifies testable pathways for future research rather than depicting confirmed causal chains.

1. Introduction

The intricate connection between urban environments and human well-being has been a significant focus of research, particularly as urban populations continue to grow rapidly worldwide. The urban environment, which includes patterns of land use, built structures, open spaces and transportation systems (Handy et al., 2002; Brownson et al., 2009), has the potential to influence mental health, overall well-being, and urban sustainability (Lei et al., 2025; Lee and Houston, 2024; Sheikh and van Ameijde, 2022; Wang et al., 2022a, 2022b). While much work has emphasised the negative impacts of urban living, such as noise, crowding and pollution as key stressors (Gomm and Bernauer, 2023), a growing body of evidence highlights that certain urban settings can also promote comfort (Liu et al., 2023), enhance health and well-being (Syamili et al., 2023), and support psychological recovery (Li et al., 2021; Tsurumi et al., 2024). For example, urban green spaces, public open spaces, and historical districts have been widely acknowledged for their ability to foster resilience, reduce stress, and enhance restoration

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(Jahani and Saffariha, 2020; Li et al., 2023a, 2023b; Li et al., 2024; Pazhouhanfar and M.S., 2014; Wang et al., 2016).

Restoration is generally defined as "the experience of a psychological and/or physiological recovery process that is triggered by particular environments and environmental configurations" (Joye and van den Berg, 2018). Two major theories explain how environments may promote such recovery: Attention Restoration Theory (ART) (Kaplan, 1995; Kaplan and Kaplan, 1989) and Stress Reduction Theory (SRT) (Ulrich, 1983; Ulrich et al., 1991). ART conceptualises restoration as the replenishment of cognitive resources depleted by prolonged directed attention and uses the term restorativeness to describe the perceived potential of an environment to support recovery, typically characterised by fascination, being away, extent and compatibility. SRT, in contrast, focuses on emotional and physiological stress recovery and proposes that people respond quickly and positively to certain natural features, thereby reducing stress and improving mood. Although they emphasise different mechanisms, both theories suggest that environments with these restorative qualities—often found in natural settings—can produce measurable benefits for mental and physical health and well-being (Berto, 2014; Bodin and Hartig, 2003; Hartig et al., 2014; Mitchell, 2013; Kajosaari and Pasanen, 2021). While in many studies, the built environment has been treated as stressor that limits restorative potential and benefits, recent studies suggest that thoughtfully designed urban settings combining architectural and natural elements can also exhibit these qualities (Nordh et al., 2017; Korpela et al., 2010; Roe et al., 2019; Wu et al., 2024; Bornioli and Subiza-Pérez, 2023), challenging the assumption that restoration is limited to nature alone. In this review, we use the term 'restorative value' as an umbrella concept that includes both perceived restorativeness (i.e. how restorative people judge an environment to be) and measured restoration outcomes, such as changes in affect, cognition and physiological responses.

As urbanisation accelerates, the majority of the global population now lives in cities, often in conditions that heighten daily stress levels (Stigsdotter and Grahn, 2011; Wang et al., 2016). As access to natural landscapes is limited for most urban residents, it is essential to identify opportunities for restoration within the environments they encounter daily. Urban environments are complex systems that encompass both urban green spaces such as parks, gardens, and vegetated corridors (Dempsey et al., 2011; World Health Organization, 2021), and built ("grey") environments dominated by human-made structures (Ito et al., 2024; Liu et al., 2022). Yet, restoration research has disproportionately focused on natural or rural contexts, with many urban settings, scenarios and characteristics of built environments remaining underexplored. A clearer understanding of how the diverse components of the urban fabric contribute to restorative benefits is therefore needed to support healthier, more supportive cities.

Before conducting this review, we identified nine review papers that examined the restorative value of environments (Appendix A summarizes their scope and key gaps). Three are primarily nature-focused, concentrating on rural or wilderness settings and largely overlooking variations within cities (Berto, 2014; Syed Othman Thani et al., 2024; Yao et al., 2021). Two include urban environments but only at a coarse level, without analyzing the role of specific urban elements or scenarios (Menardo et al., 2021; Sedghikhanshir et al., 2022). The remaining four adopt narrow scopes, for example by focusing on single environmental features or populations, or on restricted methodologies or time periods (Subiza-Pérez et al., 2019; Karaman Madan et al., 2024; Grave et al., 2023; Weber and Trojan, 2018). Overall, most conclude that natural settings are generally more restorative than urban environments, yet they also hint at the potential of specific urban situations, such as certain streets, squares or visual properties. However, existing reviews do not provide comprehensive, up-to-date quantitative evidence on how specific urban scenarios and design features affect restorative outcomes. In particular, an integrated, cross-disciplinary synthesis is still missing that brings together recent, state-of-art empirical work from environmental psychology, urban design, public health, and urban data science to explain how diverse urban environments support or hinder psychological restoration.

Recent advances in urban data science, neuro-architecture and neuro-urbanism have opened new possibilities for evaluating the restorative potential of urban environments. Neuro-urbanism studies increasingly use physiological indicators (e.g. heart rate variation, electroencephalogram) alongside affective scales and established restoration measures, offering more objective and finer-grained insights into how specific urban features influence cognitive, emotional and physiological states (Bradley and Lang, 2000; Lench et al., 2011). In parallel, machine learning and computer vision techniques applied to street-view images and urban modelling provide powerful tools to model and map restorative value across city and regional level (Ma et al., 2023; Zhang et al., 2024), but also introduce methodological challenges regarding validation and generalization of new findings. Yet, to our knowledge, no review has systematically synthesized how these emerging data sources and methods are being used, evaluated and validated across different contexts. This limits the prospect of these approaches to uncover the pathways between urban design and human well-being, as the restorative potential of urban environments has yet to be fully realized.

To address the above gaps in existing reviews and empirical studies, this paper provides an updated, cross-disciplinary structured narrative synthesis of research on the restorative value of urban environments. Its contributions are threefold:

- It systematically reviews and evaluates the quantitative methods and data sources used to measure restorative experiences and outcomes, including recent advances in neuro-urbanism and urban data science.
- It examines both urban green spaces and built ("grey") environments in studies published over the last 15 years, moving beyond the conventional nature-urban dichotomy to capture the full spectrum of restorative potential within cities.
- It synthesises evidence on how restorative experiences in urban contexts relate to broader health and well-being outcomes, and proposes an evidence-informed, hypothesis-generating conceptual framework mapping environmental features, restorative value, and health outcomes. The framework organises currently reported directional associations and identifies where evidence is absent or inconsistent, in order to prioritise testable hypotheses for future research directions and, in turn, urban design and public health policy.

This article aims to answer the following research questions:

1) What quantitative methods and data have been used to measure restorative value in urban environments?
2) What specific urban settings and environmental features contribute to restorative value?
3) What are the potential pathways linking urban environments, restorative value, and health and well-being outcomes?

2. Methodology of the review

2.1. Literature search

To address these questions, we conducted a literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). To capture recent evidence on urban restorative environments and state-of-the-art methodological developments, we analysed quantitative studies published between 2010 and 2024 on restorative value in urban environments (including both restorativeness and restoration). This 15-year timeframe was chosen to capture the most recent evidence on urban restorative environments and contemporary methodological developments. Searches were conducted in Web of Science, Scopus, PubMed and PsycINFO in January 2025.

The search strategy was guided by the need to understand which specific urban environmental features, both green and built (i.e., 'grey'), contribute to restorative value and how these features have been measured in recent empirical studies. To ensure a comprehensive yet precise review, we developed search terms reflecting the three key research questions: 1) structural and spatial attributes of urban environments, 2) psychological and experiential dimensions of restoration, and 3) environmental features influencing restorativeness and restoration.

The search strategy was developed around two concept sets: (A) urban environments, including built and green settings (e.g. architecture, built environment, urban environment, urban green spaces, urban parks, recreation areas), and (B) restoration and health, including restorative value and related outcomes (e.g. perceived restorativeness, restoration, restoration likelihood, restoration possibilities, health, and Kaplan's four restorative qualities: being away, compatibility, extent, fascination). Terms within each set were combined with OR and the two sets were combined with AND. The search strategy was pre-tested and refined through several trial runs (initially in Web of Science and Scopus). The two reviewers independently compared retrieved records against a set of known eligible studies and iteratively revised the search terms through discussion until both agreed that the strategy achieved satisfactory sensitivity. To ensure formal peer review, consistent reporting of quantitative methods, and comparability across databases, we restricted the search to peer-reviewed, English-language journal articles. Full database-specific search strings, field tags, filters (publication type, language, year range) and the date of the last search for each database are provided in Appendix F to support transparency and replicability.

The inclusion criteria were that each paper must present a: 1) Quantitative human study within a defined geographical setting. 2) Measures of the urban environment. Either objective (e.g., researcher or third-party assessment, GIS analysis, computational techniques, selection of varied scenarios) or subjective (e.g., participant-reported perceptions, visual preference ratings) environment feature assessment should be included. 3) Measures of restorativeness, restoration, physiological responses, or stress reduction. The search identified 2459 articles. After removing duplicates, 2304 studies remained (Fig. 1).

A screening process was used to further reduce the number of studies. To maintain a focused review on empirical evidence regarding how specific urban environments and characteristics influence restorative value, we applied the following exclusion criteria: 1) opinion, review, and comment articles; 2) studies without a geographical component; 3) those not measuring restorative value or urban environments; 4) those focusing only on natural or rural areas, ecological restoration, or resilience; 5) qualitative studies without experimental data; and 6) Studies using urban environments solely as a control group were excluded if the selected urban areas were highly degraded, homogeneous grey environments (e.g., unmaintained asphalt parking lots, vacant lots with debris, or windowless concrete tunnels) serving only to

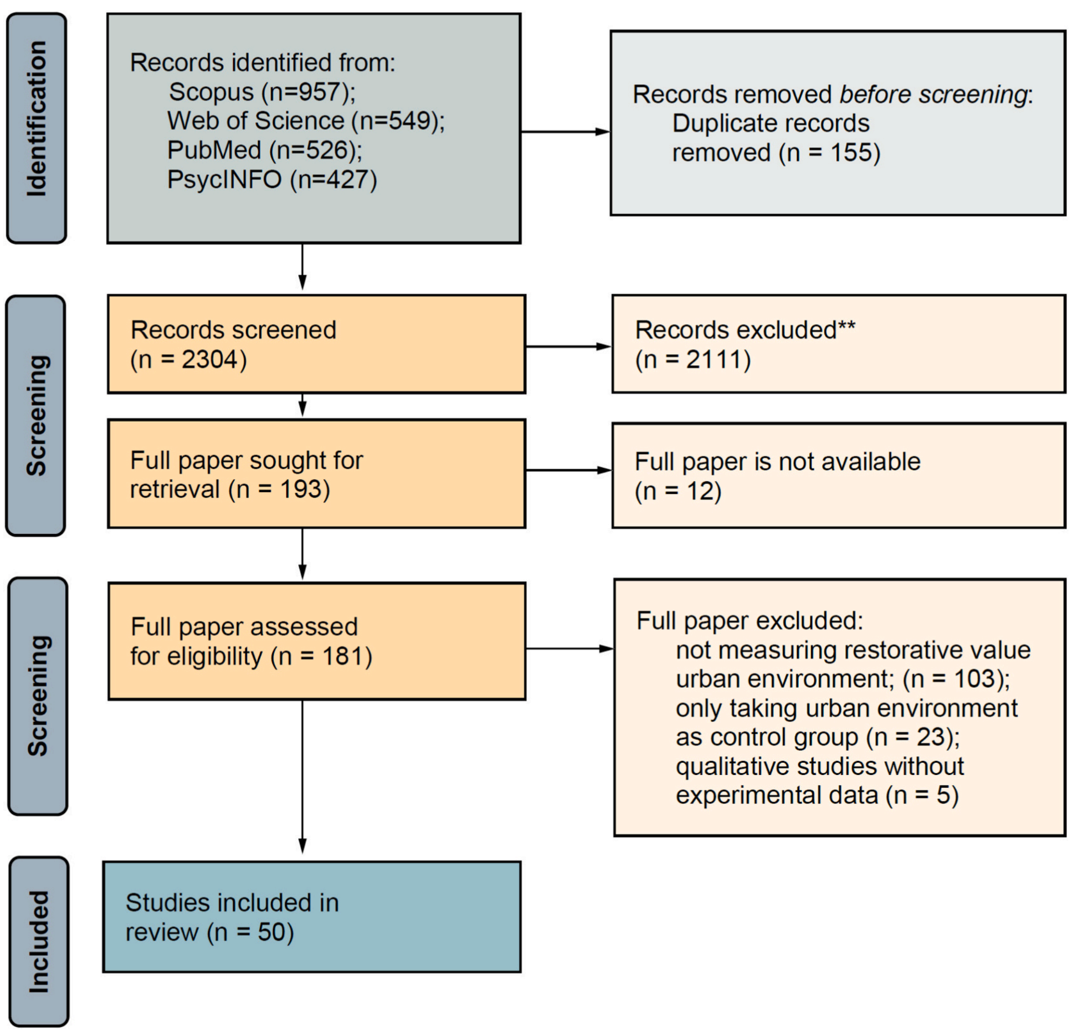

Fig. 1. PRISMA flow diagram.

maximize contrast with nature. However, studies using functional urban settings as controls (e.g., typical residential streets, commercial plazas, or urban squares) were included to assess their comparative restorative potential.

The screening process identified 193 studies for abstract and full-text review. To ensure consistency and reliability in applying this criterion, authors discussed and agreed upon the operationalization of this, achieving reliable inter-coder reliability (Kappa = 0.89). 12 studies were excluded due to unavailable full texts. The remaining 181 studies were assessed for eligibility, with 131 studies excluded for reasons such as not measuring restorative value in urban environments, using homogeneous urban settings only as control groups ($n = 23$), or lacking experimental data in qualitative studies ($n = 5$). This resulted in a final inclusion of 50 studies in the review.

2.2. Data extraction

The data extracted for this review were organized into several key categories: 1) general study information, including publication year, study design, study location, and study level; 2) participant characteristics, including sample size, and socio-demographic variables (e.g., age, gender, socio-economic status), aiming to identify potential confounders of restorative outcomes and assess sample representativeness; 3) methodological details, covering the measurement of restorative perceptions and outcomes, assessment of environmental features, health benefits, and the statistical analyses employed, with the aim of evaluating the validity and quality of study designs, as well as reviewing trends in state-of-the-art measurement and analytical techniques; and 4) key findings, focusing on the associations identified between environmental factors and restorative perceptions or outcomes, including reported effect sizes (e.g., β, r, ρ) and statistical significance (*p*-values). Effect estimates were extracted as descriptive study-level information to document the reporting heterogeneity of the field; they were not intended for direct quantitative comparison across studies owing to fundamental differences in metrics, models, and study designs.

2.3. Quality assessment

Study quality was assessed using the Effective Public Health Practice Project (EPHPP) tool (Thomas et al., 1999), which is applicable to diverse designs (e.g. observational, cross-sectional, cohort, pre–post, randomized controlled trials) and is widely used in public health reviews (e.g. Mnich et al., 2019). The EPHPP evaluates six domains: (1) selection bias, (2) study design, (3) control of confounding variables, (4) blinding, (5) data collection methods, and (6) withdrawals and drop-outs. Each domain was rated as strong, moderate, or weak. Overall study quality was classified as: strong (no weak ratings), moderate (one weak rating), or weak (two or more weak ratings). A detailed description of the criteria is provided in Appendix B.

Two independent coders assessed all included studies. After agreeing on rating principles, they coded the studies separately and resolved any disagreements through discussion to reach a consensus rating, ensuring consistency and reducing bias in the quality assessment.

2.4. Evidence synthesis

Given the substantial heterogeneity in study designs, exposure definitions, outcome assessments, and analytic strategies across the included studies, neither formal meta-analytic pooling nor quantitative moderator analysis was feasible. We therefore conducted a structured narrative synthesis following the Synthesis Without Meta-analysis (SWiM) reporting guideline (Campbell et al., 2020). Accordingly, the present review should be understood as providing a structured narrative synthesis of directional associations, methodological trends, and evidence gaps, rather than a pooled quantitative effect synthesis.

Evidence was grouped by environmental parameter. For each exposure–outcome association, we coded the direction of the reported relationship as positive, negative, or non-significant/not reported ($p < 0.05$ threshold). When multiple models for the same parameter–outcome pair appeared within a single study, the association was counted once, prioritising the fully adjusted model. Parameters examined in only one study were excluded from the summary table to avoid interpretation based on isolated findings. Mixed findings were defined as cases in which at least two studies reported associations in opposing directions or with differing statistical significance. Following the SWiM reporting guideline (Campbell et al., 2020), this review employs a vote-counting approach based on direction of effect. Throughout the study, the term ‘consistent’ (and related terms such as ‘consistency’) refers exclusively to the directional agreement among reported associations (i.e., whether included studies examining a given parameter predominantly report the same direction of association), and should not be interpreted as referring to the strength, magnitude, or generalisability of effects.

To assess the robustness of the observed directional patterns, we conducted a pre-specified sensitivity analysis targeting confounding control—the domain most directly relevant to the validity of reported associations in predominantly observational and cross-sectional designs, where uncontrolled confounders represent the primary threat to internal validity. Studies rated “weak” on the EPHPP confounders domain (i.e., important confounders neither identified nor controlled; $n = 18$) were classified as high risk of bias for the purposes of this analysis. The direction-of-effect patterns were then re-examined using only the remaining studies (those rated moderate or strong on confounding control) to determine whether principal findings were sensitive to confounding quality.

3. Analytical framework

Fig. 2 presents the conceptual framework that guided the review strategy, data analysis, and presentation of findings. Building on theories and empirical work on restorative environments (Sedghikhanshir et al., 2022; Subiza-Pérez et al., 2019; Karaman Madan et al., 2024; Weber and Trojan, 2018; Grave et al., 2023), it situates psychological restoration theory within explicitly urban contexts. The framework highlights three central components: (i) environmental exposures, (ii) restoration processes and outcomes, and (iii) links between restoration and longer-term health and well-being. In this section we briefly introduce the key concepts associated with each component, which underpin the analyses in Section 4.

3.1. Urban environments as environmental exposure

Urban environments are complex socio-spatial systems. While urban nature in green spaces (UGS) is consistently associated with psychological benefits, the wider urban built environment (UBE) also plays an important but often under-examined role in restoration (Weber and Trojan, 2018; Subiza-Pérez et al., 2019). Our framework therefore distinguishes between UGS and UBE. UBE refers to human-made structures and spaces such as buildings, streets, and other infrastructure where daily activities occur (Dempsey et al., 2011). UGS refers to areas dominated by natural elements within cities—such as parks, gardens and other vegetated spaces—that provide recreational and environmental benefits (World Health Organization, 2021). Following Weber and Trojan (2018), this UGS–UBE distinction allows us to compare their restorative potential and identify specific features within each. In relation to Research Question 2, we first summarize studies comparing UGS and UBE scenarios and then examine evidence on particular characteristics within these categories.

3.2. Measures of restorative value

Restorative value is operationalized through cognitive, affective, and

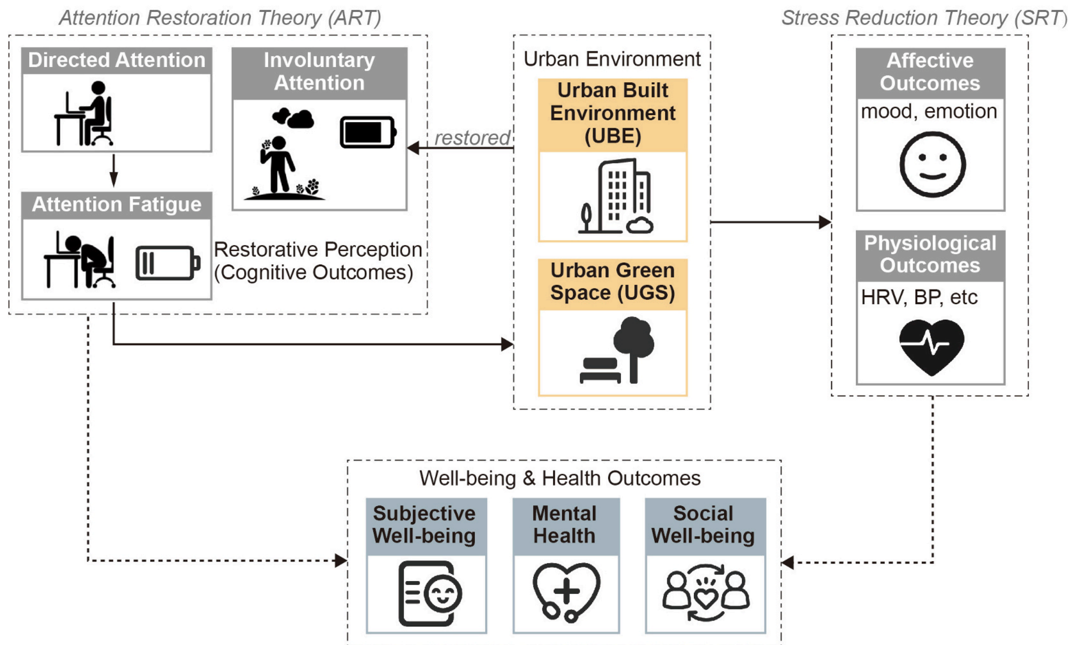

Fig. 2. Analytical Framework, illustrating how urban environments, including Urban built environment (UBE) and Urban green spaces (UGS), influence restorative outcomes based on ART and SRT. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

physiological measures, a common approach in restorative environment research (Subiza-Pérez et al., 2019). Cognitive measures capture restoration of attention and executive functioning, often linked to ART, which posits that directed attention is a limited resource that can be replenished in environments offering being-away, extent, soft fascination, and compatibility (Kaplan and Kaplan, 1989). Affective measures assess mood, emotions, and perceived arousal, drawing on SRT, which emphasises environments that rapidly reduce arousal and perceived threat, particularly those rich in natural elements (Urich et al., 1991). Physiological indicators such as heart rate variability, skin conductance, blood pressure, and cortisol (Asim et al., 2023) provide objective indices of stress and recovery processes.

3.3. Health outcomes

Restoration processes may in turn influence health and wellbeing outcomes over longer timescales (Sedghikhanshir et al., 2022; Subiza-Pérez et al., 2019). In this framework, we group these outcomes into three categories: (1) mental health, including symptoms and general mental well-being (WHO, 2021); (2) subjective well-being, or happiness and life satisfaction (Veenhoven, 1984); and (3) social well-being, referring to perceived belonging, social inclusion, and the quality of social relationships and roles (Keyes, 1998).

Guided by this framework, the Results section first reviews the measures used in the 50 studies, then examines their associations with UGS and UBE scenarios and characteristics, and finally considers reported impacts on individual health and well-being.

4. Results

The Results are organized as follows. We first describe the characteristics and methodological quality of the 50 included studies. We then summarize how restorative value has been measured and how methods and study designs have evolved. Next, we review key confounders and covariates. Finally, we synthesize evidence on associations between urban environments, restorative outcomes, and health.

4.1. Descriptive results

Among the reviewed studies, the trend in the number of research papers published from 2010 to 2024 (Fig. 3) shows a gradual increase, indicating a growing interest in the urban restorative value study over the years. The most significant surge in publications occurred from 2021 onwards, highlighting a heightened focus on this field. The studies encompass a diverse range of study areas, sample size, and level of study (Fig. 4). The majority of studies were conducted in Asia (n = 28), followed by Europe with 15 studies. Fewer studies were carried out in the Americas (n = 4), Middle East (n = 2), and Oceania (n = 1). In terms of sample size, 38% of reviewed studies included 100–500 participants (n = 19), followed by large-scale studies with over 500 participant (n = 13). A smaller number of studies involved fewer than 50 participants (n = 12) or 50–100 participants (n = 6). In terms of study scale, most were carried out at the local level (n = 36), with a smaller but growing number at the city level (n = 13), and only one conducted at the building level (n = 1). The characteristics of the 50 reviewed papers are summarized in Fig. 5, and the effect sizes of environmental features are reported in Appendix C.

4.2. Quality assessment

Using the EPHPP tool, we evaluated six domains: selection bias, study design, control of confounders, blinding, data collection, and withdrawals/dropouts. Overall study quality was acceptable: 84% (N = 42) were rated moderate, 10% (N = 5) strong, and 6% (N = 3) weak. The main weaknesses concerned selection bias and control of confounders, which limit validity and generalisability.

Selection bias was frequently an issue. Over half of the studies (56%; N = 28) were rated moderate, mainly due to convenience samples, a heavy reliance on university students, and small sample sizes (e.g. Asim et al., 2023; Li and Du, 2024; Roe et al., 2019). Thirty-six percent (N = 18) achieved strong ratings, typically by using larger or more diverse samples (e.g. Zhang et al., 2024; Wu et al., 2024; Chang et al., 2024). Four studies (8%) were rated weak because small, unrepresentative samples in online or cross-sectional surveys limited external validity (e.g. Li et al., 2023a, 2023b; Chen et al., 2022; Han et al., 2023; Wang and Li, 2024).

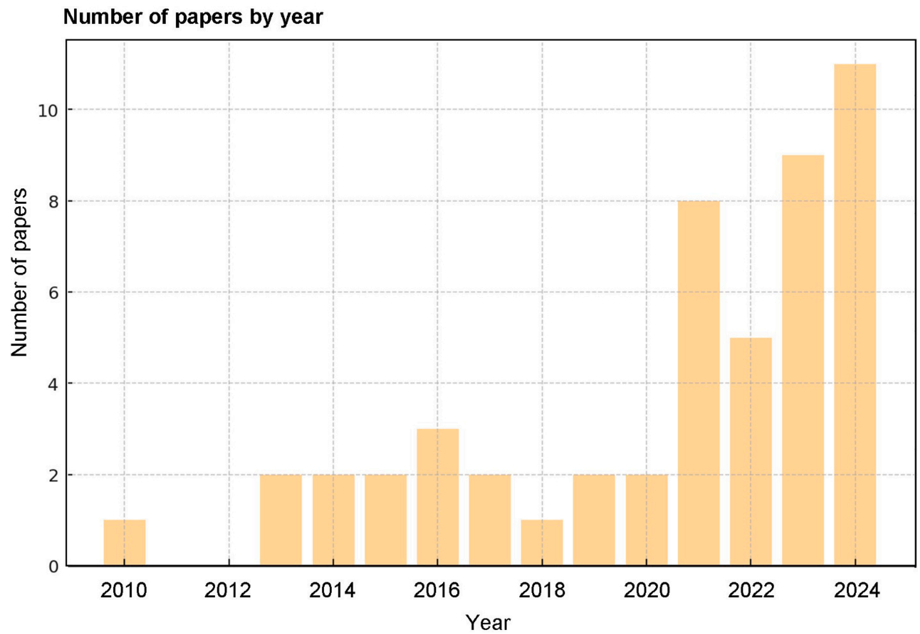

Fig. 3. Number of papers by year, indicating a growing interest in the urban restoration study from 2020 onwards.

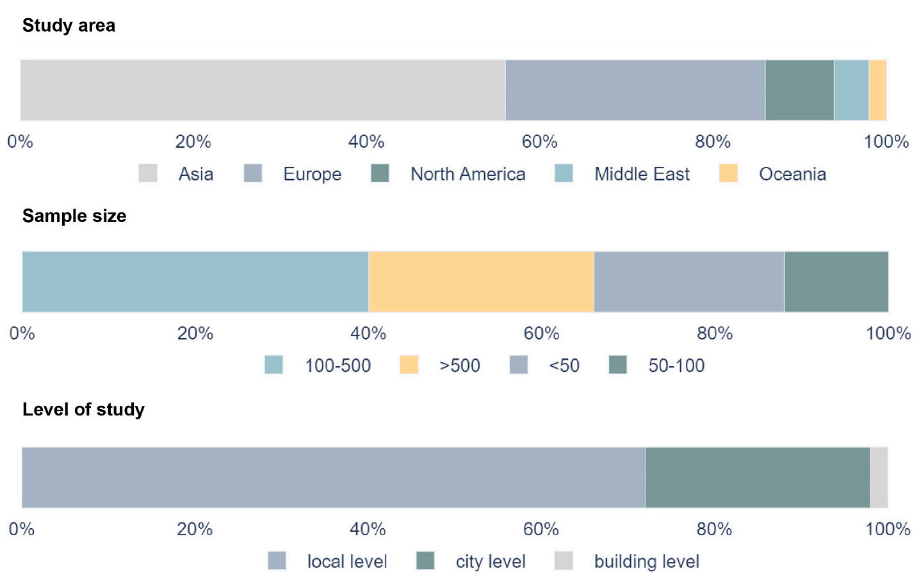

Fig. 4. Descriptive result of study area, sample size, and level of study.

For study design, 74% ($N = 37$) were rated moderate and 26% ($N = 13$) strong. Cross-sectional and quasi-experimental designs predominated. Only a minority of quasi-experiments combined random assignment, baseline measurements and control conditions (e.g. Masullo et al., 2021; Jeon et al., 2023; Asim et al., 2023). Others used fixed exposure orders (e.g. Li and Du, 2024) or lacked control groups (e.g. Wang and Li, 2024), increasing risk of bias. Cross-sectional and online surveys contributed substantial data (e.g. Wu et al., 2024; Qi et al., 2021) but offered limited causal inference.

Control of confounders was the weakest domain. Just over half of studies (52%; $N = 26$) were rated moderate, usually controlling for a small set of sociodemographic variables. 36% (N = 18) did not control for any confounders, undermining internal validity. Only six studies controlled for a broader range of factors, including personality traits, environmental preferences or health status (e.g. Subiza-Pérez et al., 2021a, 2021b; Uebel et al., 2021; Kajosaari and Pasanen, 2021).

Data collection was generally strong: 88% ($N = 44$) used well-established, validated instruments such as the Perceived Restorativeness Scale (PRS), supporting reliable measurement. Six studies (12%) were rated moderate. Two used shortened online PRS versions without reporting reliability (Han et al., 2023; Ma et al., 2023), and four relied on self-developed restorative scales (Kajosaari and Pasanen, 2021; Jahani and Saffariha, 2020; Pazhouhanfar and M.S., 2014; Hajibeigi et al., 2023), which require further validation.

Blinding and withdrawals/dropouts were largely not applicable for cross-sectional and online surveys that involved single-time-point assessments and no follow-up.

4.3. Measurement of urban restorative value

Across the 50 studies, we identified a diverse range of approaches to evaluating restorative potential in urban environments (Fig. 6). All

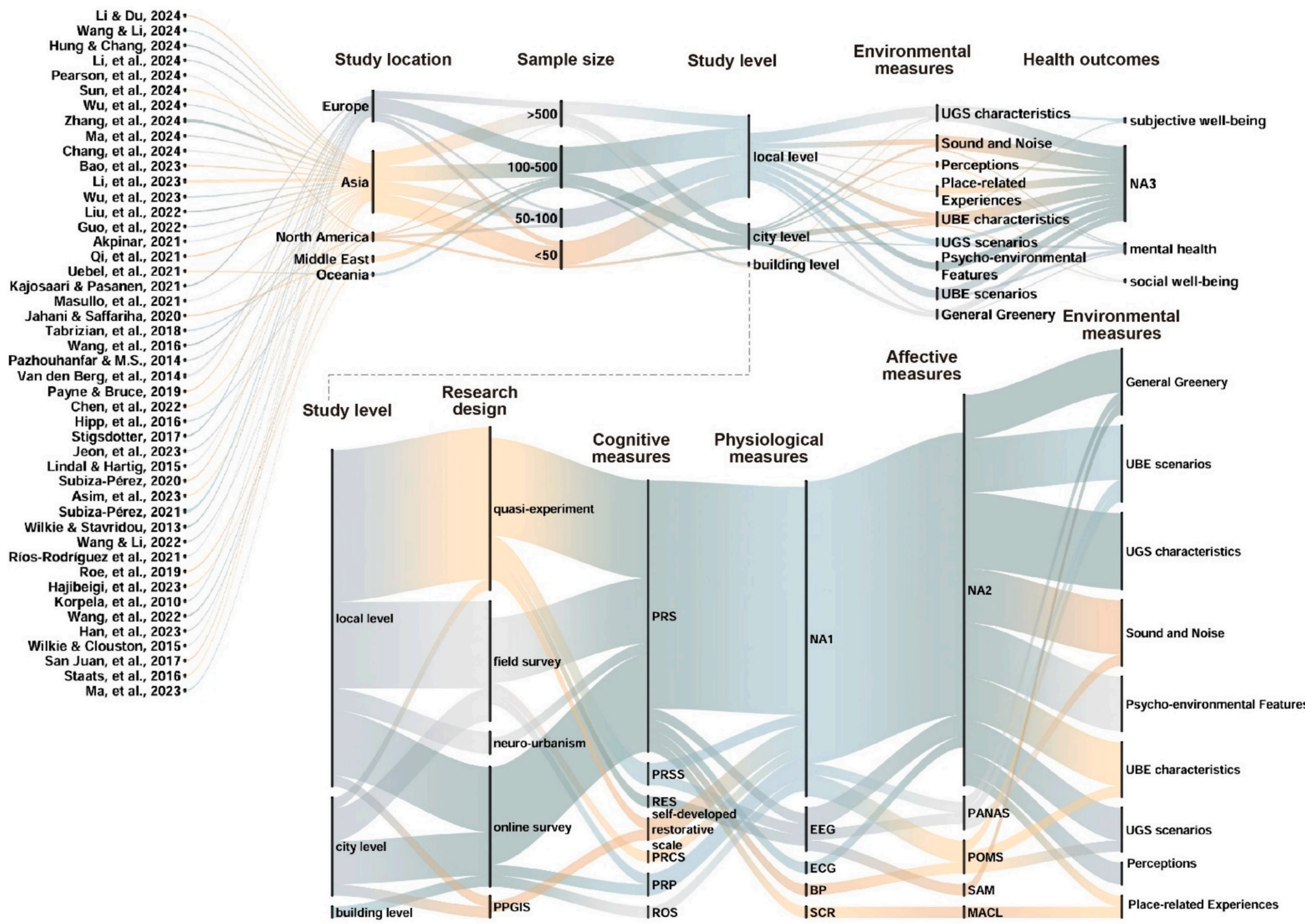

Fig. 5. Sankey diagram of the overall reviewed studies, NA denotes to 'not applicable'.

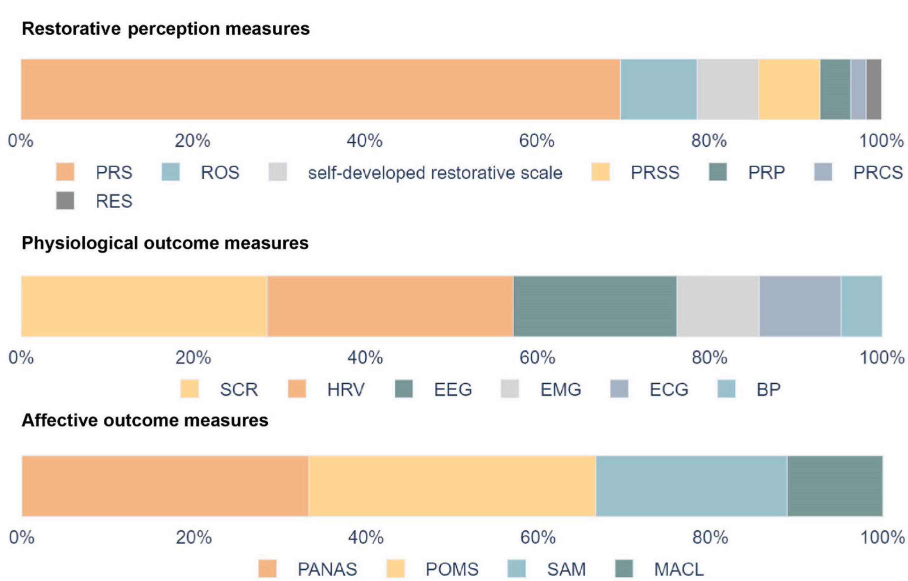

Fig. 6. Descriptive results and the measurement of restorative value.

studies used cognitive or perceived measures of restorativeness or restoration; nine incorporated physiological outcomes via neuro-urbanism techniques; and eight included affective measures. Cognitive measures remain dominant, with physiological and affective outcomes typically used as supplementary indicators. Since around 2022 there has been a clear increase in studies incorporating physiological (e.g. heart rate variability) and affective (e.g. mood) measures, signalling growing interest in capturing a more complete spectrum of restorative effects

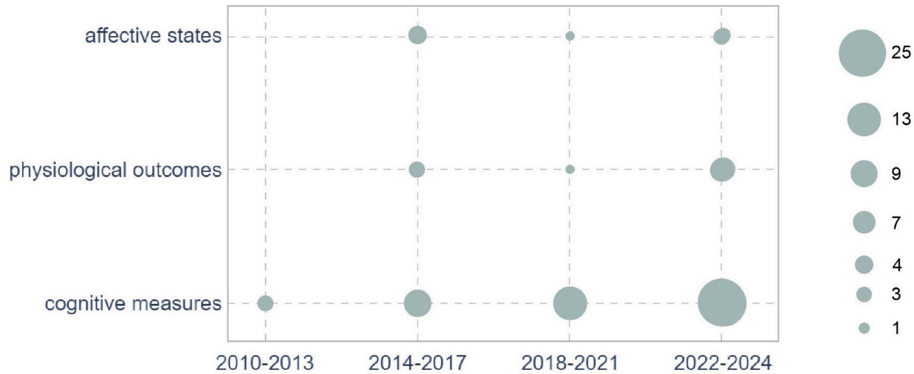

Fig. 7. Existing measurement of restorative value.

(Fig. 7).

4.3.1. Traditional survey methods

Traditional survey approaches assess either the perceived restorative qualities of environments (restorativeness), the psychological benefits experienced after exposure (restoration), or related affective states.

Restorativeness. The Perceived Restorativeness Scale (PRS) was used in 31 studies and remains the most widely applied instrument (Hartig et al., 1997). It operationalizes ART's four core qualities and has consistently high internal reliability ($\alpha \approx 0.85$–0.95). Variants include the Perceived Restorativeness Sound Scale (PRSS; $n = 2$), Perceived Restorative Potential (PRP; n = 2), and the Perceived Restorativeness Children Scale (PRCS; $n = 1$), each adapted for specific sensory domains or populations. Three studies employed bespoke restorativeness scales tailored to particular settings (Sun et al., 2024; Van den Berg et al., 2014; Staats et al., 2016).

Perceived restoration. The Restoration Outcomes Scale (ROS) (Korpela et al., 2008) was used in five studies to measure outcomes such as stress reduction, relaxation, and cognitive recovery following exposure. ROS has shown high reliability ($\alpha \approx 0.9$) and is suited to capturing short-term psychological benefits.

Affective states. Affective responses were measured less frequently, typically via validated mood inventories such as the Positive and Negative Affect Schedule (PANAS; $n = 3$), the Profile of Mood States (POMS-SF; n = 3), and the Mood Adjective Checklist (MACL; n = 1).

Overall, these surveys are well-validated and adaptable across settings and populations, but they are time- and labour-intensive and rely on self-report, which may introduce bias and limit scalability for large or longitudinal studies.

4.3.2. Big data and machine learning methods

Nine studies combined subjective ratings from online surveys with objective features extracted from street-view images (SVIs) or 3D models to predict restorative value (e.g. Wu et al., 2024; Sun et al., 2024; Zhang et al., 2024). Participants rated the restorative potential of SVIs, window views or 3D scenes using the PRS, while computer-vision techniques (e.g. semantic segmentation, object detection) and LiDAR-based modelling quantified visual and spatial characteristics such as greenery, water, built surfaces and spatial configuration. These features were then entered into machine-learning models (e.g. random forests, XGBoost, regularised regression) to predict PRS scores at larger spatial scales (e.g. district or city level).

Across these studies, typical performance metrics of machine learning models included MAE, RMSE, R^2, classification accuracy and F1-scores, with performance generally in an acceptable range ($R^2 = 0.50$–0.96; accuracy $= 0.75$–0.85). All studies reported splitting the data into separate training and test sets to evaluate model performance, while only two explicitly reported using n-fold cross-validation or out-of-bag validation procedures (Han et al., 2023; Zhang et al., 2024). No study reported external validation in independent cities or datasets.

At the same time, several sources of bias and limitation remain. SVI ratings are typically provided by self-selected online participants, which may introduce sampling bias. Seasonal and lighting differences in SVIs are rarely modelled, yet can affect both visual features and perceived restorativeness. Generalisability is also limited, as all models are each developed and validated in a single city or country. Finally, because the current studies rely mainly on visual information, they omit other sensory dimensions such as sound, smell and microclimate. Thus, current “restorative mapping” using SVIs and machine learning should be seen as an approximation of visual restorative potential rather than a full representation of multisensory restorative environments.

4.3.3. Neuro-urbanism methods

Ten studies used neuro-urbanism methods to examine physiological correlates of restoration, typically in pre–post or repeated-measures designs using images, videos, VR, or real-world exposure. These studies provide objective evidence of how urban environments influence stress and relaxation, complementing self-report data.

Guided by ART and SRT, they assessed outcomes such as heart rate variability (HRV), blood pressure (BP), electroencephalography (EEG), electromyography (EMG), and electrodermal activity/skin conductance (EDA/SCL). HRV, used in seven studies (e.g. Sun et al., 2024; Asim et al., 2023), indexed autonomic balance between stress and recovery; EEG and EMG, used in four studies (e.g. Li and Du, 2024; Jeon et al., 2023), captured changes in brain activity and muscle tension; and EDA/SCL reflected emotional arousal (e.g. Wang and Li, 2024; Liu et al., 2022).

Despite their promise, neuro-urbanism studies remain few and typically rely on small samples and lab or VR settings, which may constrain ecological validity. Future work integrating physiological measures with real-world, multi-sensory exposures and more diverse samples is needed.

4.3.4. Study designs and statistical approaches

Quasi-experimental designs and cross-sectional surveys remain the most common approaches (Fig. 8). Quasi-experiments and field/VR experiments, especially in neuro-urbanism and some survey-based work, compare different environments or scenarios (e.g. UGS vs UBE; pre–post interventions) and offer stronger causal inference but are often limited by small convenience samples. Cross-sectional and online surveys dominate large-scale investigations linking perceived restorativeness to socio-demographic factors, usage patterns, or neighbourhood characteristics, but provide limited causal insight.

Statistical approaches mirror this methodological mix (Fig. 9). Variance analysis (ANOVA/ANCOVA) and regression models are widely used for group comparisons and associations. Structural equation modelling (SEM) increasingly supports the investigation of indirect pathways (e.g. environmental features → restorativeness → health outcomes). Machine-learning techniques remain relatively rare and are

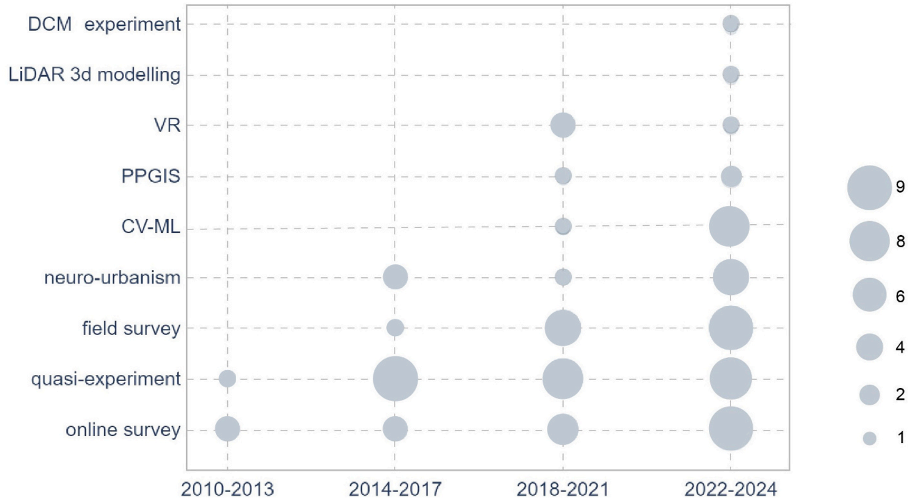

Fig. 8. Research techniques and study design.

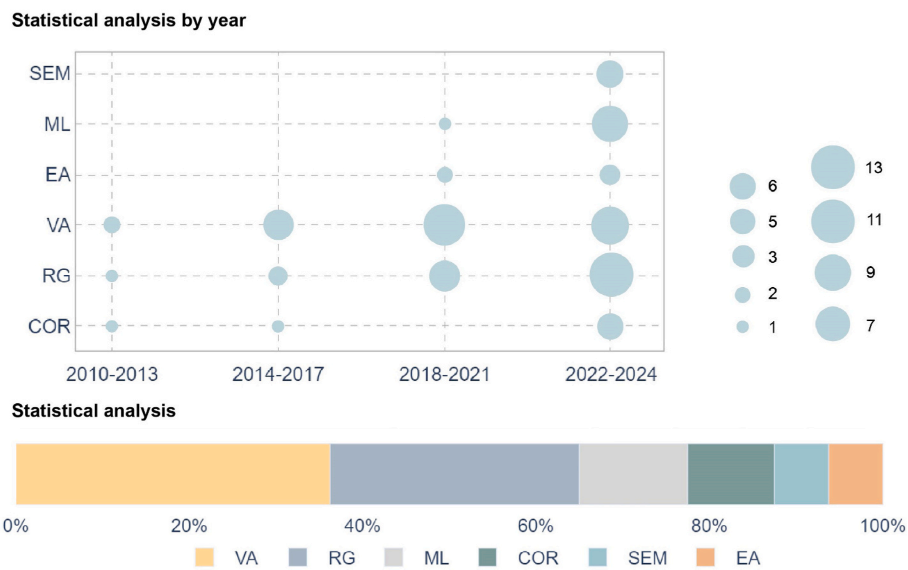

Fig. 9. Existing statistical analysis model (VA: variance analysis; RG: regression; COR: correlation; SEM: structure equation model; EA: exploratory analysis; ML: machine learning).

mainly used for prediction and spatial generalization rather than causal modelling.

Overall, restorative research in urban environments is still dominated by cognitive measures and survey-based approaches. Recent increases in the use of physiological and affective measures, as well as CV-ML and neuro-urbanism techniques, indicate a gradual move toward more multi-dimensional and data-rich approaches, although issues of sample representativeness, confounder control, and multi-sensory integration remain.

4.4. Confounders or covariates

Our review of 50 studies identified several confounders and covariates that influence the restorative value of urban environments. 18% of studies statistically adjusted for age, 30% for gender, and 18% for other socioeconomic factors including education level (Hipp et al., 2016; Wang and Li, 2022; Zhang et al., 2024), background (Tabrizian et al., 2018), residential zone (Masullo et al., 2021; Hipp et al., 2016), country (Staats et al., 2016) and time living in the area (Uebel et al., 2021; Li et al., 2023a, 2023b). 20% of studies considered personality-related characteristics, including nature hobbies and nature preference (Korpela et al., 2010; Wang and Li, 2022), urban/nature orientedness (Wilkie and Clouston, 2015; Wilkie and Stavridou, 2013; Subiza-Pérez et al., 2021a, 2021b), noise sensitivity (Uebel et al., 2021) and sense of presence (Wang et al., 2022a, 2022b). Health-related variables were controlled in 10% of studies, typically using measures of life satisfaction and social support (Wang and Li, 2022) or baseline depression, fatigue and stress levels (e.g. Korpela et al., 2010; Staats et al., 2016; Wang et al., 2022a, 2022b). Finally, usage patterns, such as frequency of visits to parks, greenways, plazas or favourite places, were included in 12% of studies (e.g., Chang et al., 2024; Chen et al., 2022).

Several variables were examined not only as potential confounders but also as effect modifiers. Nature/urban preference was modelled as a moderator in two out of the three studies (Wilkie and Clouston, 2015; Wilkie and Stavridou, 2013), showing that individuals with a strong nature preference in natural settings tended to report the highest restorative benefits, followed by those whose urban preference matched urban exposures, whereas mismatches between preference and setting were associated with lower perceived restorative potential. Frequency of visits was treated as moderator (Chang et al., 2024; Chen et al., 2022) in two out of six studies. In these studies, the impact of perceived restorativeness on well-being was stronger among those who visited the park daily or had a higher visit frequency.

4.5. Associations between urban environments and restorative effects

This section synthesises evidence on how different urban settings and environmental characteristics relate to restorative value. We first consider scenario-based comparisons between UGS and UBE, then examine specific physical characteristics of green and built environments, followed by psycho-environmental features, soundscapes, place-related experiences, and finally links to health outcomes.

The scenario- and characteristic-based evidence indicates that greener and nature-rich urban environments are more consistently associated with higher perceived restorativeness and better short-term psychological outcomes than built-up settings. As shown in Table 1, greenery is the most frequently examined parameter and shows the most consistent positive direction of association (11 positive vs. 3 negative across studies), followed by water (6 positive, 0 negative) and sky (6 positive, 1 negative). Buildings (0 positive, 6 negative) and objective noise (0 positive, 4 negative) are the most consistently negative contributors. Several other UBE features—including roads and sidewalks, ground surfaces, visual complexity, service facilities, scene depth, and fences—have been examined in relation to restorative value but show mixed directional findings across studies (Table 1). These inconsistencies likely stem from variations in study contexts (e.g., nature-oriented vs. artificial settings), simulation scenarios (e.g., residential 3D models, Street View imagery, window views), seasonal conditions (e.g., snowy vs. general weather), and study populations (e.g., university students, general citizens, adolescents). Among psycho-environmental parameters, prospect (2 positive, 0 negative), refuge (3 positive, 0 negative), and place attachment (4 positive, 0 negative) show consistently positive directional patterns, whereas perceived sensory dimensions such as culture and social qualities yielded mixed findings. Parameters appearing in more than one study are summarized in Table 1, with study-level details provided in Appendix D.

Table 1
Direction-of-effect summary of environmental parameters associated with restorative value identified in the reviewed literature. To provide a robust overview, this table includes parameters reported in at least two independent studies.

Environmental Feature	Positive	Negative	ns/nr	Total
Greenery	11	3	1	15
Sky	6	1	2	9
Building	0	6	0	6
Water	6	0	0	6
Road & sidewalk	1	2	0	3
Fence	1	2	0	3
Ground	1	2	0	3
Complexity	2	1	2	5
Design quality	3	0	0	3
Service facility	1	2	0	3
Scene depth	1	1	0	2
Objective noise	0	4	0	4
Nature sound	4	0	1	5
5Prospect	2	0	1	3
Refuge	3	0	0	3
Serene	2	0	1	3
Social	1	0	1	2
Mystery	1	0	1	2
Nature (PSD)	2	1	0	3
Space	1	1	0	2
Culture	1	0	1	2
Place attachment	4	0	2	6

Note: This table summarizes the direction of reported associations using a vote-counting approach to effect direction, following SWiM reporting guidance (Campbell et al., 2020). Because included studies differ in sample size, design, exposure definition, and confounder control, the table should be used to assess the directional consistency of reported associations, not the strength or magnitude of effects.
Ns: not significant; nr: not reported.

4.5.1. Comparison between UGS and urban areas

Across comparisons, UGS generally showed higher restorative value than UBE in terms of perceived restorativeness, stress reduction, and positive affect (e.g. Wang et al., 2016; Wilkie and Stavridou, 2013; Van den Berg et al., 2014; Ríos-Rodríguez et al., 2021). Twelve studies confirmed UGS scenarios showed consistent benefits, including increased HRV (Li and Du, 2024; Stigsdotter et al., 2017), arousal, and calmness (Wang et al., 2016), alongside reduced blood pressure (BP) (Stigsdotter et al., 2017). However, many studies contrasted highly attractive green settings with degraded or traffic-dominated urban spaces, potentially underestimating the restorative potential of well-designed UBEs.

At the same time, several UBE types, including plazas, squares, sky parks, cafés, vibrant commercial streets, and historical districts, also demonstrated meaningful restorative benefits, especially through opportunities for social interaction, refuge, and aesthetic engagement (e.g. Stigsdotter et al., 2017; Staats et al., 2016; Li and Du, 2024). Moreover, sports and exercise areas were often as or more restorative than some UGS, likely due to the combined effects of physical activity and environmental qualities (Kajosaari and Pasanen, 2021).

4.5.2. Urban green space (UGS) characteristics

Ten studies examined specific characteristics of UGS. Overall, natural elements, particularly greenery, emerged as the strongest and most consistent positive predictors of perceived restorativeness and restoration ($n = 7$). Higher levels of greenery presence, richness and structural quality were associated with increased PRS scores and perceived restoration across parks, greenways and rooftop gardens (Chang et al., 2024; Li et al., 2023a, 2023b; Li et al., 2024; Liu et al., 2022; Wang and Li, 2024; Hipp et al., 2016). Both the amount and configuration of vegetation (e.g., arrangement, vertical layering, permeability and visual complexity) appeared important (Tabrizian et al., 2018; Li et al., 2023a, 2023b). Water features such as lakes, ponds, and streams showed consistently positive associations with restorativeness in the limited number of studies that examined them ($n = 3$; Li et al., 2023a, 2023b; Liu et al., 2022; Li et al., 2024).

Evidence on sky visibility was more mixed. Some studies linked greater sky views to higher perceived restorativeness (Li et al., 2023a, 2023b; Liu et al., 2022), whereas Bao et al. (2023) reported negative associations between winter sky visibility and PRS, suggesting that seasonal, climatic and cultural contexts may shape how sky openness is experienced. Biophilic design elements, including green walls, indoor plants and natural materials, collectively enhanced restorativeness in hybrid indoor–outdoor spaces (Hung and Chang, 2024), underlining the value of design strategies that strengthen connections to nature.

In contrast, artificial features within UGS, such as buildings, extensive pavements and certain service facilities, were generally associated with lower perceived restorativeness (Wang and Li, 2024; Bao et al., 2023). When such elements dominated visual or functional experience, they appeared to erode the restorative benefits of otherwise natural settings.

4.5.3. General urban greenery

Nine studies addressed greenery embedded in predominantly built settings, including streetscapes, campuses and residential areas. These studies converged on the finding that even modest amounts of greenery can enhance restorative perceptions in UBE. Street-level vegetation—such as trees, roadside planting and flower beds—was consistently associated with higher perceived restorativeness ($n = 6$; Han et al., 2023; Lindal and Hartig, 2015; Ma et al., 2023; Wu et al., 2024). Three-dimensional metrics, including green volumetric ratio, also predicted higher PRS, suggesting that the volume and spatial distribution of vegetation matter beyond simple two-dimensional greenness indicators (Zhang et al., 2024). Research on green facades indicated that plant variety, higher vegetation coverage and certain asymmetric designs contributed positively to restorative appraisals (Hajibeigi et al., 2023).

At the same time, more greenery was not always better. An experimental study of campus window views (Sun et al., 2024) found that very dense vegetation and very high green view index values could reduce psychological and physiological benefits, likely by decreasing visual openness and perceived safety. These findings point toward an optimal balance between greenery and openness, rather than a straightforward "more is better" relationship.

4.5.4. Urban built environment (UBE) characteristics

Beyond greenery, fourteen studies examined other characteristics of UBE, including streets, squares, facades and window views. Non-green natural elements, particularly water and sky, were positively associated with perceived restorativeness in campus spaces, housing estates and streetscapes (Asim et al., 2023; Ma et al., 2023; Wu et al., 2024; Zhang et al., 2024). These elements appeared to contribute to fascination and perceived spaciousness.

The visual dominance of buildings generally showed negative associations with cognitive and physiological restoration ($n = 4$), especially where building mass was high and natural features were scarce (Wu et al., 2024; Asim et al., 2023). Yet buildings were not inherently detrimental. Several studies indicated that facade diversity and design quality could mitigate or reverse negative effects. Greater architectural variation and facade entropy were linked to higher perceived "being away" and fascination (Lindal and Hartig, 2013), while in a Middle Eastern context, facades with stone materials, balconies and articulated designs contributed positively to restorativeness, particularly when combined with greenery (Hajibeigi et al., 2023).

Findings on roads and fences were mixed. In some contexts, they were weakly positively associated with restorativeness, potentially reflecting perceived order, legibility or safety; in others, they were negatively associated with restorative outcomes (Ma et al., 2023; Han et al., 2023; Wu et al., 2023). These inconsistencies likely reflect differences in traffic intensity, design and user populations. Visual and colour complexity also emerged as an important factor ($n = 3$). High levels of visual complexity were associated with lower cognitive, emotional and physiological restoration, whereas more coherent colour palettes and moderated complexity improved restorative appraisals (Zhang et al., 2024; Sun et al., 2024).

Effects of scene depth ($n = 2$) were context-dependent: greater depth enhanced restorativeness in some housing-estate public spaces when combined with greenery and coherence (Zhang et al., 2024), but was negatively associated with restoration in certain campus streetscapes, potentially due to reduced perceived refuge or safety (Ma et al., 2023). This pattern suggests that the perceived balance between prospect and refuge may be more critical than depth alone. In contrast to findings from UGS settings, the presence of facilities was reported as a positive contributor in street-view–based studies, suggesting that functional elements may enhance restoration by creating attractive destinations that evoke fascination.

4.5.5. Psycho-environmental features

Eleven studies examined experiential and perceptual qualities that shape how urban environments are appraised. Studies using Perceived Sensory Dimensions (PSDs) consistently found that serene, natural and spacious qualities (n = 2) were strong predictors of restorative perceptions in artificial lakefront areas and rooftop gardens (Chen et al., 2022; Qi et al., 2021). These dimensions align with the notion of soft fascination in ART and with SRT's emphasis on calm, low-threat settings.

Other PSDs yielded more mixed findings. Culture was significantly and positively associated with restorative value only in a waterfront setting (Qi et al., 2021), and social qualities were positively related to restoration only in a rooftop garden (Chen et al., 2022), highlighting their strong context-dependence. Rooftop gardens can encourage gathering and social interaction; such interaction and entertainment opportunities may foster relaxation and stress reduction, thereby supporting restoration (Chen et al., 2022). In contrast, in more nature- or tranquillity-oriented spaces such as waterfronts or greenways, people may instead seek solitude to recover, making social or cultural stimuli less consistently beneficial (Qi et al., 2021; Akpınar, 2021). Sensitivity to cultural features also differed by age: they were positively valued by adults but not by teenagers, suggesting that adolescents experiencing stress may prefer small, safe green spaces where they can be alone and engage directly with nature rather than culturally focused settings (Akpınar, 2021).

Prospect (n = 3) and refuge (n = 3) were examined both alongside other PSDs and as standalone predictors. Across studies, both were consistently positively associated with perceived and, where measured, physiological restoration, indicating that environments offering both outlook and a sense of shelter tend to support higher restorative value (Asim et al., 2023; Akpınar, 2021; Chen et al., 2022). Novelty and uncertainty were also associated with positive outcomes when combined with perceived safety (Asim et al., 2023). Emerging, culturally grounded concepts such as the Traditional Environmental Qi scale further highlighted that perceptions of harmony, balance and "energy" can strongly correlate with restorativeness and may capture dimensions not fully reflected in existing PSD frameworks (Hung & Chung, 2024).

4.5.6. Sounds and urban noise

Nine studies investigated the role of soundscapes in restorative experiences. Overall, natural sounds and urban noise exerted contrasting effects. Natural sounds, including birdsong and water, consistently enhanced perceived restorativeness ($n = 4$) and mood and, in some cases, reduced physiological arousal (Jeon et al., 2023; Masullo et al., 2021; Guo et al., 2022; Bao et al., 2023; Uebel et al., 2021). They also frequently strengthened the restorative impact of visually green settings. In contrast, traffic noise and intrusive human noise (n = 4) were consistently negatively associated with restorativeness, mood and physiological indicators of stress (Asim et al., 2023; Li et al., 2024; Jeon et al., 2023; Wu et al., 2023). Perceived noise annoyance often explained more variance than objective sound levels, underscoring the importance of cognitive appraisal.

Noise sensitivity amplified negative responses to urban noise (Qi et al., 2021), and traffic noise was shown to partially cancel out the benefits of birdsong in experimental settings (Uebel et al., 2021). Taken together, these findings indicate that designing restorative environments requires attention not only to visual and spatial qualities, but also to the enhancement of positive sounds and mitigation of unwanted noise.

4.5.7. Place-related experiences

Nine studies explored how emotional and symbolic bonds with place contribute to restorative experiences. Place attachment, including place identity, was positively associated with perceived restorative quality and outcomes in historical districts, greenways and favourite everyday settings (Li et al., 2023a, 2023b; Li et al., 2024; Guo et al., 2022; Subiza-Pérez et al., 2021a, 2021b; Korpela et al., 2010). Repeated visits to favourite places were linked with higher perceived restoration, suggesting that familiarity, personal meaning and memories can amplify the benefits of supportive physical attributes. However, these associations were not always observed; some onsite surveys in urban squares did not detect strong links between attachment and restorative outcomes, likely due to weaker emotional bonds with these spaces or limited sample sizes (Subiza-Pérez et al., 2020; Subiza-Pérez et al., 2021a, 2021b).

Sense of place also emerged as an important moderator. In park settings, it strengthened the impact of physical characteristics such as sky visibility and greenery on perceived restoration, indicating that physical and symbolic qualities interact in shaping restorative experiences (Li et al., 2024). Overall, the evidence suggests that environments are most restorative when supportive spatial and sensory characteristics are combined with positive meanings, memories and social experiences.

4.5.8. Sensitivity analysis

To assess whether the principal findings of this review were robust to study quality, we conducted a pre-specified sensitivity analysis stratified by risk of bias (RoB). Studies rated “weak” on the EPHPP confounders domain were classified as high/moderate RoB; the remaining studies were classified as low RoB. Table 2 presents direction-of-effect counts by stratum for all features reported in at least two independent studies.

The core findings of this review were supported by evidence from low RoB studies. Greenery, water, and sky each showed predominantly positive associations with restorative value in the low RoB stratum, consistent with the patterns observed in higher-bias studies. Building retained consistently negative associations in both strata. Among psycho-environmental features, prospect and refuge showed positive associations in both strata with no contradictory evidence, and design quality was positively associated with restorativeness across both strata. Several features examined exclusively in low RoB studies also showed clear directional patterns: objective noise was consistently negatively associated with restorative value, while nature sound, serene, and place attachment showed consistently positive associations. Social and culture each showed tentatively positive directions in low RoB studies, though the evidence base remained limited.

However, several features showed directional patterns that diverged between strata or lost statistical significance in lower-bias studies. Road and sidewalk and service facility both showed positive associations in the high/moderate RoB stratum but reversed to negative associations in low RoB studies. For complexity, both positive and negative associations were observed in higher-bias studies, but only non-significant findings were present in the low RoB stratum. A similar attenuation was observed for mystery, which showed a positive association in higher-bias studies but only non-significant findings in lower-bias research. These features should be interpreted with particular caution, as their robustness is not confirmed across study quality levels. Nature (PSD) and space, examined only in low RoB studies, showed opposing directions within that stratum, precluding firm conclusions. Fence and ground also showed mixed directions across both strata, with no clear predominant pattern.

Scene depth was the only feature examined exclusively in the high/moderate RoB stratum, with no low RoB studies available. Its observed mixed associations should therefore be interpreted with caution, as they cannot be validated in lower-bias research.

Table 2
Sensitivity analysis of environmental features associated with restorative value, stratified by risk of bias (RoB). Studies rated “weak” on the EPHPP confounders domain were classified as higher RoB; remaining studies were classified as lower RoB.

Environmental Feature	RoB Stratification	Positive	Negative	Ns/nr	Total Number
Greenery	Higher RoB	6	2	0	8
	Lower RoB	5	1	1	7
Sky	Higher RoB	3	0	0	3
	Lower RoB	3	1	2	6
Building	Higher RoB	0	3	0	3
	Lower RoB	0	3	0	3
Water	Higher RoB	2	0	0	2
	Lower RoB	4	0	0	4
Road & sidewalk	Higher RoB	1	0	0	1
	Lower RoB	0	2	0	2
Fence	Higher RoB	1	1	0	2
	Lower RoB	0	1	0	1
Ground	Higher RoB	0	1	0	1
	Lower RoB	1	1	0	2
Complexity	Higher RoB	2	1	1	4
	Lower RoB	0	0	1	1
Design quality	Higher RoB	1	0	0	1
	Lower RoB	2	0	0	2
Service facility	Higher RoB	1	0	0	1
	Lower RoB	0	2	0	2
Scene depth	Higher RoB	1	1	0	2
	Lower RoB	0	0	0	0
Objective noise	Higher RoB	0	0	0	0
	Lower RoB	0	4	0	4
Nature sound	Higher RoB	0	0	0	0
	Lower RoB	4	0	1	5
Prospect	Higher RoB	1	0	0	1
	Lower RoB	1	0	1	2
Refuge	Higher RoB	1	0	0	1
	Lower RoB	2	0	0	2
Serene	Higher RoB	0	0	0	0
	Lower RoB	2	0	1	3
Social	Higher RoB	0	0	0	0
	Lower RoB	1	0	1	2
Mystery	Higher RoB	1	0	0	1
	Lower RoB	0	0	1	1
Nature (PSD)	Higher RoB	0	0	0	0
	Lower RoB	2	1	0	3
Space	Higher RoB	0	0	0	0
	Lower RoB	1	1	0	2
Culture	Higher RoB	0	0	0	0
	Lower RoB	1	0	1	2
Place attachment	Higher RoB	0	0	0	0
	Lower RoB	4	0	2	6

4.6. The impact of urban Restorativeness on health outcomes

Sixteen studies in our sample reported individual health outcomes, including physical activity, general well-being, quality of life, and mental health indicators. Eight of these used health measures mainly as background or control variables, while eight directly examined how perceived restorative value relates to health outcomes. Among the eight analytic studies, five focused on mental health, including stress, depression and anxiety (Akpınar, 2021; Wang et al., 2016; Subiza-Pérez et al., 2021a, 2021b; Wang et al., 2022a, 2022b; San Juan et al., 2017), and overall mental health level (Akpınar, 2021). Four assessed subjective well-being using the Overall Happiness Scale and Satisfaction with Life Scale (Chang et al., 2024; San Juan et al., 2017; Hipp et al., 2016; Subiza-Pérez et al., 2021a, 2021b), and one explored social well-being in relation to tactical urban interventions (Roe et al., 2019). Across these studies, more restorative environments (with higher restorative quality) were consistently associated with lower stress, higher mental well-being, greater life satisfaction and happiness, and increased social well-being. However, these effects were either cross-sectional or short-term.

Four of the eight studies were cross-sectional (Chang et al., 2024; Akpınar, 2021; Hipp et al., 2016; Subiza-Pérez et al., 2021a, 2021b). Their main findings indicate that specific environmental features—including senior-friendly features, greenness, and perceived prospect and refuge—are positively associated with higher quality of life (Hipp et al., 2016) and better mental health status (Chang et al., 2024; Akpınar, 2021), as well as lower stress levels (Akpınar, 2021). Subiza-Pérez (2021) tested two squares and found that place attachment contributed not only to restoration but also to higher happiness, although its limited sample size ($n = 34$) meant that these effects did not reach statistical significance.

The other four studies used pre–post (quasi-experimental) designs, with health outcomes tested and re-tested before and after environmental exposure. It should be noted that the observed health benefits are short-term, measured immediately after exposure. Main findings include that exposure to lawns/plazas and squares/small lakes/walkways/gardens/river scenes enhanced restoration and, at the same time, reduced anxiety (Wang et al., 2016) and depression (Wang et al., 2022a, 2022b), and increased happiness (San Juan et al., 2017). Tactical urban interventions with bamboo and greenery decoration at a waterfront increased social trust and restoration (Roe et al., 2019).

We also note that two of these eight analytic studies did not control for confounders such as demographic factors, socioeconomic status, or nature/urban preference, which may have introduced confounding bias. Further evidence on the link between restorative environments and health outcomes is therefore needed, using longitudinal experimental designs with appropriate control groups and covariate adjustment. Moreover, within our inclusion criteria (quantitative human studies that included both urban environment measures and explicit restoration outcomes), we found no studies that used large-scale or big-data approaches to examine links between urban restorative value and health outcomes at the population level.

5. Discussion and agenda

5.1. A comprehensive framework for multi-dimensional factors of urban restorative value

This review systematically mapped and narratively synthesized 50 studies from the past 15 years on the restorative potential of urban environments, encompassing both green spaces and the wider urban built environment. Using a structured framework (Fig. 2), we examined how different urban settings and features relate to cognitive, affective, and physiological restoration. Since around 2021, research has increasingly moved beyond generic greenery to scrutinise specific urban scenarios and design attributes, supported by emerging techniques such as computer vision, virtual reality, and neuro-urbanism. Our EPHPP assessment indicates overall acceptable study quality but highlights common limitations, including a scarcity of quasi-experimental or longitudinal designs, limited confounder control, and unrepresentative samples.

Compared with earlier reviews that focus mainly on natural landscapes or broadly defined green and blue spaces (Berto, 2014; Subiza-Pérez et al., 2019; Menardo et al., 2021), or on specific aspects such as indoor daylight, ageing, or architectural stimuli (Weber and Trojan, 2018; Madan et al., 2024; St-Jean et al., 2022; Grave et al., 2023), our structured narrative synthesis offers a more fine-grained and explicitly urban perspective. By jointly analyzing UGS and UBE and integrating survey-based, physiological, and CV-ML approaches within a single framework, we map how particular urban scenarios and features have been associated with restorative value and how these associations may, in turn, relate to broader health and well-being outcomes. A further methodological contribution is the RoB-stratified sensitivity analysis (see Table 2), which allowed us to distinguish findings that are consistent across study quality levels from those that appear sensitive to confounding control.

Fig. 10 summarizes the key environmental features associated with urban restorative value identified in this review. The framework integrates both positive and negative contributors, illustrating how urban nature, built form, perceptions, design quality, and social experience shape restorative benefits.

Among natural elements, greenery showed the most consistent positive directional pattern across studies, followed by water and sky; these patterns were confirmed in the lower RoB stratum (Table 2). In line with ART, these features are thought to support involuntary attention and provide relief from directed attention fatigue. However, restorative benefits appear to depend on spatial configuration and perceived coherence rather than vegetation quantity alone (Bao et al., 2023; Sun et al., 2024), with design aspects such as planting arrangement and maintenance appearing to matter more than sheer diversity (Hajibeigi et al., 2023; Li and Du, 2024).

Our synthesis also indicates that built environments may offer restorative potential when thoughtfully designed, with historical streets, public squares, sky parks, and sports areas associated with positive affect and restoration (Wang et al., 2016; Stigsdotter et al., 2017; Payne and Bruce, 2019; Li and Du, 2024). Design quality and architectural variation (e.g., façade entropy, material diversity) showed consistently

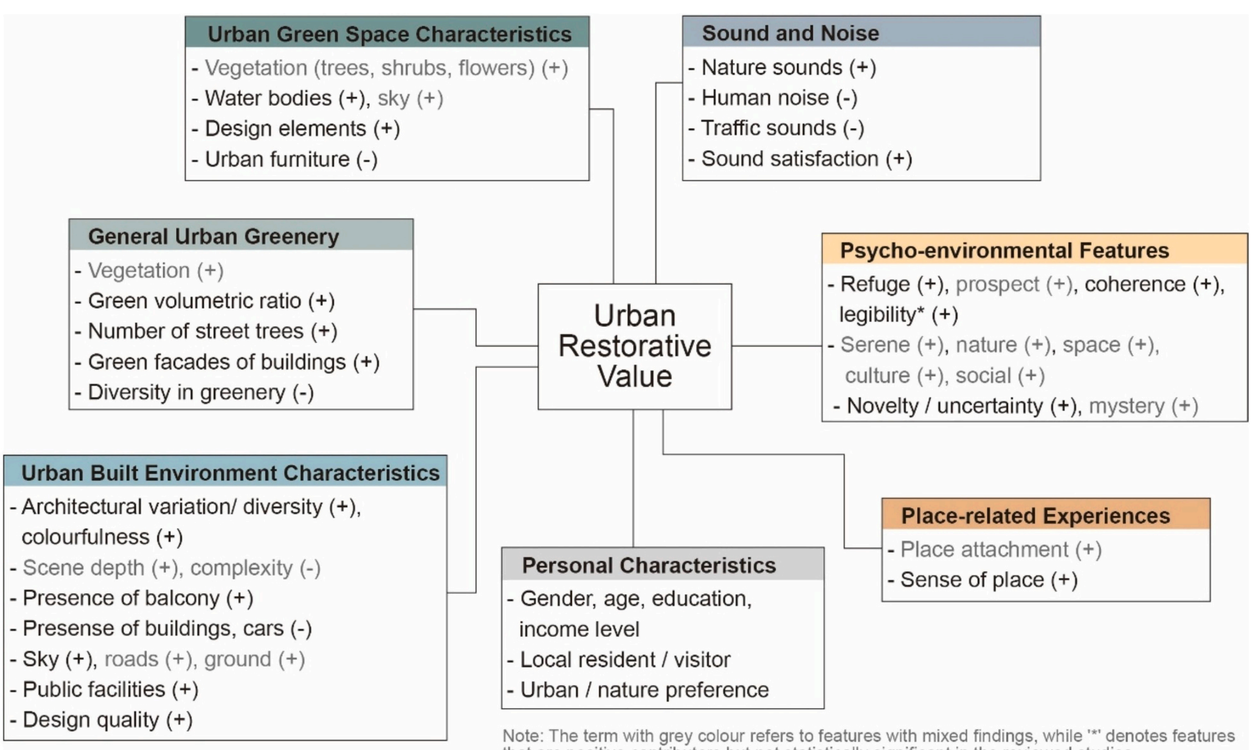

Fig. 10. Urban restorative value and its associated urban environment parameters. Summary of all characteristics affecting restorative value in the reviewed studies. UGS characteristics refer to features extracted specifically from urban parks or designated green spaces; General urban greenery refers to green elements identified in broader built environments (e.g., streetscapes, historical districts, plazas). Terms in grey indicate characteristics for which evidence is mixed (i.e., positive, negative, and/or non-significant findings across studies). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

positive associations across both RoB strata, and may help offset the otherwise negative associations of large building surfaces. In contrast, road and sidewalk and service facility showed positive associations only in higher RoB studies, with directions reversing in the lower RoB stratum, suggesting that their apparent positive effects may be confounded by co-occurring environmental attributes.

Building dominance and objective noise emerged as the most consistently negative contributors, with these patterns confirmed in lower RoB studies, suggesting that urban design may benefit from limiting excessive building mass and reducing artificial noise exposure. Natural sounds, by contrast, were consistently associated with enhanced restorative perceptions and, in experimental settings, strengthened the benefits of visually green environments.

Perceptions and social experience also play an important role. Environments perceived as serene, offering prospect and refuge, showed positive associations across both RoB strata—consistent with ART and SRT. However, complexity and mystery showed positive associations only in higher RoB studies, with findings losing significance in the lower RoB stratum, indicating that their reported benefits require further confirmation. Culture and social PSDs showed mixed patterns across studies, suggesting that experiential qualities are not universally beneficial but may depend on the type of space and user needs. Place attachment and sense of place have been suggested as factors that may shape the relationship between physical characteristics and restorative outcomes, although this has not been formally tested in the reviewed studies. Urban design and policy-making that support placemaking and everyday social use may therefore enhance not only the physical but also the experiential dimensions of restoration.

5.2. Associations between urban environment attributes, restorative value, and well-being outcomes

To organise existing evidence and identify hypotheses and gaps for future research, we mapped the observed associations between urban environment attributes, restorative value, and health outcomes into an evidence-informed, hypothesis-generating conceptual framework (Fig. 1). Given the predominantly cross-sectional evidence base, limited confounder control in a substantial proportion of included studies (36% rated weak on confounding), and the absence of longitudinal data, this framework should be interpreted as identifying where associations have been reported and where critical gaps remain, rather than as confirming an empirically well-established causal pathway.

5.2.1. Environment attributes – subjective perceptions – restorative value

The most extensively supported association in this review is the link between physical environment attributes and restorative value. Forty-three studies directly examined how combinations of natural and built elements relate to cognitive, affective, or physiological restoration. An additional 11 studies demonstrated that this relationship is partially mediated by subjective perceptions: environments appraised as aesthetic, serene, or offering prospect and refuge show stronger associations with restorative outcomes (e.g., Qi et al., 2021; Wu et al., 2023; Asim et al., 2023). One study also suggested that place attachment may moderate the physical environment–restoration relationship (Li et al., 2023a), though this was tested only within a single urban park context and requires replication.

5.2.2. Restorative value - short term wellbeing and health outcome

A smaller subset of studies ($n = 8$) examined associations between restorative appraisals and broader well-being or health indicators. Higher restorative quality was associated with lower stress, depression, and anxiety and with higher mental well-being ($n = 5$; Akpinar, 2021; Wang et al., 2016; Subiza-Pérez et al., 2021a, 2021b; Wang et al., 2022a, 2022b; San Juan et al., 2017), as well as greater life satisfaction and happiness ($n = 4$; Chang et al., 2024; San Juan et al., 2017; Hipp et al., 2016; Subiza-Pérez et al., 2021a, 2021b). One study reported an

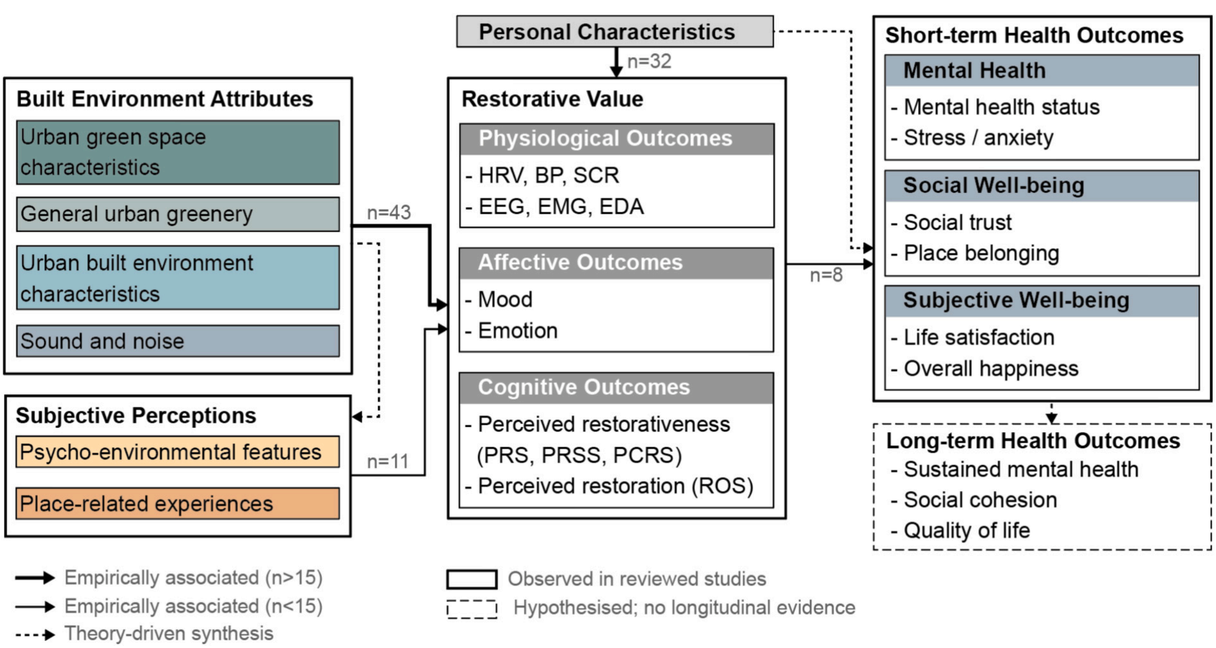

Fig. 11. Evidence-informed, hypothesis-generating conceptual framework mapping associations between urban environment attributes, restorative value, and well-being outcomes identified in this review. Arrow weight indicates the volume of supporting studies: thick solid arrows denote associations reported in more than 15 studies, thin solid arrows denote associations reported in fewer than 15 studies, and dashed arrows denote theory-driven connections not empirically tested in the reviewed sample. Border style distinguishes evidence status: solid-bordered boxes contain constructs for which cross-sectional or short-term pre–post evidence was found; the dashed-bordered box (Long-term Health Outcomes) contains constructs discussed on theoretical grounds only—no longitudinal study in our sample tracked cumulative restorative benefits over time. Numbers adjacent to arrows (n) indicate the count of studies supporting each connection. Given the limited methodological quality of many included studies, all arrows reflect the predictor–outcome direction specified in original study designs and should not be interpreted as confirmed causal effects.

association with social well-being following a tactical urban intervention (Roe et al., 2019), though this finding is context-specific. Because these studies are either cross-sectional or employ short-term pre–post designs, the evidence currently supports only contemporaneous or short-term associations, not long-term causal effects.

5.2.3. Short-term benefits - Long-term mental and social well-being

The proposition that repeated restorative experiences accumulate into sustained improvements in mental health, social cohesion, or quality of life is grounded in theoretical frameworks—including hedonic and eudaimonic well-being models (Kahneman et al., 1999; Ryff and Keyes, 1995), Self-Determination Theory (San Juan et al., 2017), and place-attachment theory (Scannell and Gifford, 2010)—but is not empirically demonstrated within the studies included in this review. No longitudinal study in our sample tracked cumulative restorative benefits over time. This connection is therefore represented as a dashed line in Fig. 1 and constitutes a priority gap for future research.

5.3. Research gaps and future directions

Our review identified several gaps in the current research on the restorative value of urban environments and suggests future directions to enhance understanding in this field. The limited number of studies in the past 10 years – 50 papers - suggests that this area is still emerging, offering considerable potential for further exploration.

First, while neuro-urbanism is a growing trend, offering many advantages such as capturing causal impacts and momentary physiological responses, it currently represents only a minority of the evidence base (approximately one-fifth of the included studies) rather than a dominant approach. Tools such as EEG, fNIRS, and wearable biosensors enable real-time measurement of stress recovery and attentional restoration, yet studies have yet to integrate multi-sensory dimensions such as thermal comfort, which significantly affects mood, stress, and cognitive performance (Millar et al., 2021). Incorporating thermal perception measures into urban restorativeness assessments can advance climate-responsive urban design and deepen understanding of environmental comfort in psychological restoration.

Second, while street view images (SVIs), LiDAR, and computer vision (CV) with machine learning (ML) have been applied in several recent studies of urban restorativeness, their current use is constrained by limited external validation, limited integration of non-visual sensory dimensions, and limited control for key confounders (e.g. demographic and socio-economic characteristics). Future studies should address these gaps by integrating comprehensive data on potential confounding variables (Cui et al., 2023). Additionally, longitudinal studies and time-series analyses (Liang et al., 2023) using SVIs could provide deeper insights into how restorative experiences evolve over time, offering a more dynamic understanding of urban environments' impacts on restoration. Finally, it appears that the field has yet to capitalise on the increasing volume of openly available tools and data (Hou et al., 2024).

Finally, future research should explore how restorative environments contribute to long-term well-being, life satisfaction, and physical activity. Current studies focus primarily on short-term psychological and physiological responses, yet Self-Determination Theory (Deci & Ryan, 2000) and Hedonic vs. Eudaimonic Well-Being Models (Kahneman et al., 1999; Ryff & Keyes, 1995) suggest that repeated exposure to restorative environments fosters resilience, emotional regulation, and social well-being. However, little research has examined how restorative urban environments promote walkability or encourage physical activity, particularly among stressed or vulnerable individuals such as commuters, women, or older adults. Given that walkable environments support both mental and physical health, future studies could investigate how perceived restorativeness influences walking behaviours and active travel habits, which can contribute to more vibrant and inclusive urban communities. Moreover, leveraging longitudinal health datasets could clarify how urban restorativeness shapes active lifestyles, life satisfaction and overall happiness (Foster et al., 2020), providing evidence to guide age-friendly, gender-inclusive, and commuter-oriented urban planning.

CRediT authorship contribution statement

Sifan Cheng: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Project administration. **Pu Jiang:** Formal analysis, Writing – review & editing. **Filip Biljecki:** Writing – review & editing, Supervision. **Jeroen van Ameijde:** Conceptualization, Resources, Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eiar.2026.108659.

Data availability

Data will be made available on request.

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