SEMARAK ILMU PUBLISHING

Semarak International Journal of Design, Built Environment and Sustainability

Journal homepage:
https://semarakilmu.my/index.php/sijdbes/index
ISSN: 3083-9025

Recovering Attention with Restorative Environment Against Driving Fatigue at Expressway Service Areas: A Scoping Review

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ARTICLE INFO

Article history:
Received 19 July 2025
Received in revised form 16 August 2025
Accepted 31 August 2025
Available online 16 September 2025

Keywords:
Attention restoration; restorativeness; motorway service area; highway service area; driving fatigue; fatigue recovery

ABSTRACT

Prolonged driving on expressways can induce fatigue and lapses of attention, undermining road safety. Because expressway service areas are key sites for driver recovery, there is a pressing need for design guidance that effectively mitigates fatigue and restores attention. This study aims to develop a theoretical framework for restorative service area environments. We conducted an extensive review of the peer-reviewed literature by searching Web of Science and Scopus, screening records against predefined criteria, and closely analyzing 45 eligible studies. The synthesis addressed three guiding questions: 1. What is the impact of the spatial environment of expressway service areas on driving fatigue? 2. What are the key characteristics in constructing a restorative environment at expressway service areas? 3. Which factors are critical for restoring attention? Across the 45 studies, we consolidated recurrent evidence into a three-stage framework for practice: co-defining environmental indicators with users and experts; assessing perceptions to identify attention restoring characteristics; and validating design interventions through empirical evaluation. The review also maps typical constructs used to capture restoration (e.g., perceived restorativeness and attention outcomes) and highlights commonly examined environmental features and assessment approaches. Overall, the principal result is an integrative framework that links environmental indicators, perceptual responses, and evaluation pathways to guide the design and appraisal of restorative service areas. We conclude that applying this framework can standardize indicator selection, sharpen measurement of attention-related outcomes, and support evidence-based upgrades of expressway service areas. These contributions provide a theoretical foundation for subsequent research and offer actionable direction for practitioners seeking to enhance drivers' recovery during breaks.

1. Introduction

As the global economy continues to expand, the vehicles per capita is increasing annually, including in emerging economies such as China. According to data from the Ministry of Public Security of China [1], by the end of 2022, the number of vehicles in China reached 319 million, an increase of 17.52 million from 2021, marking a growth of 5.81%. With the continuous increase in vehicle

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https://doi.org/10.37934/sijdbes.3.1.5077

numbers, the rate of traffic accidents has generally increased [2]. Among the various factors, driver fatigue, often characterized by attention lapses, is a critical concern [3,4]. Compared to other road types, the simple and uniform geometric design of expressways can make long, high-speed trips monotonous [5]. Drivers need to expend a significant amount of energy to maintain concentration, leading to physical and mental exhaustion and the emergence of driving fatigue [6]. The American Automobile Association (AAA) Foundation for Traffic Safety estimate that, in the United States, 6%-10% of all reported accidents and 16%-21% of fatal crashes involve driver fatigue [7-9]. Driving performance tends to decline after 1-2 hours of continuous driving, with longer reaction times and reduced attention and alertness [10]. Although strategies such as listening to music, opening windows, or lowering cabin temperature may offer only limited, short-term relief [11], stopping to rest is generally considered the most effective approach to alleviate driver fatigue [12]. Evidence suggests that at least 15 minutes of rest after a period of continuous driving can help restore baseline concentration, with longer driving times requiring longer rests [10].

In many countries, such as China, South Korea, and the USA, expressways are operated as access-controlled facilities, where vehicles enter and exit only at designated points and are prohibited from stopping except at designated areas or in emergencies [13,14]. To save time and costs, many drivers avoid exiting the expressway [15]. Therefore, expressway service areas (ESAs) have become the primary resting spots for drivers. The physical environment of these areas plays a crucial role in alleviating fatigue and supporting the recovery of attention.

The positive influence of natural environments on health outcomes is well established [16-18], and growing evidence indicates that features of the built environment also support health and restoration [19]. For example, exposure to natural settings is associated with reduced stress and improved attention restoration and psychological recovery [21,22]. built settings may likewise confer restorative effects through aesthetic qualities and affordances for reflection [23,24]. Furthermore, well-designed spaces and comprehensive facilities can enable a range of activities, thereby supporting individuals' recovery and health [25]. Despite the known benefits of built settings or natural environments on attention and fatigue recovery, research on restorative environments within critical transportation infrastructures, such as expressway service areas, remains limited.

Despite growing evidence that natural and built environments can support recovery from fatigue and aid attention restoration, research specific to expressway service areas remains scarce; most studies focus on associations between service-area use and fatigue-related crashes and rarely operationalize concrete design indicators, perceptual mediators, and evaluation pathways for attention outcomes. This gap matters because road travel has rebounded after the pandemic, road freight remains dominant in many countries, and more than 7,000 expressway service areas in China are shifting from quantity to quality, creating an urgent need for an evidence-based, design-oriented framework to guide upgrades that measurably enhance drivers' recovery during breaks [26-28]. Accordingly, using the literature review method proposed by Ibrahim and Mustafa Kamal [29], this review synthesizes literature on expressway service areas, restorative environments, and attention restoration to develop a practice-oriented framework that links environmental indicators to perceptual responses and attention-related outcomes. We address three questions: 1. What is the impact of the spatial environment of expressway service areas on driving fatigue? 2. What are the key characteristics in constructing a restorative environment at expressway service areas? 3. Which factors are critical for restoring attention?

2. Methodology

2.1 Research Method

The literature review follows the "Literature Review Synthesis Process" introduced by Ibrahim and Mustafa Kamal [29] and elaborated by Masiran *et al.,* [30]. This approach is a distinct review method that emphasizes inter- and cross-disciplinary integration to inform early theoretical framing in research conceptualization [31-33]. Using the Research Question (RQ) categorization developed by Ibrahim [34,35], we defined three research questions addressing "WHO" (the entity affected by the research), "WHAT" (the information or knowledge needed to address the problem), and "HOW" (the anticipated impact of the research). In this review, "WHO" refers to drivers; "WHAT" is subdivided into two subthemes: "expressway service areas" and "restorative environments"; "HOW" concerns approaches and mechanisms for restoring attention.

This review synthesizes key findings from the selected papers, identifies gaps and future research opportunities, and highlights areas needing further development. For each sub-theme, we develop a synthesized commentary addressing the three RQs. In the discussion, we apply the Point of Departure (POD) tree, following Ibrahim and Mustafa Kamal [29], to integrate insights across sub-themes and propose an interdisciplinary framework.

2.2 Search Strategy

Based on the aforementioned analysis, this review searched for papers related to "expressway service areas," "restorative environments," and "attention restoration" in two databases, Web of Science and SCOPUS. The keywords used included "expressway service area," "restorative environment," and "attention restoration," with the search restricted to papers in English from February 2004 to February 2024. However, the literature on "expressway service areas" is so scarce that no time restriction was applied to it. The specific combinations of search keywords are shown in the Table 1 below.

Table 1
Search Keywords

Theme	Advanced search keyword
Restorative Environment	((TS= ("restorative environment*" OR "healing environment*" OR "restorative space*" OR "healing space*" OR "healthy environment*") AND PY= (2004-2024)) AND DT=(Article)) AND LA=(English)
Expressway Service Area	(((TS= ("road" or "highway" or "expressway" "freeway" or "motorway")) AND TS= ("Service Area" OR "Parking Area" OR "Rest area" OR "Travel Plaza" OR "Service Plaza" OR "public rest areas")) AND DT=(Article)) AND LA=(English)
Attention Restoration	((TS= ("Attention restoration" or "Attention recovery" or "Attention replenishment" or "Attention rejuvenation" or "Attention renewal") AND PY= (2004-2024)) AND DT=(Article)) AND LA=(English)

2.3 Search Results

The initial search yielded 4684 papers, from which duplicates were removed, leaving 3873 papers. Of these, 102 related to "expressway service areas," 3283 related to "restorative environments," and 488 related to "attention restoration." After screening titles and abstracts, 67 papers met the criteria for full-text review. After the full-text review, we excluded 29 papers, obtained an additional 7 papers through the snowball method, and ultimately included 45 papers in the review. We allocated these

papers to the three themes, with each theme comprising 15 papers, and then cross-analyzed them to integrate findings and facilitate discussion. Figure 1 illustrates the flowchart of the literature review methodology.

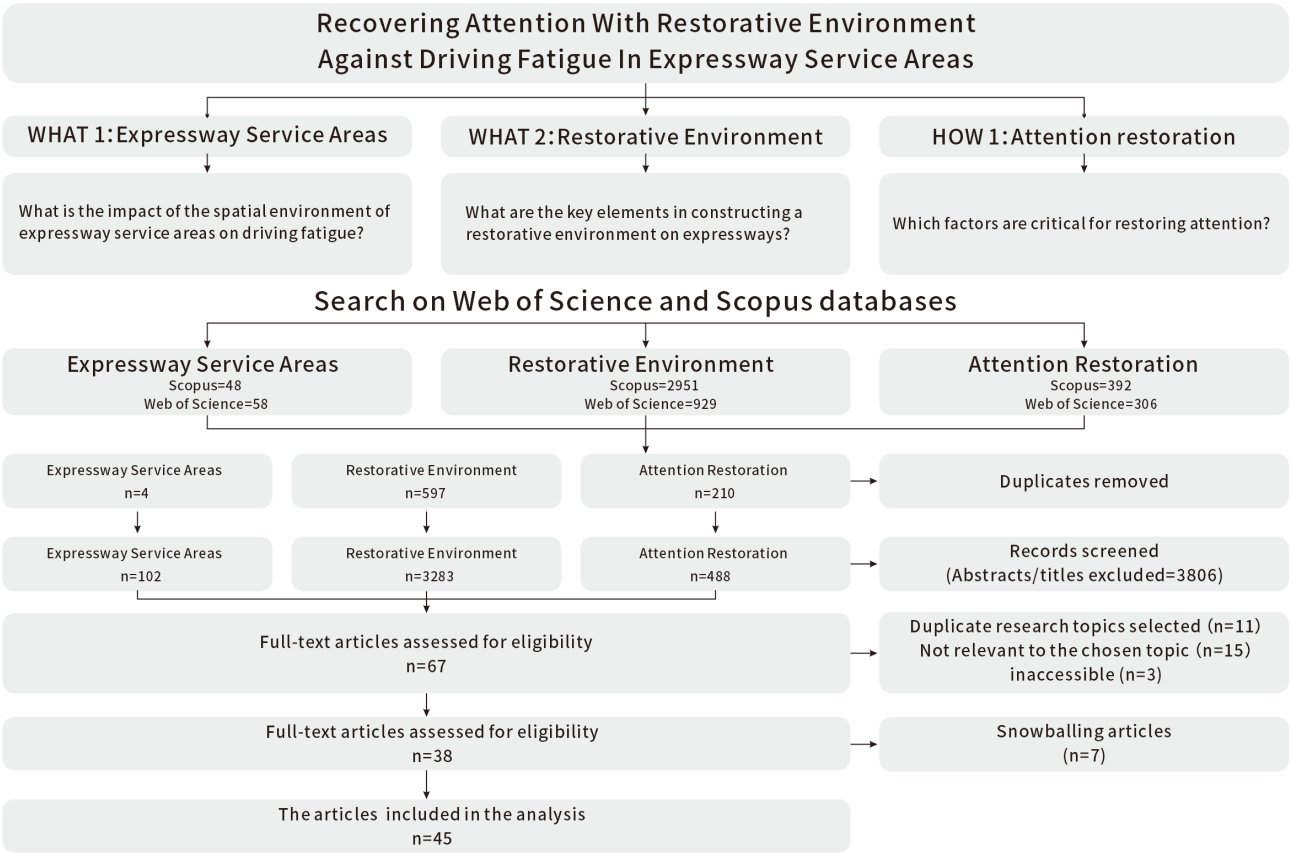

Fig. 1. The flowchart of the methodology for the literature review

3. Results

This chapter provides a comprehensive review of the literature related to each sub-theme to address the respective sub-questions.

3.1 Expressway Service Areas

This section focuses on the environmental characteristics of expressway service areas and the factors through which they influence driver fatigue, addressing RQ1: What is the impact of the spatial environment of expressway service areas on driving fatigue? The set of reviewed studies and their key attributes is summarized in Table 2.

Table 2
Expressway service area review papers

Study	Study	Study location	Main Content	Main Content
1	Al-Kaisy *et al.,* [37]	North America United States	Analyzed the usage patterns of expressway service areas.	The average dwell time of vehicles in service areas is approximately between 14 and 24 minutes. The parking duration varies by vehicle type. Daytime

				parking times are significantly shorter than nighttime parking times.
2	Pérez-Acebo and Romo-Martín, [15]	Europe Poland	Analyzed the facilities provided by rest areas and service areas on Polish expressways and the distances between them.	The main facilities offered at rest areas and service areas include restrooms, gas stations, shops, and cafes. Excessive distances between service areas are not conducive to drivers' rest and driving safety.
3	Zaleckis *et al.,* [38]	Europe Lithuania	The paper explores how to use GIS databases to determine the optimal locations for service areas. GIS can be combined with spatial syntax to identify the best and most efficient locations for rest areas.	When determining rest area standards, it is necessary to consider a comprehensive set of factors including road usage, surrounding environment, and accessibility.
4	McArthur *et al.,* [39]	North America United States	The study explores the factors influencing the frequency of accidents in relation to rest areas.	Service areas play a crucial role in alleviating driver fatigue and reducing the rate of related accidents.
5	Reyner *et al.,* [13]	Europe United Kingdom	The study primarily focuses on the planning, layout, and optimization of rest areas and roadside parking lots.	Within a 16-kilometer range after expressway rest areas, the rate of traffic accidents significantly decreases.
6	Jung *et al.,* [14]	Asia Korea	The effect of installed auxiliary rest areas on reducing fatigue-related driving accidents.	Auxiliary rest areas can reduce fatigue-related traffic accidents by approximately 14%.
7	Bunn *et al.,* [28]	North America United States	The paper primarily analyzes accidents involving commercial vehicle drivers caused by fatigue or drowsiness.	Traffic accidents involving fatigued commercial vehicle drivers are more likely to occur on road segments 20 kilometers or more away from rest areas. These accidents are also more likely to happen on park roads, as well as during nighttime and on dry road surfaces.
8	Kolodinskaja and Bertulienė [40]	Europe Lithuania	Analyze the current state of service areas in Lithuania and provide optimization suggestions.	Drivers and passengers prioritize factors such as safety, convenience, and service quality when selecting rest areas.
9	Wieszała *et al.,* [41]	Europe Poland	The study analyzed the acoustic environment of rest areas along expressways.	The lack of noise barrier measures results in high noise levels in parking lots, affecting the relaxation and rest of drivers and other individuals.
10	Poliak and Poliakova, [42]	Europe	The discussion primarily addresses the issue of insufficient parking capacity for freight vehicles in Europe.	Freight drivers have difficulty finding parking spaces during peak nighttime hours, leading to irregular rest and decreased work efficiency. The lack of adequate rest and safety facilities in many parking areas causes drivers to be concerned about the safety and comfort of these locations.
11	Seya *et al.,* [43]	Japan	Analyze the factors determining the parking locations and durations for trucks on expressways.	Truck parking times are longer as they approach their destination. The presence of restaurants and shops, as well as the number of parking spaces for trucks and trailers, are important factors influencing parking duration. Drivers tend to park in familiar locations.
12	Ding *et al.,* [44]	Asia China	An optimization model for planning expressway truck service areas was established.	Adequate truck parking spaces at expressway service areas are crucial for alleviating driving fatigue. This need can be met through a nonlinear optimization model for planning truck service areas, ensuring sufficient parking for drivers.
13	Chen and Xie [45]	North America United States	The study primarily analyzes the impact of commercial truck drivers' rest patterns on driving safety.	Increasing the total rest time and the number of rest breaks can effectively reduce the risk of fatigue-related accidents.

14	Bayraktar *et al.,* [46]	North America United States	The study focuses on analyzing and providing improvement suggestions for truck parking issues in Florida.	Utilizing weigh stations can help alleviate the shortage of truck parking spaces. Drivers need accurate information to locate private parking facilities.
15	Wang and Pei [10]	Asia China	The paper primarily investigates the impact of continuous driving time and rest periods on the driving performance of commercial long-distance bus drivers.	Continuous driving time exceeding 2 hours significantly affects drivers' attention, reaction speed, and subjective fatigue levels. The longer the driving time, the longer the recovery period required.

Expressway service areas are facilities located alongside expressways, designed to provide rest and maintenance services for drivers and passengers [33]. They offer a range of amenities, including parking, dining, restrooms, and vehicle or cargo checks, to support safe stopping and recovery from fatigue [33]. Fatigued and sleepy drivers utilize these areas as safe stopping points to rest and recover [47]. The service-area environment is therefore critical for meeting basic needs, restoring attention, and alleviating driver fatigue [15].

Expressway service areas can be classified based on building area, traffic volume, and economic factors [37]. They are mainly divided into service areas and rest areas, with service areas offering a wider range of services, while rest areas provide basic parking and restrooms [15]. The selection of service area locations considers factors such as policy, legal issues, road safety, and nearby natural and cultural heritage [37].

Rest and recovery from driver fatigue are primary functions of service areas [48]. Studies indicates that driving continuously for more than two hours significantly impacts drivers' attention and slows reaction time, with the required restoration time increasing as driving time extends [10]. At this point, drivers need to recuperate in service areas to avoid problems and accidents caused by driving fatigue. Empirical studies have found a strong correlation between expressway service areas and accidents caused by fatigue. McArthur *et al.,* [39] modeled crash occurrence as a function of distance to service areas and found a strong relationship suggesting that proximity can reduce fatigue and crash rates. Ronen *et al.,* [49] reported that fatigue-related crashes decline on road segments closer to rest areas, with the effect diminishing as distance increases, corroborating McArthur et al. [39]. In South Korea, Jung *et al.,* [14] investigated the role of auxiliary rest areas, smaller rest facilities located between larger conventional rest areas, in the Korean expressway system in reducing accidents caused by fatigue driving, finding that auxiliary rest areas could reduce traffic accidents caused by driving fatigue by about 14%. Bunn *et al.,* [28] explored accidents involving commercial drivers in the USA, particularly those caused by fatigue or sleepiness, finding that accidents involving fatigue driving among commercial vehicles tend to occur more than 20 kilometers from rest areas and are generally more severe.

The spatial configuration and amenities of service areas shape the quality of rest. Using expert assessments, Kolodinskaja and Bertulienė [40] found that safety and convenience are the most valued attributes when choosing where to stop. Seya *et al.,* [43] also found that the presence of restaurants and shops in service areas is an important factor in drivers' decisions to stop and the duration of their stay. Wieszała *et al.,* [41] reported that, in the absence of noise barriers, parking areas experience elevated noise levels that degrade rest quality.

Parking design, especially for trucks, is a persistent planning priority [41]. Because truck parking occupies substantial space, service-area planning must optimize capacity and address parking-area safety so that drivers can rest fully and securely [43,44]. Parking spaces and the overall spatial layout can also be arranged rationally according to the parking duration and time of various vehicles [37]. Furthermore, the integration of various service facilities and functions and the intelligent

management of expressway service areas can effectively enhance the efficiency of service areas, providing better rest for drivers [13,45]. Reyner *et al.,* [13] found that although some expressway service areas have a good effect on reducing driving fatigue accidents, the impact of other service areas varies, and they inferred that these differences might be related to the attractiveness of the service areas, the distance to the destination, and the surrounding environment of the service areas. Therefore, to attract more drivers, expressway service areas can improve the quality of their spatial environment, encourage more frequent rest breaks, and cater to various basic needs such as napping, walking, dining, refueling, and vehicle maintenance [37,43,45]. By extending drivers' rest durations, these improvements help reduce the risk of accidents caused by fatigue [37,43,45].

Overall, existing research concentrates on truck-parking optimization [42], basic needs assessment [13,45], and infrastructure recommendations [15]. Much of this work emphasizes engineering solutions or relies on interviews and descriptive accounts with limited quantitative evidence. While several studies associate rest areas with reduced fatigue-related crashes [10,14,28,39,49], few isolate the specific spatial-environmental factors that support fatigue recovery. Moreover, English-language studies are concentrated in Europe and the United States, with some work in South Korea and China; given the strong regional and policy contingencies of service areas, broader applicability remains to be tested [38].

Answer to RQ1. Resting at expressway service areas is an effective way to alleviate driver fatigue and reduce fatigue-related crashes [14,28,39,49]. The service-area environment plays a crucial role: well-designed spatial configurations and amenities can increase the likelihood of stopping and improve recovery outcomes [28]. Planning should therefore consider perceived attributes, such as safety and convenience [40], and physical factors such as noise [41], while ensuring adequate parking capacity and facilities for different vehicle types so that lack of space does not deter drivers from stopping to rest [42,44].

In conclusion, resting at expressway service areas is an effective way of alleviating driver fatigue. In order to enable drivers to get a better rest, expressway service areas planning needs to focus on spatial configuration (e.g., restaurants, stores), facilities (e.g., parking facilities, service facilities), and the overall spatial perception of the user (e.g., safety, convenience) and other factors.

3.2 Restorative Environments

Restorative environments originate from the field of environmental psychology and are based on Restorative Environment Theory (RET), primarily defined as environments that facilitate restoration from a state of fatigue [50]. This theory has evolved into two main branches: Attention Restoration Theory (ART) and Stress Reduction Theory (SRT).

A restorative environment is not a single type of environment but is composed of specific environmental characteristics and restorative characteristics [25]. Identifying spatial environmental elements with restorative effects and constructing a framework for restorative environment design in expressway service areas are the core of this subsection. This section primarily concentrates on the research methodologies of selected literature to explore suitable approaches for identifying restorative environmental elements for expressway service areas. The methods and design of these studies are detailed in Table 3.

Table 3
The main research methods of restorative environments

Type of Study	Author	Study Setting	Research Methodology	Number of Participants and Participant Demographics	Primary Analytical Methods	Environmental Factors Measurement	Recovery Outcomes Measurement
Experi-mental	Zhao *et al.,* [51]	Urban Park	Video Recording	Students and Teachers n=89	One-Way Analysis of Variance (ANOVA); Least Significant Difference (LSD)	Objective Measurement	Subjective Questionnaire: Perceived Restorativeness Scale (PRS) Physiological Indicators: Skin Conductance Response (SCR); Electrocardiogram (ECG) - Ratio of High-Frequency Power to Low-Frequency Power (HF/LF)
	Huang *et al.,* [52]	Material	VR Simulated Scenarios	n=89 Students	ANOVA; Measures Analysis of Variance (MANOVA); Paired Sample t-Test	Type of Environment	Physiological Indicators: Skin Conductance Level (SCL) Psychological Indicators: Positive and Negative Affect Schedule (PANAS)
	Deng *et al.,* [53]	Urban Park	Field Study	n=60 Students	Paired Sample t-Test; ANOVA; Wilcoxon Signed-Rank Test; Kruskal-Wallis Test	Type of Environment	Objective Physiological Indicators: Systolic and Diastolic Blood Pressure; Pulse Rate; Blood Glucose Levels; Electroencephalogram (EEG) Subjective Questionnaire: Emotional State (using POMS Questionnaire); Perception of Landscape Restorativeness (LPRS); Attention and Meditation Levels (EEG Results)
	Wang *et al.,* [54]	Urban Park	Video Simulation (Video and Audio)	n=140 Students	ANOVA; Mann-Whitney U Test; Kruskal-Wallis Test (K-W Test); Paired Sample t-Test	Type of Environment	Physiological Indicators: ECG - R-R Interval; SCR Psychological Indicators: Digit Span Backward (DSB) Test; State Version of Spielberger's State-Trait Anxiety Inventory (STAI-S) Subjective Evaluation Questionnaire: PRS
	Hooyberg *et al.,* [55]	Beach	Photographs	n=102 Students	ANOVA; Generalized Linear Mixed Models (GLMM)	Type and Components	Subjective Evaluation Questionnaire: PRS
	Zhu *et al.,* [56]	Urban Waterfront Space	VR Simulated Scenarios	n=60 Students	Correlation Analysis;	Type and Components	Subjective Evaluation Questionnaire: Restorative Outcome Scale

			(Video and Audio)		Regression Analysis		Physiological Indicators: Electrodermal Activity (EDA); Heart Rate (HR)
Cross-Sectional Study	Gao and Zhang [57]	Hospital Ward	Field Questionnaire	n=150 Inpatients	Spearman Correlation Analysis; Principal Component Analysis (PCA); Statistical Weight Calculation	Subjective Evaluation	Subjective Evaluation Questionnaire: Hospital Indoor Restorative Scale (HIRS)
	Yusli *et al.,* [58]	University Campus	Field Questionnaire	n=150 Students	Partial Least Square-Structural Equation Modeling (PLS-SEM)	Subjective Evaluation	Subjective Evaluation Questionnaire: Restorative Components Scale (RCS-22 items) to measure perceived restorativeness Subjective Evaluation Questionnaire: Restorative Outcomes Scale (ROS-6 items) to measure restorative experiences
	Guo *et al.,* [25]	University Campus	Field Questionnaire	n=478 Students	Structural Equation Modeling (SEM)	Subjective Evaluation	Subjective Evaluation Questionnaire: Four-item Psychological Restoration Benefit Assessment
	Wu *et al.,* [59]	Urban Park	Field Questionnaire	n=904 Mixed	Independent Sample t-Test; ANOVA; Path Analysis	Objective Measurement Subjective Evaluation	Subjective Evaluation Questionnaire: PANAS; PRS
	Wu *et al.,* [60]	Forest Trails	Field Questionnaire	n=412 Mixed	SEM	Subjective Evaluation	Subjective Evaluation Questionnaire: PRS
	Zhao *et al.,* [61]	Streets	Online Questionnaire (Photographs)	n=1473 Mixed	Correlation Analysis; Multiple Linear Regression Analysis	Subjective Evaluation	Subjective Evaluation Questionnaire: Short Revised Restorative Scale (SRRS)
	Bai *et al.,* [62]	High School Campus	Field Questionnaire	n=224 Students	PCA; Pearson Correlation Analysis; ANOVA	Objective Measurement	Subjective Questionnaire: Revised Perceived Restorativeness Scale (RPRS)
	Du *et al.,* [63]	University Campus	Field Survey, Photographs	n=354 Students	ANOVA; LSD Post Hoc Test; Chi-Square Test; Linear Regression Analysis	Type of Space	Subjective Evaluation Questionnaire: Restorative Potential Score
	Subiza-Pérez *et al.,* [64]	Indoor and Outdoor Environments	Self-Report	n=945	ANOVA; Multiple	Type of Environment	Subjective Evaluation Questionnaire: ROS

	University Students and Staff	Linear Regression

Among the 15 studies on restorative environments selected, 6 are experimental studies, and 9 are cross-sectional studies. Research settings span urban parks and green spaces (n=5) [51,53,54, 59,60], campus environments (n=4) [25,58,62,63], built environments (indoor, streets) (n=4) [52,57,61,64], and blue spaces (beaches, waterfront spaces) (n=2) [55,56]. Sample sizes primarily range from medium to small, varying from 60 to 1473. Sample sizes are generally small to medium (≈ 60-1473). Most studies investigate student samples (mean age ≈ 20 years) with relatively balanced sex distributions; one study targets hospital patients (n=1) [57].

Specifically, Among the 6 experiments, 5 classified spatial environments by certain types and characteristics, such as spatial area and vegetation coverage [61], material types of spaces [52], and landscape types and elements [53,54]. Participants were divided into groups to experience different settings, with pre–post (within-condition) and between-condition comparisons of restorative outcomes. Most experiments use virtual reality (VR) and video-based simulations [52,53], and one is conducted onsite [53]. Data analysis methods primarily included ANOVA and t-tests. One study used photo-based methods, extracting content (environmental characteristics) from photos to analyze their impact on participants' restorative effects, establishing mathematical models linking environmental characteristics with restorative outcomes [55]. Five studies combine subjective questionnaires with objective physiological measures [52-54,56,61]. one additionally includes the DSB test to assess attention and memory changes pre–post [54]. The remaining study relies on subjective questionnaires only [55]. Restoration assessment questionnaires included evaluations of mood states (Profile of Mood States) [53], PANAS [52], Spielberger's STAI-S [54], and PRS or LPRS [51,53-56]. Physiological measures mainly used were systolic, diastolic blood pressure; heart-rate variability; pulse rate, R-R intervals; blood glucose levels, and skin conductance levels.

Besides experimental studies, 9 papers employed cross-sectional research methods [25,58-64]. These studies focused on establishing statistical relationships between environmental characteristics of research settings and restorative effects, using analysis methods such as regression and SEM. Measures of environmental characteristics were either subjective or objective. Subjective measures included context-specific assessment scales [25,57,59,60,64], such as through photo-based environmental characteristics evaluations [63,61] and self-reports [64]. Objective data included spatial openness, distance, area [62], as well as air-quality indices, sound-quality indices, and thermal-environment indicators [59]. Several studies also incorporated social and personal factors, such as environmental preferences, place attachment, personality traits, and types of activities, as mediating factors between environmental contact and restorative outcomes [25,59,60,64], to identify potential pathways affecting restoration. Regarding outcome assessment, many studies used the PRS and its variants, including the HIRS [57] and the revised SRRS [51]. Other studies directly linked environmental characteristics with psychological recovery and emotional experiences, such as positive and negative affect [59], and employed the ROS [64].

Overall, research related to restorative environments predominantly uses experimental and cross-sectional methodologies. While both probe the restorative potential of environments, they differ in focus and inferential strength. Experimental studies are better suited for causal inference about links between spatial environments and restorative outcomes. However, they typically consider a limited set of environmental factors to maintain experimental control. Although researchers believe that VR devices, videos, and photo stimuli can approximate visual aspects of selected scenes, they still differ from real-world settings in terms of overall ambience, social context, opportunities, physical activity, and multisensory cues (e.g., haptic and olfactory), which can limit

detection of mediating processes that rely on these features [65]. Participants in these studies are predominantly university students, who are convenient to recruit but may not represent the general population [66,67]. Furthermore, many simulation experiments require little or no interaction with the environment and focus primarily on visual perception, which may underestimate additional effects of environmental characteristics and amenities [68].

Cross-sectional studies typically use surveys to assess environmental perceptions, allowing respondents to experience the actual ambient and social context directly, thus providing more realistic reports. However, cross-sectional designs face limited control over environmental variables, substantial confounding and self-selection, and large individual heterogeneity, which together hinder causal inference. Cross-sectional tasks based on photo or recalled scenes lack both the experimental control of lab studies and the immersive, multisensory qualities of real environments. Differences in immersion, sustained attention, and memory accuracy may bias responses [69]. In terms of measuring spatial environmental characteristics, most research uses questionnaires or objective environmental indicators selected by researchers, such as perceived environmental characteristics [25,59] and vegetation coverage [51], with few studies considering user experience [63]. Although these aforementioned aspects are critical for restorative outcomes, relying on a fixed indicator set across disparate spaces risks omitting context-specific attributes. Therefore, a more comprehensive identification of restorative characteristics in environments requires combining user feedback, expert opinions, and statistical methods to develop more comprehensive measurement indices [57]. Many studies use only a single subjective questionnaire to assess restorative outcomes, which can lead to significant variations in evaluations due to individual differences in scale interpretation.

Drawing on the respective strengths and limitations of experimental and cross-sectional designs, we argue that a serialized, systematic research program is preferable to a one-off study for investigating restorative environments. First, conduct preliminary fieldwork to gather feedback from the target user group and, together with statistical analysis and expert interviews, develop a comprehensive, context-sensitive index of environmental attributes. Second, integrate both research types: begin with cross-sectional studies using SEM or path analysis to specify the relationships among environmental characteristics, mediators, and potential confounders, thereby establishing a concrete mechanism linking attributes to restorative outcomes; then use experiments to analyze and validate the effects of individual factors. This integrated pathway enables more accurate identification of key restorative characteristics, enhances the interpretability of findings, and is particularly well suited to complex settings such as expressway service areas. Figure 2 shows the restorative environments research design pathway.

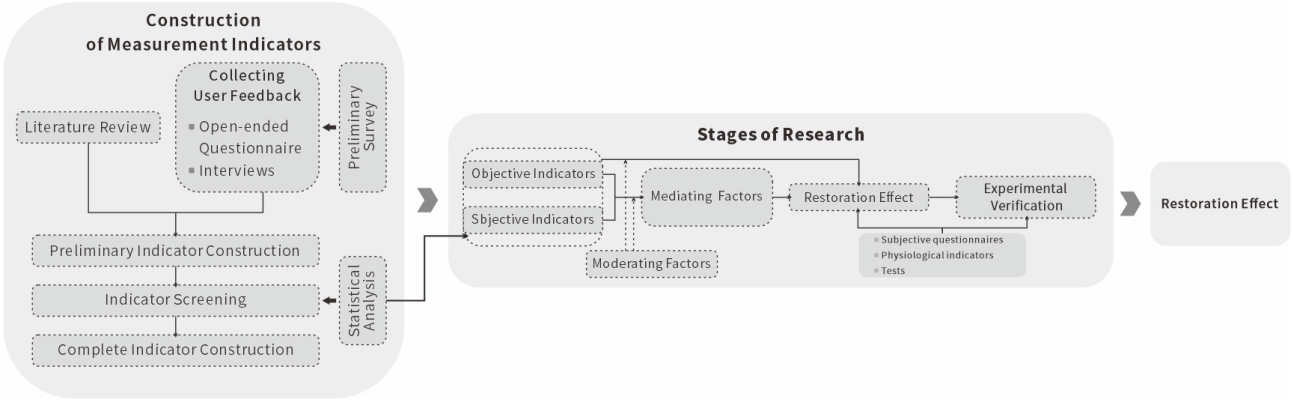

Fig. 2. The restorative environments research design pathway diagram

In summary, the construction of a restorative environment should initially integrate literature data, user surveys, and expert interviews to determine spatial environmental indicators for the scenario, and establish a path model linking these indicators with restorative effects, identify key restorative characteristics within the scenario, and finally validate these through experiments to establish specific causal relationships.

3.3 Attention Restoration

In psychology, attention is commonly described in terms of directed (top-down, effortful) attention and involuntary (bottom-up, effortless) attention. Directed attention is essential for task execution because it enables people to focus on task-relevant cues while inhibiting distractions [50,70]. However, sustaining it draws on limited cognitive resources and leads to fatigue over time [50,70].

ART proposes that many natural settings elicit soft fascination, which engages involuntary attention and thereby allows depleted directed attention to recover [71]. Evidence also indicates that certain built environments, such as service places and neighborhood spaces, can support restoration, although distinct environmental characteristics may influence attention through different pathways [72,73]. The aim of this section is to identify factors that shape attention restoration and to integrate them into a coherent framework.

Across the 15 attention-restoration studies reviewed, factors influencing attention restoration can be categorized into three main aspects: environmental characteristics (physical and perceived environments) [21,24,74-78], social factors [72,73], and personal factors [80-83]. Table 4 summarizes the classification and main findings. These factors may act as predictors, mediators, or moderators of attention restoration (and in some cases as confounders).

Table 4
Dimensions and findings of attention restoration research

Author	Study Setting	Research Method	Participant Demographics Number of Participants	Study Type	Study Dimension	Data Analysis Methods	Restoration Outcome Measurement Methods	Major Findings
Lu and Fu [79]	University Campus	Video Recording	n = 360 Students	Cross-Sectio n-al Study	Physical Environment or Environmental Perception	Classification Regression (CATREG), Correlation Analysis	Subjective Evaluation Questionnaire: Restoration Potential Assessment	Environmental perception factors (visibility, accessibility, comfort, cognitive recognition, sense of belonging) are crucial for the restorative experience of the environment. Spaces with water and vegetation are most favored, while hardscape and unshaded environments

								have negative effects on restoration.
Subiza-Pérez *et al*., [80]	Urban Beaches and Parks	VR Simulation Scenarios	n = 429 Mixed Mixed	Cross-Sectional Study	Personal Dimension	Chi-Square Analysis, MANOVA, Hierarchical Linear Regression	Subjective Evaluation Questionnaire: ROS	Urban beaches and parks play a significant role in providing restorative experiences. Place attachment and identification, along with perceived restorativeness, are key factors influencing psychological restoration. Psychological and subjective experiences are more crucial in promoting mental restoration compared to physical and design characteristics.
Lin *et al.,* [75]	Forest	Simulated Scenarios	n=140 Young Adults	Experimental	Physical Environment or Environmental Perception	ANOVA	Physiological Indicators: Attention Restoration	Images with a low trunk ratio and a moderate to high sky and leaf ratio are effective in reducing stress and restoring attention.
Jiang *et al.,* [76]	Roadways	Simulated Scenarios	n=33 Mixed	Experimental	Physical Environment or Environmental Perception	ANOVA	Subjective Evaluation Questionnaire: Psychological States (boredom, anger, frustration, avoidance, anxiety, tension, mental fatigue)	The amount and orderliness of roadside greenery can reduce drivers' negative psychological states The complexity of the road landscape is positively correlated with the level of negative psychological states.

Chiang *et al.,* [77]	Roadways	Simulated Scenarios	n=144 Mixed	Experi-mental	Physical Environment or Environmental Perception	ANOVA	Tests: Attention Level (measured by Digit Span Test and Stroop Color-Word Test), Reaction Time (RT)	As the level of roadside greenery increases, drivers' attention levels significantly improve. The optimal greenery dose, where drivers performed best in attention tests, was found to be between 31% and 40%.
Kumar *et al.,* [78]	Servicescapes	Questionnaire	n=327 Mixed	Cross-Section-al Study	Physical Environment or Environmental Perception	SEM, ANOVA	Subjective Evaluation Questionnaire: Attention Restoration	Exposure to biomorphic design can help individuals restore attention, enhance focus, and increase relaxation.
Jiang *et al.,* [74]	Urban Streets green infrastruc-ture	Photographs	n =43 Mixed	Experi-mental	Physical Environment or Environmental Perception	ANOVA	Tests: Sustained Attention to Response Task (SART), Physiological Indicators: Functional Magnetic Resonance Imaging (fMRI) Assessment	Trees and the combination of trees with bioretention basins have a positive impact on attention restoration, while streets without green infrastructure deplete attention.
Stragà *et al.,* [24]	Natural and Built Environments	Photographs	n =184 Students	Cross-Section-al Study	Environmental Perception	SEM	Subjective Evaluation Questionnaire: Overall Perceived Restorativeness	The restorative effects of natural and built environments depend not only on the type of environment (natural or built) but also on specific environmental characteristics such as sense of safety, opportunities for reflection, and coherence.
Wong *et al.,* [72]	Restaurants	Interviews	n=31 Customers	Qualita-tive	Environmental Perception	Content Analysis and	Interviews: Attention Restoration	The service experience in smart restaurants

						Coding Strategies		positively influences customers' attention restoration.
Liu *et al.,* [82]	Urban Parks	Questionnaire	n=290 Residents from Two Locations	Cross-Sectional Study	Personal Dimension	ANOVA, Regression Analysis	Subjective Evaluation Questionnaire: PRS	Familiar urban park settings can provide restorative potential comparable to natural environments. Place dependence and place identity play significant roles in this restorative potential.
Sun *et al.,* [73]	Neighbor-hood Spaces	Questionnaire	n=362 Older Adults	Cross-Sectional Study	Environmental Perception and Personal Dimension	SEM	Subjective Evaluation Questionnaire: PRS	Environmental perceptions of neighborhood spaces (such as accessibility, safety, openness, and familiarity) have a significant positive impact on the perceived restoration of older adults. Neighborhood social cohesion and place attachment mediate the relationship between environmental perception and perceived restoration.
Malekin ezhad *et al.,* [21]	University Campus	Questionnaire	n=440 Students	Cross-Sectional Study	Environmental Perception	SEM	Subjective Evaluation Questionnaire: ROS-6 items	Perceived sensory dimensions (PSD) and perceived restorativeness (PR) have a positive impact on the restoration experience of university students. Perceived

								restorativeness (PR) partially mediates the relationship between PSD and the restoration experience.
Gonçalves *et al.,* [74]	Urban Parks	Questionnaire	n=610 Mixed	Cross-Sectional Study	Physical Environment or Environmental Perception	Generalized Linear Model (GLM)	Subjective Evaluation Questionnaire: Perceived Restorativeness (PR)	Perceptions of biodiversity, the proportion of broadleaf and evergreen tree species, and emotional connection and satisfaction with the park have positive impacts on psychological restoration High levels of environmental fragmentation have a negative impact.
Wang *et al.,* [83]	University Campus	Questionnaire	n=200 Students	Cross-Sectional Study	Personal Dimension	SEM	Subjective Evaluation Questionnaire: Psychological Recovery	Plant scape preference has a significant positive impact on psychological recovery, with prototype landscape consciousness partially mediating this effect.
Pazhouhanfar and Kamal [81]	Urban Natural Land-scape Scenes	Questionnaire	n=120 Students	Cross-Sectional Study	Personal Dimension	Path Analysis	Subjective Evaluation Questionnaire: Perceived Restorative Potential (PRP)	Perceived restorativeness partially mediates the relationship between visual preference and perceived restorative potential (PRP) Coherence, complexity, and mystery within visual preferences directly or indirectly influence PRP through perceived

		restorativeness, while legibility does not have a significant impact on restorative potential.

Among all environmental types, natural settings are frequently reported to have strong restorative potential [84]. 6 studies examine green (urban greenery, forests, campus greens) and blue settings (beaches, water features) [21,22,74,75,80,81]. Reported supportive characteristics include the types, distribution, layout, and proportion of vegetation, canopy density, and water characteristics. The studies cover a wide range of regions, with some focusing on roadside greenery [76,77], finding that higher levels of roadside planting are associated with improved psychological states, shorter reaction times, and better performance during emergency maneuvers. Jiang *et al.,* [22] show that viewing tree-lined urban scenes helps maintain directed attention, whereas scenes without green infrastructure are linked to declines in directed attention. Beyond trees and other green elements, the restorative effects of blue spaces (water characteristics, sky) have also been widely validated. Subiza-Pérez *et al.,* [80] report that beaches and primarily plant-based green environments provide comparable restorative outcomes, with beaches sometimes offering even greater restoration. In university campus settings, spaces with water elements are rated by students as having the highest restorative potential [79]. Lin *et al.,* [75] found that different proportions of sky, trunks, and leaves have varying impacts on restoration, with better restorative effects occurring when the proportion of tree trunks is low and that of sky and leaves is moderate. Moreover, nature-inspired design in built settings can also facilitate attention restoration, such as in Kumar *et al.,* [78] find that incorporating biomorphic or fractal patterns into service facilities enhances place attachment and produces attention restoration outcomes similar to those observed in natural environments.

Beyond natural elements, many studies have found that perceived environmental qualities also play a key role in attention restoration. These include the Perceived Sensory Dimensions (PSD) [21], Biodiversity Perception (BDP) [74], and perceptions of safety, convenience, and comfort. These are not physical characteristics of a scene but are reflected through users' perceptions of environmental characteristics, hence some studies also consider perceptual factors as mediating variables between actual environmental characteristics and restorative outcomes [74]. Stragà *et al.,* [24] found that both natural and built settings perceived as unsafe or hostile are far less restorative, in such contexts, attention is redirected toward safety monitoring rather than freely allocated to the environment. Additionally, Design interventions that improve usability and perceived hygiene or maintenance, for instance, providing essential amenities and sanitary facilities, are associated with higher comfort [79]. Nighttime lighting is associated with longer hours of use, higher visit frequency, and greater perceived safety [79]. It's noteworthy that some studies use the PRS as the dependent variable in their research [73,82]; however, in a broader sense, perceived restorativeness only measures the potential of an environment to facilitate attention restoration and is not an actual restoration outcome. Thus, in the complete path from environmental characteristics to attention restoration, it can only serve as a factor of the perceptual dimension.

Regarding social factors, social cohesion and service quality or experience in service facilities also impact attention restoration. Sun *et al.,* [73] show that community cohesion mediates between neighborhood environmental perceptions and restoration among older adults by strengthening social support and participation, reducing loneliness, and enhancing psychological health and perceived restorativeness. Wong *et al.,* [72] find that service quality and experience in service

settings, e.g., robotic service trials that provide a temporary psychological escape from daily hassles, are associated with improved attention restoration reports.

Personal factors primarily refer to users' environmental preferences and place attachments, which usually have a significant predictive effect on restoration outcomes or act as mediators between the environmental characteristics and restorative effects. environmental preference refers to the degree of individual preference for specific environmental scenes based on perception and judgment, formed through processes of environmental stimulation, sensory response, brain interpretation, and cognitive judgment, ultimately leading to expressed preferences [83]. Additionally, environmental preferences are often considered related to personal childhood experiences and familiarity with the scene, positively influencing place attachment. For example, when people observed their familiar environments or elements, they would evoke memories of hometown scenes stored in memory, generating feelings of intimacy and identification, positively affecting psychological and cognitive restoration [82]. Wang *et al.,* [83] conceptualized this concept of childhood memories as "archetypal landscape awareness" and confirmed its mediating effect between environmental preferences and perceived restorativeness. Liu *et al.,* [82] also found that people have higher attachment and identification with environments they are familiar with, as familiarity is usually considered a key component of environmental preference. In another study, Pazhouhanfar and Kamal [81] validated the four key predictive factors of environmental preference, such as complexity, coherence, mystery, and legibility, and their impacts on the four key assessment factors of restorative environments and restorative outcomes themselves. On the other hand, place attachment is also considered a key predictive factor for attention restoration, intertwining with social factors [81,82]. Place attachment refers to the emotional bond individuals have with places they frequently visit or use, involving both physical dependence on the environment and psychological identification [85]. Specifically, "place dependence" primarily concerns the functional needs of the place, while "place identity" refers to complex emotional bonds and a sense of belonging with a place, considered an extension of individual and social identity [86]. Research suggests that finding the most restorative environments depends not only on their naturalness but on their compatibility with previous place attachments; thus, the degree of attachment to a place can often predict the restorative outcome of the place on an individual [82].

In summary, the review finds that while physical, social, and personal factors have restorative effects on directed attention, they present a complex network of effects and detailed elements. For example, physical environmental characteristics are not simply additive or linearly increasing but are closely related to the described scene and overall environmental resource allocation. For instance, Jiang *et al.,* [76] found that although increasing the greening rate of roadside greening positively impacts drivers' psychological states, the same proportion under chaotic tree arrangements can lead to higher levels of negative psychological states, which is detrimental to cognitive restoration. Moreover, in nature-dominated settings, man-made facilities are considered negatively correlated with environmental restorativeness [22,24], while some studies find that environmental and sanitary facilities should be considered in campus environments because they are closely related to the comfort of the environment [79]. These inconsistent results, besides being due to differences in settings, is also related to age, gender, income, educational level, family structure, and the choice of mediating factors. Therefore, in terms of details, studies should select setting-appropriate indicators, and explicitly model confounding, moderation, and mediation.

Although the results related to scenes, environments, vegetation, distance, size, and perception in the studies are inconsistent, they still provide valuable directions and content for consideration. It is evident that these factors are not independent but interconnected. Among them, physical environmental characteristics typically serve as sources of stimuli, with various perceptual factors

acting as responses to physical environmental contact, subsequently influenced by social and personal factors. For example, well-designed facilities and spaces can evoke feelings of safety and comfort in users, offering better opportunities for social interaction and promoting attention restoration [24,74]. Additionally, incorporating artificial elements or plants within a space can enhance users' sense of connection to the place, influencing their environmental preferences and inducing pleasant, relaxed psychological states, thereby facilitating attention restoration [77]. Therefore, in developing a specific research framework, researchers should pay attention to the physical environment itself and the impact of mediating factors on restorative effects. However, these factors are currently tailored to specific spatial environments, and their applicability and specific relational pathways in expressway service areas still require further analysis and validation.

In conclusion, multiple factors influence the effect of attention restoration, including environmental characteristics (objective characteristics and subjective perceptions), social contexts, and individual differences. Researchers need to conduct path analysis to identify the specific pathways between environmental characteristics and attention restoration, thereby more effectively pinpointing the environmental characteristics that facilitate restorative effects.

4. Discussion

4.1 Construction of the Theoretical Framework

This study analyzed the spatial characteristics, facilities, and functions of expressway service areas, as well as their impact on driving fatigue, the research needs, this section is divided into three levels, synthesizing the content summarized from the three domains in the previous chapter. The aim is to integrate key content from different fields to address the main questions of this paper.

Initially, based on the literature reviews of "expressway service areas," "restorative environments," and "attention restoration" from previous chapters, the first level of the "Point of Departure Tree" (POD Tree) can be formed. Figure 3 shows the complete POD tree diagram.

Fig. 3. The POD tree diagram

Next, by cross-referencing and integrating the summaries of the three themes from the first level, the second level of the "Point of Departure Tree" (POD Tree) is achieved. The integration of POD1 and POD2 reveals that combining user interviews, expert feedback, and the characteristics of Expressway Service Areas, establish environmental characteristic measurement indicators and analyze their path relationships with restorative effects to identify key restorative elements within expressway service areas, and validate these through experiments to establish causal relationships (see POD4). The synthesis of POD2 and POD3 shows that by integrating user interviews, expert feedback, and scenario characteristics, establish environmental characteristic measurement indicators and create path relationships with restorative effects, considering the roles of mediating factors such as perception, social, and individual differences, to identify environmental characteristics that aid in restorative effects, and subsequently validate these through experiments to establish causal relationships (see POD5). The integration of POD3 and POD4 indicates that when planning Expressway Service Areas, it is essential to analyze their environmental characteristics and incorporate mediating factors such as perception, social, and individual differences. Conduct path analysis between these factors and attention restoration to establish a restorative environment model for expressway service areas, enabling fatigued drivers to achieve more effective rest through expressway service areas (see POD6).

Thirdly, by further synthesizing the content from the second level, the third level of the paper is obtained. The integration of POD5 and POD6 reveals that combining user interviews, expert feedback, and the characteristics of Expressway Service Areas, establish environmental characteristic

measurement indicators for expressway service areas; by fully considering mediating factors such as individual, social, and environmental perceptions, develop a path model linking these with restorative effects, identify key restorative characteristics within the scenario, and validate these through experiments to establish causal relationships (see POD7). The synthesis of POD5 and POD6 also shows that combining user interviews, expert feedback, and the characteristics of Expressway Service Areas, establish environmental characteristic measurement indicators for expressway service areas, incorporating mediating factors such as individual, social, and environmental perceptions, and analyze the path relationships with attention restoration to identify and validate key restorative characteristics within expressway service areas, thereby facilitating more effective rest for fatigued drivers (see POD8).

Finally, by synthesizing the two contents from the third level, the final framework of this paper is established, namely: Planning for expressway service areas can begin by integrating user interviews, expert feedback, and expressway service area characteristics to establish environmental characteristic measurement indicators for expressway service areas, and by thoroughly considering mediating factors such as individual, social, and environmental perceptions, analyze the relationships between these factors and attention restoration outcomes to identify environmental characteristics within expressway service areas that facilitate attention restoration, ultimately validating these through experiments to enable more effective rest for fatigued drivers (see POD9).

4.2 Existing Knowledge on the Construction of Expressway Service Areas

Expressway service areas are vital rest and service facilities within access-controlled expressway systems. They provide amenities such as rest, dining, and vehicle maintenance, enabling drivers and passengers to recover and reduce the risk of fatigue-related driving [47]. During the literature search for this review, it was found that there is a scant number of English literatures on expressway service areas, despite the early starting year, they have not garnered significant academic attention over time. Methods used in the selected studies fall into two broad strands. The first links service areas to fatigue-related crash risk, typically via location or distance measures, to assess safety impacts. While this work shows associations between proximity to service areas and lower fatigue-related crashes, it rarely examines fine-grained environmental characteristics of the areas themselves. The second strand consists of survey-based observational studies that analyze drivers' needs and perceptions of service-area environments. These studies often rely on qualitative or descriptive evidence and struggle to specify measurable links between environmental characteristics and fatigue or cognitive restoration. Besides these two categories, some studies focus on single aspects of expressway service area construction, such as parking lots and facilities [41,42]. Unlike the former, these studies focuses on single components, such as parking design and ancillary facilities, without situating them within the broader spatial system or connecting them to restoration outcomes. Additionally, the review found that the spatial design of service areas is greatly influenced by regional policy, operational regimes, and local cultural practices [38], with empirical evidence primarily concentrated in Western contexts. This limits generalizability and transferability to other regions. Therefore, future research should focus on specific regions, integrating prior findings with national and regional characteristics to identify key restorative characteristics for expressway service areas. On the other hand, attention could be directed towards the macro domain, by integrating evidence across multiple regions to develop widely applicable standards or guidelines for service area planning and design, while explicitly accounting for policy and operational differences.

4.3 Methodological Considerations

4.3.1 Measuring environmental characteristics

Literature on restorative environments largely pertains to assessing environmental characteristics and quality, primarily using subjective questionnaires and objective measurements. Common objective indicators include vegetation cover (e.g., Normalized Difference Vegetation Index), air-quality metrics, and microclimate measures (e.g., temperature and relative humidity). Subjective measures usually rely on validated perceptual scales, such as the widely used PSD and BDP scales. Most studies utilize a single scale, with few combining both subjective and objective measurement methods. However, a single scale may not capture the full complexity of environmental characteristics. For example, vegetation cover can indicate the amount of vegetation but not its quality, accessibility, or usability, potentially assigning similar values to inaccessible overgrowth and well-maintained public parks [87]. Moreover, perceived dimensions can diverge from instrument-based measurements due to perceptual biases, temporal sampling differences, in addition to individual heterogeneity.

Additionally, context also shapes what users attend to. Applying the same measurement battery across different settings risks omitting context-relevant factors that influence restoration. Particularly in complex areas like expressway service areas, due to their specific locations and functions, generic measurement questionnaires may not fully capture environmental characteristics. Therefore, these spaces also need customized measurement indices based on their specific characteristics. We propose a customized measurement workflow for complex settings. First, First, generate candidate indicators via a literature scan combined with open-ended surveys, cognitive interviews, and expert elicitation to collect user feedback. Next, field a larger survey to rate the salience and clarity of candidate items and conduct exploratory/confirmatory factor analyses (EFA/CFA) for item reduction and construct modeling. Then, refine indicators via expert review or Delphi, and evaluate reliability and validity, including measurement invariance across user groups and sites. Finally, combine subjective indicators with objective measures to mitigate common-method bias and to enhance ecological validity [57]. Although this mixed-methods, staged approach enables a more comprehensive evaluation of setting-specific environmental characteristics, the extant literature contains few examples that develop context-tailored composite indices specific environments.

4.3.2 Pathways between environmental characteristics and attention restoration

Environmental characteristics typically influence attention restoration through various pathways. Previous chapter group the determinants into environmental characteristics (physical and perceived), social factors, and personal factors. These pathways rarely act in isolation, but more likely, they operate in parallel or serial and may interact, shaping attention restoration in non-additive ways [88]. Variables that transmit the effect of physical environmental characteristics to attention restoration are commonly modeled as mediators. Baron and Kenny [89] defined a mediator as “a third variable representing the mechanism through which the focal independent variable impacts the dependent variable of interest,” and proposed a causal-steps procedure to assess mediation. However, this method has its limitations, as it requires that the direct effect between the independent and dependent variable be significant to identify mediators. This requirement could lead to overlooking some indirect paths [90]. This review finds that most studies used more complex and accurate methods for mediator analysis, such as SEM and the SPSS PROCESS macro [25,58,81]. SEM models latent constructs to account for measurement error and evaluates model fit to the

observed covariance structure, enabling tests of multiple indirect paths independent of the total effect [91], while PROCESS provides flexible Ordinary Least Squares (OLS) based estimation for parallel or serial mediation, moderation, and conditional process models with bootstrap confidence intervals.

When analyzing mediators, it is crucial to specify competing pathway structures. Different configurations—parallel vs. serial mediators—can yield different conclusions. For instance, Dzhambov *et al.,* [92] found that when social cohesion was used alone or in parallel as a mediator in studies on green spaces and mental health, its results were not significant. However, when it was serialized with recovery quality, its results became significant. Accordingly, researchers should develop theory driven mediator sets, test alternative pathway specifications, including potential moderators, and assess indirect effects using bias-corrected bootstrap confidence intervals, while adjusting for plausible exposure, mediator and mediator, outcome confounders.

4.3.3 Research design

In terms of research design, this review finds that studies on restorative environments primarily utilize experimental research and survey-based research, each with distinct advantages. Cross-sectional field surveys, the most common observational approach, can elicit ecologically situated reports, particularly when conducted in field, and are well suited to modeling the roles of social and personal factors with contemporary analytical tools. However, cross-sectional data can only demonstrate statistical associations and hypothesized pathways, not causal relationships. By contrast, experimental designs can manipulate environmental factors and strengthen internal validity for specific links between environmental characteristics and restorative outcomes. Yet experiments typically manipulate a limited set of factors and face resource constraints (time, equipment, site access). Laboratory or VR settings may also reduce ecological validity, producing effects that differ from those in real world contexts [93]. For these reasons, we advocate a standardized, mixed method, and staged research program rather than reliance on a single study. For example, in selecting experimental subjects, many studies recruit university students, a convenient but narrow population that may not represent the full user base [89]. In addition, some experiments omit stress or fatigue induction, which can attenuate effects and undermine construct validity [94]. Where appropriate, researchers should use validated inductions and manipulation checks and diversify samples through stratified or multi-site recruitment.

A sequential, integrated design can leverage the strengths of multiple methods. First, employ interviews and observations to identify salient spatial characteristics and user concerns. Next, deploy survey-based models to estimate pathways linking site-specific environmental characteristics to perceived attention restoration. Finally, use experiments, in the lab, VR, or the field, to test specific environmental attributes under controlled conditions. Complementary quasi-experimental opportunities (e.g., before–after renovations, stepped-wedge rollouts, difference-in-differences) can further enhance causal inference in real settings.

Because such programs require time and resources, standardization and transparency are essential, such as pre-registration, a priori power analysis, multi-method outcome batteries (e.g., PRS or ROS plus task-based attention and physiological markers), clear reporting checklists, and open materials or data. For reproducibility, Browning *et al.,* [69] recommend sharing simulation scene models and datasets to enable independent replication and cumulative evidence building.

4.4 Integrated Model

We present a research framework through a critical review of the literature, integrating expressway service areas (environmental characteristics), restorative environments (theoretical models), and attention restoration outcomes. Specifically, the planning for Expressway Service Areas involves combining user interviews, expert feedback, and the unique characteristics of expressway service areas to establish environmental characteristics measurement indices. This approach also considers personal, social, and environmental perceptual mediating factors to analyze their relationship pathways with attention restoration outcomes, identifying key environmental characteristics within expressway service areas that facilitate attention restoration. Subsequently, we validate these elements experimentally to enable more effective rest for fatigued drivers. As shown in Figure 4, this section will detail and demonstrate the framework integrated from these three domains.

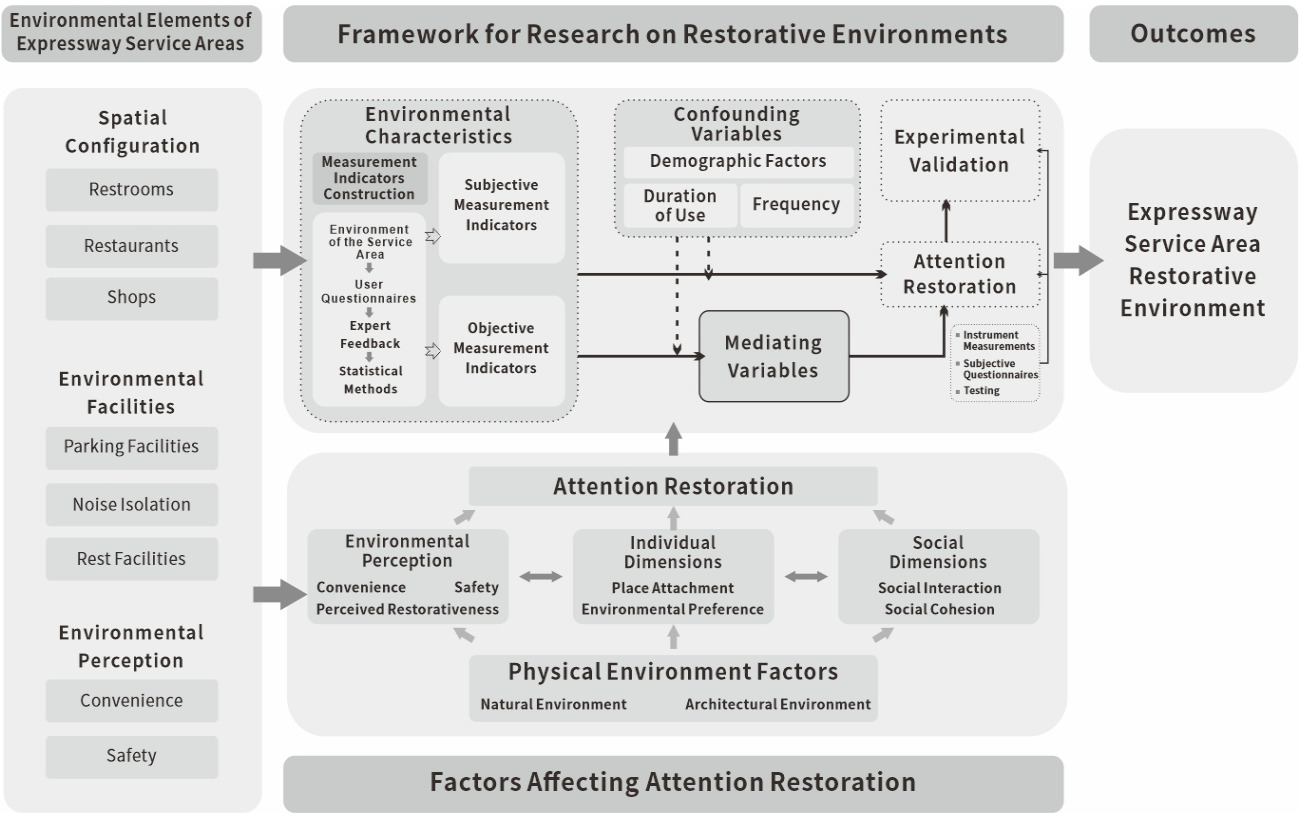

Fig. 4. The integrated framework diagram for the study of attention restorative environments

In research related to expressway service areas, we initially found extensive evidence supporting the positive impact of expressway service areas on alleviating driver fatigue. In terms of specifics, we identified spatial characteristics affecting drivers' rest, including parking areas, environmental perceptions (such as safety and convenience), and facilities. To gain a more comprehensive understanding of the spatial environmental characteristics of expressway service areas, it is advisable to conduct interviews and open-ended questionnaires with the primary users of these spaces to understand their needs and main concerns. Specifically, different types of drivers (such as long-haul truck drivers and family trip drivers) could be interviewed or given open-ended questionnaires to gather their feedback. After this, a combination of preliminary research, statistical methods, and

expert interviews can be used to refine and validate the listed environmental characteristics measurement projects for optimal results.

We have identified several factors that may affect attention restoration outcomes, namely physical and perceived environmental factors, personal factors, and social factors. Since these are summarized from various studies, their potential for restoration may not be consistent. These factors often do not independently affect recovery outcomes but interact, forming complex pathway relationships. Generally, physical environmental characteristics usually serve as stimuli, impacting recovery outcomes through direct or indirect pathways (environmental perception, personal factors, social factors). These variables in the pathways between physical environmental characteristics and restoration outcomes are typically referred to as mediators. Furthermore, users' personal characteristics and behavioral habits (such as gender, age, duration of use, frequency, etc.) may influence their restoration experience [59].

Regarding research methods, researchers can first employ cross-sectional studies to analyze the pathways between the environmental characteristics of expressway way service areas and restoration outcomes. At this stage, SEM appears to be a more ideal analysis method. Compared to traditional Baron and Kenny causal step methods and difference coefficient approaches, SEM is better suited for handling complex mediation relationships [95]. Researchers can establish pathways for mediators by first constructing a preliminary model that integrates a literature review and exploratory data analysis. Subsequently, researchers can optimize the model progressively using fit indices or by evaluating various pathways to identify the most effective model.

Following the analysis, significant factors could be experimentally validated to ascertain specific causal relationships between these factors and restoration outcomes. Currently, conducting experiments in simulated environments is a common choice in most experimental studies. Simulated scenes can more accurately control environmental factors, but they usually focus only on visual effects simulation, with some studies incorporating scene sounds and few involving multisensory simulations (such as olfactory or tactile). Additionally, some reviews have found that positive effects of exposure in simulated environments are generally higher than in real settings, and studies with weaker designs are more likely to report positive outcomes [69]. Therefore, during experiments, a rigorous procedure is essential, considering factors including participant selection, experimental equipment, sorting out confounding factors, random grouping during the experiment, and participant familiarity with the test items during repeat tests.

To comprehensively evaluate attention restoration outcomes, researcher can use a combination of subjective questionnaires such as the ROS, objective physiological indicators like Heart Rate Variability (HRV), EDA, and Electroencephalography, along with behavioral tests such as the DSB. Lastly, longitudinal studies could be combined to further verify the validity of the experimental results through long-term observation.

4.5 Strengths and Limitations

This scoping review is the first to synthesize literature across three domains—expressway service areas, restorative environments, and attention restoration—and proposes a research framework concerning the restorative environment of expressway service areas. We advocate for a more comprehensive and interdisciplinary approach that integrates content from different domains and extends the study of restorative environments to the realm of transportation facilities. To date, there has been no research on the restorative environments of expressway service areas; hence, we attempted to apply a restorative environment research framework to this context and integrate key content about attention restoration and expressway service areas into an exploratory research

framework. Overall, this framework can guide future research directions, provide methodological references for similar studies of restorative environments, and offer information and theoretical support for related practical projects and policymakers.

Admittedly, this review has several limitations. We employed a scoping review method to explore the potential synergies and research mechanisms when considering these dimensions comprehensively. By focusing on specific areas of the literature, we did not provide an exhaustive overview of all existing evidence related to highway service areas, restorative environments, and attention restoration. Additionally, we did not conduct a detailed evaluation of each study's design quality and outcome effects, which may affect the precision of our findings. Furthermore, the literature we reviewed encompassed a wide range of research methods, including field questionnaires, photographic assessments, and virtual reality simulations. The significant variations in experimental methods and participant populations led to some conflicting results. While these inconsistencies do not undermine the overall research framework we proposed, they may reduce the framework's validity.

Integrating knowledge from different fields into a usable methodology is challenging. Future related research should incorporate more literature and employ more standardized and systematic assessment methods, such as meta-analysis, to provide a comprehensive evaluation of research methods, data, and results for more precise outcomes.

5. Conclusions

Through this cross-literature synthesis, we established the final theoretical framework for developing restorative environments in expressway service areas. To construct a restorative environment in expressway service areas that effectively aids fatigued drivers, planning for expressway service areas can incorporate environmental characteristics (spatial environment, facilities, perceptual factors) referenced from user feedback, combined with personal psychological and social mediating factors. This approach establishes specific pathway models with perceived restorativeness to identify key restorative characteristics within the service area, validated through experimentation. Overall, the construction of restorative environments and the identification of factors influencing restorative effects are not dependent on a single domain but are the results of interdisciplinary and comprehensive efforts. This review serves as a model for cross-disciplinary research in transportation, environmental design, and environmental psychology, offering new perspectives for related fields. The results contribute to further exploration and improvement of the layout, facilities, and perceptual factors of expressway service areas, thus improving the overall quality and safety of expressway travel and promoting ongoing development in the field of transportation architecture and human-environment research. This plays a crucial role in supporting the well-being of drivers during long-distance journeys.

Acknowledgement
This study forms part of the PhD research undertaken by the first author.

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