

Quantifying the Restorative Effects of Green–Water–Hardscape Ratios: Evidence from a Simulated Landscape Experiment in Chiang Mai

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ABSTRACT

Modern life presents significant stressors that negatively impact mental well-being. While the importance of mental health is increasingly recognized, effective stress management strategies are still crucial. This study explores the potential of landscape perception as a natural intervention to enhance proximal restorative outcomes. By investigating the physiological and psychological responses of individuals to diverse landscape stimuli, we aim to understand how specific combinations of landscape elements (e.g., green spaces, water features) can promote psychological restoration. The study design intended to collect psychological and physiological (heart rate and blood pressure) responses, measured before and after stress-inducing tests and landscape exposure. Scores from self-reported questionnaires were collected from 140 participants ($n = 140$) exposed to seven virtual landscape scenarios with varying proportions of green (G: vegetation), water (W: blue infrastructure), and hardscape (H: pathways, seating, shelters) elements. Results revealed that balanced landscapes (e.g., MMM: 0.33/0.33/0.33) and nature-dominated landscapes with low hardscape (MML: 0.45/0.45/0.1) elicited the strongest positive responses across all psychological dimensions (aesthetic preference, comfort, concentration, and behavioral preference). In contrast, hardscape-dominated landscapes (LLH: 0.1/0.1/0.8) consistently performed the poorest. While physiological measures showed general stress reduction across all scenarios, no statistically significant differences were found between GWH compositions. This study investigates how the relative proportions of landscape elements significantly affects perceived restoration and preference, although short-term physiological differences are negligible. These results could guide the development of evidence-based interventions and design strategies utilizing the sustainable way to improve restorative experiences for individuals and communities.

Keywords: virtual landscape, landscape perception, mental well-being, Green–Water–Hardscape (GWH) ratios, evidence-based design

INTRODUCTION

Background

Chronic stress is known to cause multiple adverse health outcomes, including cardiovascular disease, compromised immune function, and a spectrum of psychological disorders such as anxiety and depression (Hartig et al., 2014). In countering this, empirical evidence robustly demonstrates that exposure to natural environments serves as a powerful antidote, significantly reducing physiological stress markers like cortisol, blood pressure, and heart rate (Jiang et al., 2014; Suppakittpaisarn et al., 2023). While the therapeutic benefits of nature are well-established, the specific role of landscape composition, the proportional interplay among green elements (vegetation), blue space (water), and hardscapes (built elements), remains underexplored. Recent methodological advancements have begun to address this by utilizing quantitative visual metrics, such as the Sky-Leaf-Trunk (SLT) ratio, to evaluate landscape structures and predict restorative outcomes (Lin et al., 2023). Building on this momentum toward ratio-based evaluations, a more comprehensive framework encompassing blue infrastructure and built elements is necessary.

To address this gap, this study aims to investigate how different proportional compositions of greenery (G), water (W), and hardscape (H)—denoted as GWH ratios— influence visual preference and perceived stress reduction within the unique environmental and cultural context of Chiang Mai, Thailand. This research quantifies the impact of Green–Water–Hardscape (GWH) ratios, with the broader objectives of (1) designing for well-being by creating evidence-based guidelines for urban spaces that enhance mental and physical health, (2) optimizing healthcare through insights that can inform nature-based therapeutic interventions, and (3) guiding sustainable development by promoting the integration of restorative green infrastructure into urban planning for more livable, resilient cities.

Nature and Well-being

Rapid urbanization has become a defining global challenge of the modern day, with over half of the world's population now living in cities. This shift has brought many challenges, fundamentally reshaping human living patterns and public well-being. As cities densify to accommodate growing populations, the natural environment is frequently compromised, leading to a pronounced decline in both the quantity and quality of accessible green spaces (United Nations, 2018). Specific health issues are exacerbated by conditions prevalent in cities, including pollution, a lack of green space, and inadequate infrastructure for physical activity (Hartig et al., 2014). Furthermore, the urban landscape is directly linked to an escalating mental health crisis, as the public faces an increased risk of psychological stress and mental fatigue (van den Bosch & Meyer-Lindenberg, 2019).

The constant exposure to environmental stressors such as noise and air pollution, combined with the high-paced demands of urban life, can deplete cognitive resources and elevate chronic stress levels across all demographics (van den Bosch & Meyer-Lindenberg, 2019). In response to this challenge, urban green spaces emerge as a critical and low-cost solution. They are more than just aesthetic and environmental enhancement of cities; they serve as vital hubs for physical health promotion, social cohesion, and psychological restoration by providing a powerful buffer against the strains of city life (Bratman et al., 2019; Twohig-Bennett & Jones, 2018).

Empirical Evidence for Landscape Effects on Well-being

A growing body of research demonstrates that exposure to natural environments (real or virtual) can lower physiological stress markers such as blood pressure, heart rate, Skin Conductance Levels (SCLs), and cortisol levels (Depledge et al., 2011; Huang et al., 2020; Suppakittpaisarn et al., 2023). This aligns with Ulrich's Stress Reduction Theory (SRT), which proposes that natural environments evoke rapid positive

emotional responses, reducing physiological arousal (e.g., lowered heart rate, cortisol) (Ulrich et al., 1991). This approach is evident in most prior empirical studies. For example, a laboratory study states that exposure to tree-covered landscapes significantly lowered salivary cortisol and skin conductance levels (SCLs), with optimal stress reduction at 24-34% tree cover (Jiang et al., 2014). Similarly, a review study concluded that natural settings consistently reduce stress, though the mechanisms (e.g., visual aesthetics, auditory stimuli) vary (Hartig et al., 2014).

Furthermore, the restorative benefits of nature extend beyond the physiological to the cognitive, as explained by Attention Restoration Theory (ART) (Kaplan, 1995). ART suggests that natural environments engage “soft fascination,” which allows depleted cognitive resources, particularly directed attention and executive functioning, to recover. This is supported by experimental evidence; a study found that participants who walked in an arboretum performed significantly better on subsequent tasks measuring attention and working memory compared to those who walked in a dense urban setting (Berman et al., 2008). Recent studies further support these mechanisms through many approaches. For instance, a study on the attention restoration effect of sky-leaf-trunk ratios found that a balanced sky and leaf ratio improves attention (θ/β power), providing evidence for the restoration of directed attention mechanisms (Lin et al., 2023). Complementing this, results from psychological questionnaires from one experiment state that landscapes with high naturalness outperformed artificial-dominated space in restoration and that sky elements are a key factor in improving environmental coherence (Yi et al., 2025). Moreover, an online survey experiment finds that presence of trees, flowers, and water significantly enhances overall restorative potential, while elements like birds specifically increase feelings of fascination (Wang et al., 2019).

This dual mechanism is evident across methodologies; studies using virtual reality (VR) and controlled experiments have further confirmed that even brief exposure to nature, whether real or simulated, can induce measurable restorative effects (Depledge et al., 2011; Huang et al., 2020; Suppakittpaisarn et al., 2023).

Despite these findings, critical gaps remain in understanding how specific landscape compositions, particularly the interplay between different landscape components, can influence stress recovery and attention restoration. Most prior research has treated vegetation as a single element or examined the impacts of elements in isolation, such as general “greenness” or the presence of water, rather than investigating their combined and proportional effects (Gascon et al., 2015; Hartig et al., 2014; Jiang et al., 2014). A few studies have begun to explore combinations of elements but have not quantified their exact ratios (Deng et al., 2020; He et al., 2024; Wang et al., 2019). This oversight limits practical applications in urban design, where space constraints require strategic balancing of natural and built features.

Landscape Elements and Benefits

The restorative effects of a landscape are not a simple binary function of whether it is “natural” or “urban”. Research suggest that the quality and composition of urban landscape may be as important as their mere presence (Xu et al., 2025). The restorative potential of an environment is not uniform but is a function of the proportion and interaction. Understanding the unique contributions of elements is essential for creating efficient restorative urban environments.

Green Elements (Vegetation). The core component of a natural landscape, vegetation, is extensively linked to restorative experiences, with benefits influenced by type, density, and spatial arrangement. Research consistently shows that green elements outperform built environments. For example, a study comparing virtual environments found that scenes with grass and trees led to significantly greater reductions in SCLs, compared to concrete only scenes (Huang et al., 2020). The density of greenery, particularly tree cover, appears to follow a dose–response relationship. Jiang et al. (2014) established that for men, stress reduction (measured via salivary cortisol and SCL) followed an inverted U-shaped curve in response to tree cover density along residential streets. This finding is crucial for landscape design, suggesting that maximizing green cover is not always optimal. Furthermore,

the specific composition of green elements matters. Studies breaking down landscapes into constituent parts found that elements like shrubs, flowers, and trees significantly enhance aesthetic preference, perceived restorative potential, and feelings of security, comfort, and positivity in a healing landscape (Ren et al., 2024; Wang et al., 2019). The evidence suggests that prioritizing a mix of vegetation types (grass, trees, shrubs) is important to optimize both physiological stress reduction and perceived restorative experience.

Water Elements (Blue Space). The visual presence of water is a significant predictor of stress reduction. A study on campus landscapes in China, found that “water visibility was the most impactful single element for stress relief” (He et al., 2024). Similarly, in a study on patients with depression, water-based landscapes were ranked highly for stress reduction, following closely behind grasslands and forests (Shu et al., 2022). The benefits of water are not limited to the visual domain; the auditory component is also benefited. A study on the integration of visual and auditory stimuli found that the sound of flowing water was a key positive predictor of restorative potential and aesthetic preference (Deng et al., 2020). This research demonstrated that mountain forest scenes paired with natural sounds (flowing water and bird song) received the highest scores, significantly outperforming visual-only stimuli. This points to the multi-sensory nature of restoration and the critical role of water sounds in creating a “generalized restorative environment.”

Hardscapes (Built Environment). Hardscape and artificial elements (e.g., buildings, pavements, park furniture) typically play a contrasting role to nature, often acting as a negative or neutral factor in restoration that must be carefully managed. Although ideas of green spaces are frequently defined by lush greenery, hardscapes should be taken into consideration for their functionality and accessibility. Hardscapes, ranging from paved pathways that allow for easy mobility to thoughtfully positioned benches that provide respite, improve physical activity for users (Francis, 2016). However, the role of hardscapes is not universally negative; it depends on context and integration. A study found that while natural elements were most impactful, certain combinations of artificial and natural element, such as “building façade + sky area” and “plant species + paving area” were

effective for stress relief (He et al., 2024). Moreover, healing landscapes with landscape elements of seating and tree pools, and shrubs improve security, comfort and positivity (Ren et al., 2024). This highlights the importance of a balanced design where nature is used to soften and integrate necessary built infrastructure.

Auditory Element (Soundscape). The auditory component of the environment is one of the independent factors that significantly influences restorative outcomes. The integration of soundscape is essential for creating a truly immersive and effective restorative experience. Studies state that combined auditory–visual stimuli (e.g., natural landscape with natural sounds) enhance immersion and reduce mental load (Deng et al., 2020; Liu et al., 2014; Liu et al., 2019).

Efficacy of Virtual Landscape Exposure

While exposure to real natural environments is ideal, the use of virtual nature is a necessary methodological tool in research to isolate key variables and ensure consistency across participants. A strong body of evidence confirms that exposure to virtual nature scenes can effectively promote psychological restoration and stress recovery, often yielding results comparable to real-world nature exposure (Huang et al., 2020; Shu et al., 2022; Yang & Kang, 2022). Exposure of virtual landscape offers a controlled, replicable method for studying landscape effects (Depledge et al., 2011). One study suggests that 5-minute VR exposure to nature helps optimal stress recovery, outperforming shorter or longer durations (Suppakittpaisarn et al., 2023). Beyond stress, virtual nature improves mood and contributes to attention restoration (Lin et al., 2023).

Prior to the wide adoption of VR, photomontage served as a foundational tool for achieving similar experimental control in landscape perception research. This method involves the digital editing of photographs to create realistic yet manipulated images, allowing researchers to systematically isolate and test the impact of specific visual elements. For instance, prior studies utilized photomontage to precisely control variables like

the presence of water, flowers, trees, and animals, demonstrating that these elements significantly enhance aesthetic preference and restorative potential (Deng et al., 2020; Huang et al., 2020; Wang et al., 2019). Therefore, while photomontage provides unparalleled control for deconstructing visual composition, multi-sensory virtual environments must be considered to achieve a truly immersive and ecologically valid research design. Building upon this methodological foundation, the present study employs a photomontage approach to systematically investigate the following research questions:

1. How does the relative proportion of each element (green space, water, and hardscape) influence stress reduction in landscape perception?
2. Do specific landscape compositions impact cognitive functions related to attention restoration?
3. What are the GWH ratios that are most preferred and most likely to promote perceived restorative outcomes in this context?

METHODOLOGY

The study focused on Chiang Mai University students, ages 20 and older, with no prior history of depression or anxiety disorder and heart conditions. It was conducted using images of existing open spaces in Chiang Mai: More Space. This space, selected for its abundant green spaces and aesthetic views of mountain scenery, is easily accessible for residents and students and is also used for commercial purposes in some sections. The base image is shown in Figure 1.

The researchers then manipulated the images to incorporate different ratios of greenery (G), water (W), and hardscape (H). Determination of this ratio was done according to (Lin et al., 2023). The Green–Water–Hardscape (GWH) ratio will be used to describe the proportional relationship between the three elements: G (Green), referring to the green elements, i.e., trees, plants, and grassy areas, as well as seasonal flowers; W (Water), referring to areas of blue infrastructure; and H (Hardscape), referring to the functional elements, i.e., pathways, seating areas, lighting features, and shelters. Every component of the image can be classified as having a GWH ratio of 1.

Figure 1

The Original Photograph of the Study Area to be Used in Photo Manipulation



Note. The base image shows the existing open space at "More Space" in Chiang Mai, which was selected for its mountain views and accessibility. This photograph served as the foundation for all subsequent digital manipulations.

Figure 2

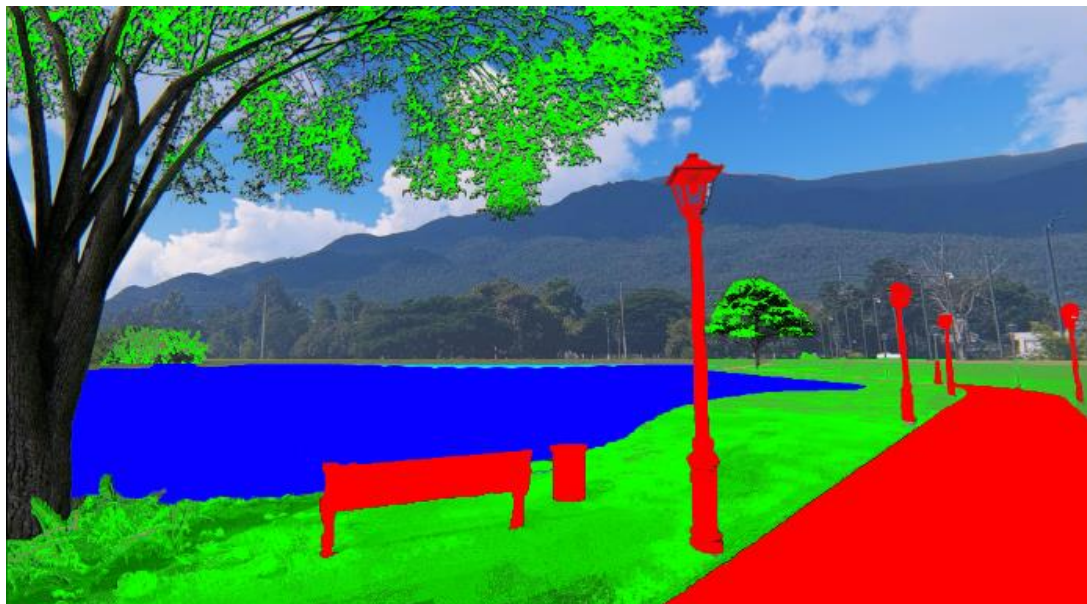
Stimulated Landscape Scenario With Balanced GWH Ratio



Note. This simulated landscape represents a balanced Green–Water–Hardscape (GWH) ratio with balanced proportions. The image was created by digitally manipulating the base photograph in Figure 1 using Lumion.

Figure 3

Using Photoshop Histogram to Calculate the GWH Ratio



Note. The Photoshop Histogram Tool was used to calculate the precise pixel area occupied by green, water, and hardscape elements, allowing for the accurate quantification of each component's ratio in the GWH composition.

The percentage of each ratio component in the landscape scenery can vary from 0 to 1. The examples of photomanipulation and GWH components (identified by Photoshop Histogram Tool) are shown in Figure 2 and Figure 3.

To ensure experimental consistency and eliminate potential confounding variables, the GWH ratio calculation was strictly limited to the manipulated foreground and mid-ground design elements. Background features, specifically the sky and the distant Doi Suthep mountain range (as depicted in Figure 1), were intentionally excluded from the proportional analysis. By holding these background elements constant across all simulated scenarios, they served as a baseline visual control. This methodological decision ensures that any observed variations in psychological or physiological responses are directly attributable to the manipulated GWH proportions, effectively isolating the impact of the targeted landscape components from broader contextual influences (Deng et al., 2020; Wang et al., 2019).

In considering the different scenarios, the three variables are expressed using a ternary diagram

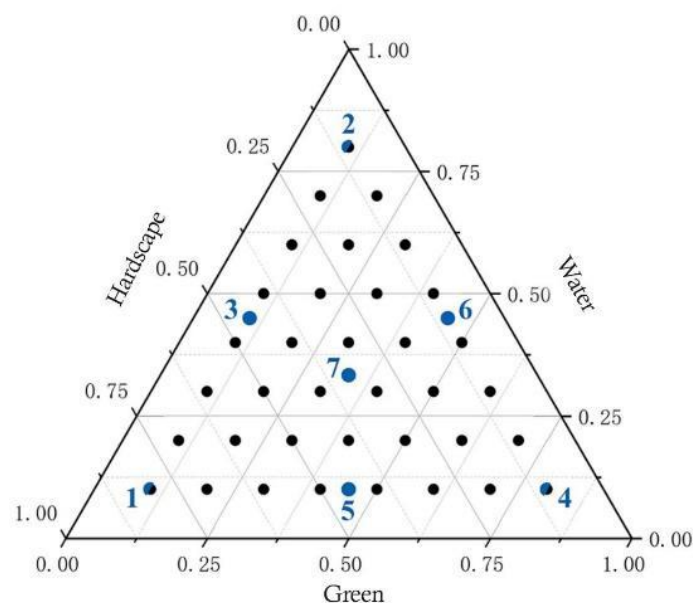
in which the values of the variables are simultaneously displayed as shown in Figure 4. The coordinates of a point in a ternary diagram can be used to express the quantitative relationship between the three components of visual perception of any landscape scenario, and the values of the GWH ratios add up to 1.

By the corresponding points in the ternary diagram, a total of 36 sets of scenarios with different GWH ratios were generated, with seven significant landscape scenarios marked with blue dots. Each image will contain all three variables, and each variable will range from a value of 0.1 (lowest) to 0.8 (highest).

The value of each variable was considered L (Low), M (Medium), or H (High), with scenarios therefore described as low-low-high (LLH: GWH ratio: 0.1/0.1/0.8), low-high-low (LHL, 0.1/0.8/0.1), low-medium-medium (LMM, 0.1/0.45/0.45), high-low-low (HLL, 0.8/0.1/0.1), medium-low-medium (MLM, 0.45/0.1/0.45), high-low-low (HLL, 0.8/0.1/0.1), medium-medium-low (MML, 0.45/0.45/0.1), and medium-medium-medium (MMM, 0.33/0.33/0.33), as shown in Table 1.

Figure 4

Exploring Seven Categories of Landscapes With GWH Ratio as Corresponding Points in a Ternary Diagram



Note. Adapted from "The Therapeutic Look Up: Stress Reduction and Attention Restoration Vary According to the Sky-Leaf-Trunk (SLT) Ratio in Canopy Landscapes," by W. Lin, C. Zeng, Z. Bao, and H. Jin, 2023, *Landscape and Urban Planning*, Article 104730, p. 234 (<https://doi.org/10.1016/j.landurbplan.2023.104730>). Copyright 2023 by Elsevier B.V.

Table 1*Seven Categories of Landscape Scenarios With Different GWH Values*

Value of Each Component			GWH Ratio	GWH Value
<i>Green</i>	<i>Water</i>	<i>Hardscape</i>		
Low	Low	High	LLH	0.10/0.10/0.80
Low	High	Low	LHL	0.10/0.80/0.10
Low	Medium	Medium	LMM	0.10/0.45/0.45
High	Low	Low	HLL	0.80/0.10/0.10
Medium	Low	Medium	MLM	0.45/0.10/0.45
Medium	Medium	Low	MML	0.45/0.45/0.10
Medium	Medium	Medium	MMM	0.33/0.33/0.33

Note. This table defines the seven primary landscape scenario categories based on their Green–Water–Hardscape (GWH) ratios. Values are categorized as Low (L: 0.1), Medium (M: 0.45 or 0.33), and High (H: 0.8).

To control the precise proportion of the three variables, Lumion and Adobe Photoshop were used as digital tools to generate the images for the experiment. Micro-dynamic effects were considered in each of the seven images. To maximize ecological validity, the landscape scenarios were presented as 5-minute dynamic audio-visual simulations rather than static images. Likewise, visual animations with swaying leaves and moving clouds were integrated with a continuous, standardized soundtrack (comprising birdsong, wind, and rustling leaves) to replicate a realistic, multisensory restorative environment. These effects were created using the smooth transition function of Adobe Photoshop. For each of the seven categories, a single image was used to ensure consistency and eliminate potential confounding variables beyond element ratios—as well as for cost and time efficiency. Images are presented in Table 2.

Participants

For a study of this nature, most psychological experiments require sample sizes of 20–30 people per group. Here, the participants reached 140, with each category randomly assigned to groups of 20 participants, to ensure detection of moderate effect sizes while remaining manageable for data collection and analysis. The physiological reactions of participants were thereby gathered for the seven categories of images.

Participants were students between 20 and 34 years of age, since this particular population experiences significant academic stress, making them a particularly relevant population for the study of stress reduction through landscape exposure. Moreover, they are easily located on campus and are generally comfortable with technology and viewing photomontages, minimizing technical difficulties. The participants were recruited throughout campus by randomly approaching students with brochures and sending invitations to students/others via a student network that is easily accessible.

Table 2

Seven Categories of Landscapes With Different GWH Ratios Using Histogram

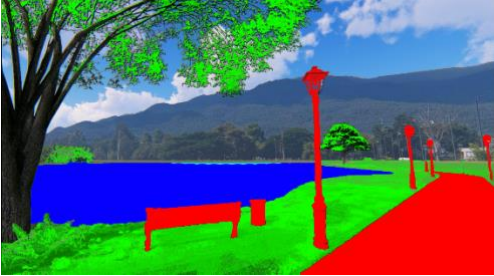
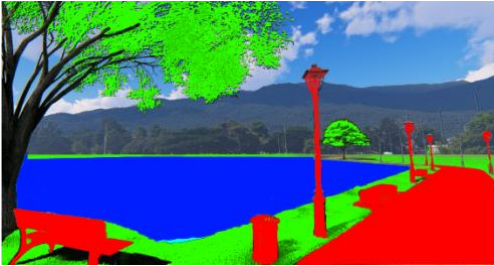
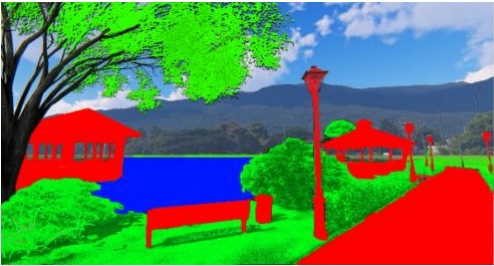
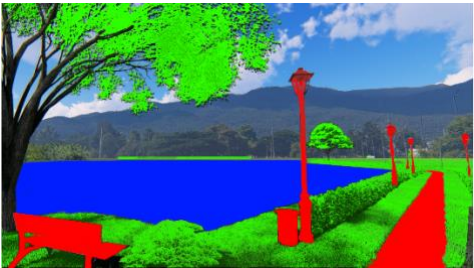
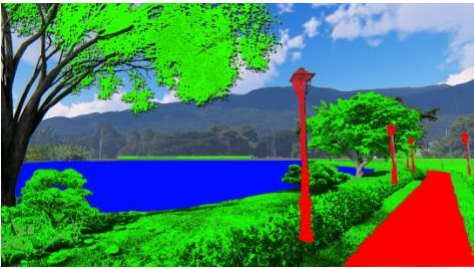
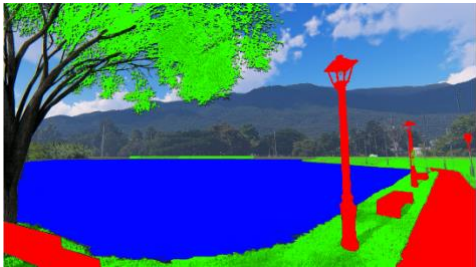
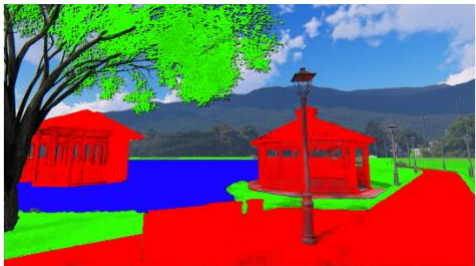
Landscape Scenarios	GWH Ratio	GWH Value		
		<i>Green</i>	<i>Water</i>	<i>Hardscape</i>
	MMM	30.0%	30.0%	30.0%
	LMM	17.0%	41.5%	41.5%
	MLM	45.0%	10.0%	45.0%
	MML	45.0%	45.0%	10.0%
	HLL	75.0%	13.0%	12.0%

Table 2 (Continued)

Landscape Scenarios	GWH Ratio	GWH Value		
		Green	Water	Hardscape
	LHL	14.0%	74.0%	12.0%
	LLH	12.0%	12.0%	76.0%

Note. This table presents the seven manipulated landscape scenarios used as visual stimuli in the experiment, alongside their corresponding GWH ratios and the calculated percentage of each component.

Procedure

The experiment measured data from physiological and psychological indicators. The former was collected through a heart rate and blood pressure monitor. The latter was collected through the self-report measurement method Short-version Revised Restoration and Preference Scale (SRRPS), which includes items corresponding to emotion, cognition, physiology, behavior and aesthetic preference.

The procedure for each subject is described in Figure 5. When a participant arrived at the site, the procedure and requirements of the experiments were explained. Next, their heart rate (HR) and blood pressure (BP) were measured for the first time (T1) before a pre-test task, the Trier Social Stress Test (TSST), was administered to induce stress levels. Heart rate and blood pressure were then recorded as a baseline for statistical analysis after the tasks were completed (T2). After the test, the participants viewed an image for 5 minutes. This specific exposure duration was selected based on prior empirical evidence demonstrating that a 5-minute virtual exposure facilitates optimal

physiological stress recovery, significantly outperforming both shorter and longer durations (Suppakittpaisarn et al., 2023). Following this exposure, their HR and BP were assessed again to collect as the dependent variables (T3). As for the final stage, all seven categories were provided to participants to rate the preferences based on the Likert scale using SRRPS. Demographic information such as age, gender, major was collected after all the tests were completed to avoid the impact on the pre-test and post-test tasks. The time taken for the whole procedure was estimated at 40 to 50 minutes.

Psychological Measurement

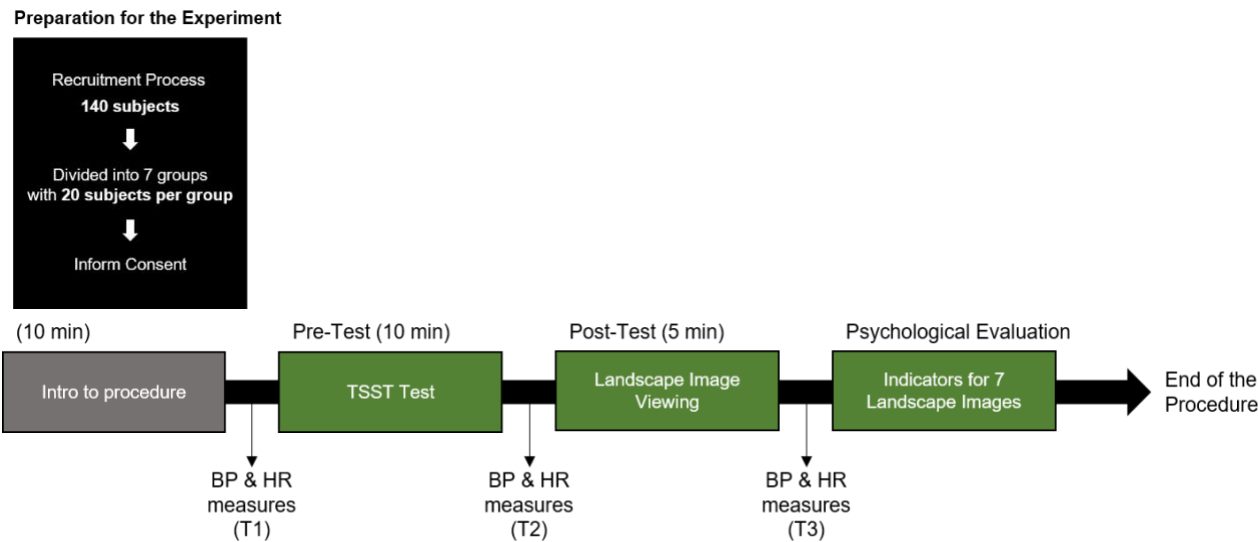
The five questions from the Short-version Revised Restoration and Preference Scale (SRRPS) were answered on a Likert-like scale (1 to 5) and can be categorized into three main dimensions. The emotional dimension was measured by the statement, "This landscape is aesthetically pleasing," assessing aesthetic pleasure, as well as, "I would feel comfortable spending time in this landscape," reflecting comfort and willingness. The cognitive dimension

was captured by, "After spending time in this landscape, I would feel more alert" and "I would feel better able to concentrate after being in this landscape," highlighting mental clarity of attention restoration and concentration. Finally, the behavioral dimension was assessed by, "Compared to other landscapes, how much would you prefer to spend time in this one?"; capturing participants' relative landscape preference. All responses were recorded using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The conceptual categorization of these five items is summarized in Table 3.

Physiological Measurement

Physiological responses were assessed through discrete measurements of systolic blood pressure (SYS), diastolic blood pressure (DIA), and heart rate (HR) using a digital sphygmomanometer. The procedure comprised three phases: The baseline measurement (T1), measurement after the stress induction (T2), and measurement after the landscape viewing (T3). Changed values ($\Delta = T2-T3$) were computed for all measurements (SYS, DIA, HR) to quantify stress recovery attributable to virtual landscape exposure.

Figure 5
Study Design



Note. The study design flowchart outlines the experimental procedure for each participant, including baseline measurement (T1), stress induction via the Trier Social Stress Test (TSST), post-stress measurement (T2), landscape exposure and measurement (T3), and final psychological and demographic data collection.

Table 3*The Categories of the Psychological Questionnaire, according to SRRPS*

Dimension	Category	Question
Emotional	Aesthetic Pleasure	"This landscape is aesthetically pleasing."
	Comfort and Willingness	"I would feel comfortable spending time in this landscape."
Cognitive	Attention Restoration	"After spending time in this landscape, I would feel more alert."
	Concentration	"I would feel better able to concentrate after being in this landscape."
Behavioral	Prefer to spend time	"Compared to other landscapes you have seen; how much would you prefer to spend time in this one?"

Note. The psychological questionnaire, based on the Short-version Revised Restoration and Preference Scale (SRRPS), is organized into emotional, cognitive, and behavioral dimensions to assess participants' perceptions of landscape scenarios.

RESULTS

The study included a total of 140 participants, with a gender distribution of 80% female ($n = 112$) and 20% male ($n = 28$). The majority of participants (91.43%) fell within the 20–24 age range, with the remaining individuals aged 25–34, as shown in Table 4. Academic backgrounds were diverse, spanning eight major fields of study. The largest subgroup comprised students from Science & Technology ($n = 40$, 28.6%), followed by Business & Management ($n = 24$, 17.1%), Social Sciences ($n = 22$, 15.7%), and Engineering & Technology ($n = 15$, 10.7%). Smaller but notable representations included Agriculture & Environment ($n = 14$, 10.0%), as well as Education & Humanities, Health & Medical Science, and Arts & Architecture, which collectively accounted for the remaining 17.9% of the sample, as shown in Figure 6.

Psychological Results

The descriptive analysis of psychological responses (measured on a 1 to 5 scale) revealed consistent and significant patterns in evaluation of the seven landscape scenarios. To ensure the internal consistency of the psychological questionnaire, a reliability analysis was

conducted. The five items of the SRRPS demonstrated high reliability, yielding a Cronbach's alpha of 0.85. The balanced landscape composition (MMM) demonstrated superior ratings across all measured dimensions, achieving the highest mean scores for aesthetic appeal ($M = 4.21$), comfort ($M = 4.11$), attention ($M = 3.16$), concentration ($M = 3.81$), and preference ($M = 3.92$). In striking contrast, the hardscape-dominant landscape (LLH) consistently ranked lowest in every category, with particularly notable deficits in concentration ($M = 2.86$) and preference ($M = 2.73$). The low-hardscape with balanced nature (MML) closely followed MMM in performance, nearly matching its scores for aesthetic quality ($M = 4.16$) and comfort ($M = 4.04$), while other landscape types showed intermediate results as shown in Table 5.

We focused the Tukey's Honestly Significant Difference (HSD) test on key comparisons to interpret the most meaningful contrasts. These included: extreme mean differences (e.g., the highest-scoring scenario (MMM) versus the lowest (LLH), and the second-highest (MML) versus the lowest (LLH)), as well as practically significant contrasts between landscapes with the highest green proportion (HLL) or highest water proportion (LHL) and the hardscape-dominant landscape (LLH). For each dimension, the following results were observed:

1. Aesthetic/Comfort/Cognition: Large differences ($*p* < 0.001$, $*d* > 0.8$) confirm hardscapes (LLH) are consistently least preferred, while balanced/natural designs (MMM, MML, HLL) perform best.

2. Attention Restoration: Non-significant results ($*p* > 0.05$) suggest complexity may not drive restorative potential.

3. Effect Size Context: Even if statistically significant, prioritize pairs with $*d* \geq 0.5$ (medium/large effects) for design decisions. All the detailed results are shown in Table 6.

Emotional Dimension. For Aesthetic preference, landscapes with a high hardscape proportion (LLH) were least preferred comparing to other landscapes with medium to large effect (Cohen’s $*d* > 0.465$). Large effect sizes (Cohen’s $*d* > 0.9$) confirmed that a balanced

proportion of landscape elements (MMM) and medium green and water with low hardscapes (MML) scenarios were strongly preferred over hardscape-dominated landscapes (LLH). Green-dominated landscape (HLL, $*d* = 0.69$) and Water-dominated landscape (LHL, $*d* = 0.74$)

also outperformed Hardscape-dominated landscape (LLH), though with medium effects.

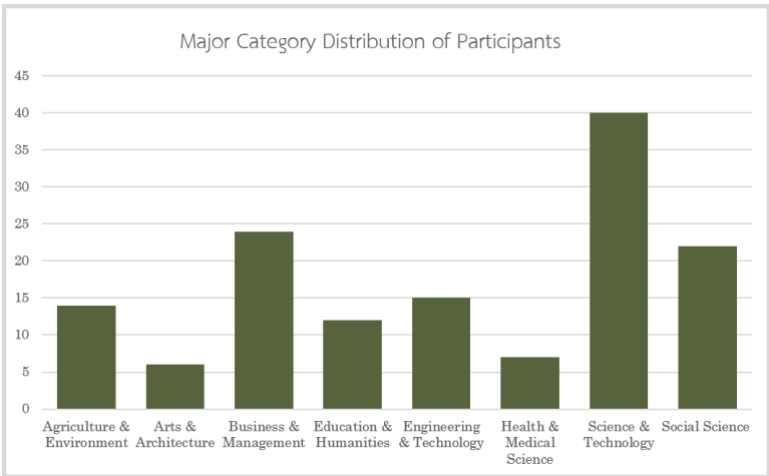
For Comfort and Willingness, balanced landscapes (MMM, $*d* = 0.75$) and high Green+Water scenes (MML, $*d* = 0.68$) had large advantages over hardscape-dominated landscapes (LLH). Water-dominated designs (LHL, $*d* = 0.56$) were more comfortable than hardscapes, while green-dominated scenes (HLL, $*d* = 0.39$) had smaller effects. For Attention Restoration, no significant differences were found, as shown in Table 7.

Table 4
Frequency of Gender and Age Groups

Variable	Category	Frequency	Percentage
Gender	Female	112	80.00%
	Male	28	20.00%
Age Group	20-24	128	91.43%
	25-29	11	7.86%
	30-34	1	0.71%

Note. Frequency distribution of participant demographics by gender and age group (N = 140).

Figure 6
Distribution of Academic Majors Among Participants



Note. Distribution of participants' academic majors. The sample represented eight major fields of study, with the largest subgroups from Science & Technology (28.6%) and Business & Management (17.1%).

Table 5*Descriptive Results of Emotional Dimensions for Seven Types of Landscape*

Scenario (N = 140)	Aesthetic (Mean (S.D.))	Comfort (Mean (S.D.))	Attention (Mean (S.D.))	Concentration (Mean (S.D.))	Preference (Mean (S.D.))
MMM	4.21 (0.69)	4.11 (0.81)	3.16 (1.24)	3.81 (1.05)	3.92 (1.04)
LMM	4.09 (0.78)	3.95 (0.88)	3.05 (1.18)	3.56 (1.09)	3.59 (1.16)
MLM	3.76 (1.07)	3.71 (1.11)	3.14 (1.24)	3.29 (1.28)	3.36 (1.31)
MML	4.16 (0.7)	4.04 (0.93)	3.15 (1.24)	3.79 (1.02)	3.75 (1.12)
HLL	3.96 (0.94)	3.76 (1.05)	2.99 (1.30)	3.39 (1.23)	3.30 (1.26)
LHL	4.00 (0.8)	3.86 (0.96)	2.91 (1.26)	3.49 (1.20)	3.09 (1.23)
LLH	3.36 (1.06)	3.37 (1.08)	2.79 (1.12)	2.86 (1.32)	2.73 (1.25)

Note. Descriptive statistics (Mean and Standard Deviation) for psychological responses to the seven landscape scenarios across five measured dimensions (N = 140). All items were scored on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree).

Table 6*One-Way ANOVA to Test the Differences Between Means of Psychological Measurements*

		Source of Variation	SS	df	MS	F	p-value	F crit
Emotional Dimension	Aesthetically Pleasing	Between Groups	72.31	6	12.05	15.73	2.68502 E-17	2.11
		Within Groups	745.51	973	0.77			
		Total	817.82	979				
	Comfortable	Between Groups	51.27	6	8.55	8.88	1.86516 E-09	2.11
		Within Groups	935.93	973	0.96			
		Total	987.20	979				
Cognitive Dimension	Attention	Between Groups	16.61	6	2.77	1.84	0.09	2.11
		Within Groups	1460.80	973	1.50			
		Total	1477.41	979				
	Concentration	Between Groups	88.47	6	14.74	10.69	1.58843 E-11	2.11
		Within Groups	1342.46	973	1.38			
		Total	1430.93	979				
Behavioral Dimension	Prefer Spending Time	Between Groups	138.48	6		16.05	1.14316 E-17	2.11
		Within Groups	1398.84	973	1.44			
		Total	1537.32	979				

Note. Results of one-way ANOVA tests comparing mean scores across the seven landscape scenarios for each psychological dimension. Bold *p*-values indicate statistical significance ($p < 0.001$).

Cognitive Dimension. No significant differences were found in "Attention" scores across scenarios ($F(6, 973) = 1.84, p = 0.088$), suggesting that attention levels were comparable regardless of the environment, as described in Table 7.

For the concentration improvement, landscapes with a high hardscape proportion (LLH) were least preferred among the landscapes with medium to large effect (Cohen's $*d^* > 0.43$). Balanced landscapes (MMM, $*d^* = 0.80$) and high Green/Water landscapes (MML, $*d^* = 0.79$) had large advantages over hardscapes. Water-dominated designs (Scenario 6, $*d^* = 0.53$) were

moderately better than hardscapes, while green-dominated scenes (Scenario 5, $*d^* = 0.44$) had smaller effects. Green and Water did not differ meaningfully ($*d^* = 0.09$).

Behavioral Dimension. Behavioral dimension showed large effects favoring balanced designs (Scenario 1, $*d^* = 1.00$) and high Green/Water scenes (Scenario 4, $*d^* = 0.85$) over hardscapes (Scenario 7). Mixed designs (Scenarios 2–3) had medium effects ($*d^* = 0.53$ – 0.71), while green- or water-only designs showed smaller advantages ($*d^* = 0.30$ – 0.48). Water and green did not differ meaningfully ($*d^* = 0.18$), as detailed in Table 7.

Table 7

Tukey HSD Test for Statistically Significant Dimensions

			Scenarios Comparison	MD	Critical HSD	Cohen's d	Significance Effect
Emotional Dimension	Aesthetically Pleasing	Extreme Difference	MMM vs LLH	0.85	0.31	0.97	Large
			MML vs LLH	0.80	0.31	0.91	Large
		Practical Importance	HLL vs LLH	0.61	0.31	0.69	Medium-Large
			LHL vs LLH	0.64	0.31	0.73	Medium-Large
	Comfortable	Extreme Difference	MMM vs LLH	0.74	0.35	0.75	Medium-Large
			MML vs LLH	0.67	0.35	0.68	Medium-Large
		Practical Importance	HLL vs LLH	0.39	0.35	0.39	Small
			LHL vs LLH	0.49	0.35	0.56	Medium
Cognitive Dimension	Concentration	Extreme Difference	MMM vs LLH	0.94	0.41	0.80	Large
			MML vs LLH	0.93	0.41	0.79	Large
		Practical Importance	HLL vs LLH	0.52	0.41	0.44	Medium
			LHL vs LLH	0.62	0.41	0.53	Medium
Behavioral Dimension	Prefer Spending Time	Extreme Difference	MMM vs LLH	1.19	0.42	0.99	Large
			MML vs LLH	1.02	0.42	0.85	Large
		Practical Importance	HLL vs LLH	0.57	0.42	0.48	Medium
			LHL vs LLH	0.36	0.42	0.30	Small

Note. Post-hoc Tukey Honestly Significant Difference (HSD) test results for statistically significant psychological dimensions, showing mean differences (MD), critical HSD values, Cohen's d effect sizes, and their practical significance.

Physiological results

Table 8 Provides a detailed breakdown of the mean changes and p-values of physiological responses across seven landscape scenarios. All landscapes elicited favorable blood pressure reduction, with landscapes ($\Delta\text{SYS}/\Delta\text{DIA} > 0$) having a low proportion of green and balanced proportions of water and hardscape (LMM) demonstrating the strongest effects (ΔSYS : +4.2 mmHg; ΔDIA : +6.0 mmHg; $*p < 0.05$). Surprisingly, landscapes with a high proportion of green (HLL) showed minimal systolic benefit (+0.8 mmHg, $*p = 0.459$), while balanced landscapes (MMM) had the weakest diastolic effect (+1.3 mmHg, $*p = 0.254$). For heart rate, mean changes were either negligible or adverse. Landscapes with a low proportion of water (MLM) exhibited a borderline-significant increase (−3.5 bpm, $p = 0.062$), suggesting these interventions

may preferentially target vascular stress pathways rather than autonomic regulation.

ANOVA revealed no significant differences between landscapes for systolic ($F = 0.55$, $*p = 0.771$) or diastolic BP ($F = 1.14$, $*p = 0.345$), as described in Table 9, suggesting comparable efficacy across interventions. Similarly, heart rate responses did not vary by landscape ($F = 0.81$, $*p = 0.562$).

Effect sizes for systolic (SYS) and heart rate (HR) measures were negligible across all scenarios ($\eta^2 < 0.04$; CIs included zero). Diastolic (DIA) responses showed a small but statistically detectable effect ($\eta^2 = 0.049$, 95% CI [0.008, 0.090]), though its clinical significance remains uncertain given the minimal variance explained. Negative epsilon (ϵ^2) and omega-squared values (ω^2_f , ω^2_r) for SYS and HR indicate that observed differences were smaller than random variability expected under the null hypothesis, as detailed in Table 10.

Table 8
Mean Change and P-Value From T-Test for Physiological Changes For 7 Landscape Scenarios (T2-T3)

No.	GWH Ratio	Landscape Scenarios	Measurement	Mean Change	p-value
1	MMM		ΔSYS	1.55	0.200
			ΔDIA	1.30	0.250
			ΔHR	-0.40	0.370
2	LMM		ΔSYS	4.20	0.030
			ΔDIA	6.00	0.020
			ΔHR	0.30	0.420
3	MLM		ΔSYS	2.10	0.060
			ΔDIA	2.30	0.120
			ΔHR	-3.25	0.080
4	MML		ΔSYS	1.80	0.160
			ΔDIA	1.50	0.110
			ΔHR	-0.45	0.310

Table 8 (Continued)

No.	GWH Ratio	Landscape Scenarios	Measurement	Mean Change	p-value
5	HLL		Δ SYS	1.80	0.460
			Δ DIA	1.50	0.020
			Δ HR	-0.45	0.230
6	LHL		Δ SYS	0.15	0.030
			Δ DIA	1.80	0.050
			Δ HR	-0.95	0.110
7	LLH		Δ SYS	3.60	0.010
			Δ DIA	1.80	0.003
			Δ HR	-1.70	0.500

Note. Mean changes (Δ = T2-T3) and p-values from paired t-tests for physiological measures across the seven landscape scenarios. Bold p-values indicate statistically significant changes ($p < 0.05$).

Table 9

One-Way ANOVA Results for Physiological Changes

		Sum of Squares	df	Mean Square	F	p-value
Δ SYS	Between Groups	195.67	6	32.61	0.55	0.77
	Within Groups	7916.75	133	59.52		
	Total	8112.42	139			
Δ DIA	Between Groups	335.29	6	55.88	1.14	0.34
	Within Groups	6540.85	133	49.18		
	Total	6876.14	139			
Δ HR	Between Groups	201.79	6	33.63	0.81	0.56
	Within Groups	5508.10	133	41.41		
	Total	5709.89	139			

Note. Results of one-way ANOVA tests comparing physiological changes (Δ SYS, Δ DIA, Δ HR) across the seven landscape scenarios.

Table 10
Effect Size Estimates for Physiological ANOVAs

		Point Estimate	95% Confidence Interval	
			Lower	Upper
ΔSYS	Eta-squared (η^2)	0.024	-0.016	0.064
	Epsilon-squared (ϵ^2)	-0.020	-0.060	0.019
	Omega-squared Fixed-effect (ω^2_f)	-0.020	-0.059	0.019
	Omega-squared Random-effect (ω^2_r)	-0.003	-0.017	0.014
ΔDIA	Eta-squared (η^2)	0.049	0.008	0.090
	Epsilon-squared (ϵ^2)	0.006	-0.035	0.047
	Omega-squared Fixed-effect (ω^2_f)	0.006	-0.034	0.046
	Omega-squared Random-effect (ω^2_r)	0.001	-0.015	0.017
ΔHR	Eta-squared (η^2)	0.035	-0.005	0.076
	Epsilon-squared (ϵ^2)	-0.008	-0.049	0.032
	Omega-squared Fixed-effect (ω^2_f)	-0.008	-0.047	0.030
	Omega-squared Random-effect (ω^2_r)	-0.001	-0.017	0.014

Note. Effect size estimates for the one-way ANOVAs on physiological changes. Values in brackets represent the 95% confidence interval.

DISCUSSION

This study demonstrates that balanced and softscape-dominated landscapes (MMM, MML) elicit the strongest psychological benefits across emotional, cognitive, and behavioral dimensions, aligning with the core principles of existing theories. These findings support the GWH ratio as a practical, quantitative design tool for predicting psychological preferences, effectively bridging environmental psychology with spatial composition. This aligns with the broader move toward identifying quantifiable design elements that preserve local identity and foster harmonious environments in historic or culturally significant context (Akay, 2025). The positive effect of these mixed-element landscape reinforces the notion that complexity and coherence in natural scenery are key drivers of restorative perception (Kaplan, 1995). This finding is consistent with (He et al., 2024), who emphasized specific combinations of elements as optimal for stress relief. Similarly, the results align with study by Jiang (Jiang et al., 2014), finding an inverted-U curve for stress reduction in men peaking at 24-34% tree cover, while our study proves for purely psychological

outcomes stating a balance landscape is more effective than a single element at high density. Meanwhile, green (HLL) and water-dominated (LHL) landscapes showed comparable effects, both outperforming hardscapes (LLH) with small-to-medium effect sizes. Critically, landscapes dominant by natural elements (green or water) were similarly effective, and both provide a significant advantage over hardscapes, as supported by (Huang et al., 2020). Despite eliciting the highest psychological ratings, the balanced landscape (MMM) did not produce significantly different physiological recovery compared to other scenarios. This complexity is further supported by Deng et al. (2020), who emphasized that combinations of elements are more impactful than single elements alone. Landscapes with low proportions of green (LMM, LHL, LLH) elicited significant changes in diastolic blood pressure and systolic blood pressure, while Green-dominant landscapes (HLL) elicited significant changes in diastolic blood pressure. No significant changes of heart rate were found for all landscape images. The lack of significant heart rate change

across all scenarios is consistent with findings from a study on depressive patients of significant psychological improvements from VR exposure without corresponding significant changes in physiological measure (Shu et al., 2022). The findings provide empirical support for the idea that landscape composition plays a meaningful role in shaping perceived restorative experiences. A key methodological contribution of this study is the evaluation of the GWH ratio under dynamic, multisensory conditions. Despite utilizing immersive audio-visual simulations, manipulating visual GWH proportions alone yielded non-significant acute physiological differences. This suggests that universally restorative auditory stimuli (e.g., birdsong, wind) may elicit a generalized physiological recovery response that overrides the nuanced effects of isolated visual changes. Such results are consistent with the understanding that restorative urban identity is often tied to multisensory cues—including traditional architectural elements and environmental sounds—which collectively shape the user's experience of a space (Laohaviraphap & Mahaek, 2023). Thus, while the GWH ratio effectively predicts psychological preferences, short-term physiological recovery in multisensory environments may be predominantly driven by auditory integration. While physiological measures may not immediately reflect these advantages, the strong behavioral and emotional preferences underscore the need for evidence-based design.

A key finding is the significant mismatch between psychological preference and physiological recovery. Participants strongly preferred balanced (MMM) and nature-rich (MML) landscapes. However, these preferred landscapes did not produce the strongest physiological recovery. Notably, the most-preferred landscape (MMM) showed no significant blood pressure change, while less-preferred landscapes (LMM, LLH) elicited significant reductions in blood pressure. This discrepancy suggests a difference between active cognitive engagement and passive physiological restoration. Aesthetically pleasing scenes (MMM) may stimulate active cognitive processing, temporarily sustaining physiological arousal. Conversely, simpler landscapes (LMM, LLH) demand less cognitive load, potentially facilitating more efficient passive physiological

recovery. Consequently, conscious landscape preference may not serve as a direct indicator of acute physiological stress reduction.

While this study provides valuable insights into landscape perception, certain limitations should be acknowledged. First, the simulated landscape scenarios, though carefully designed, may not fully replicate the multisensory richness of real-world environments, potentially underestimating the restorative effects of natural elements like biodiversity, scent or tactile interaction. Second, the compositional analysis focused solely on the ratio of greenery, water, and hardscape without accounting for the background of the scenario. Furthermore, the significance of these findings is underscored by the fact that individuals often make decisions based on perceived spatial characteristics rather than actual physical measurements, a distinction that is crucial for understanding how people interact with urban environments (Janpathompong et al., 2022). Additionally, the simulated water surface lacked clear spatial boundaries. Uninterrupted water views may unintentionally amplify perceptual salience, suggesting future studies should utilize spatially bounded water features to better isolate the effects of compositional ratios. Furthermore, the relevance of the findings may be influenced by the demographic profile of the sample; the participants consisted primarily of younger adults and featured a majority of women. Factors such as surrounding urban density, seasonal changes, or cultural associations could also significantly influence perceptions. Future research should incorporate more immersive simulations (e.g., VR with auditory/olfactory cues) and contextual variables to better approximate real-world interactions. Ultimately, these findings provide empirical support for the idea that landscape composition plays a meaningful role in shaping perceived restorative experiences. Future longitudinal research is required to assess whether these benefits translate into sustained psychological changes.

These findings underscore the importance of prioritizing natural elements in design, reducing hardscape dominance, and tailoring landscapes to user preferences. For practitioners, this means adopting evidence-based strategies such as integrating balanced greenery-water ratios, offering varied restorative features, and using psychological metrics to evaluate success.

Future research should explore long-term physiological impacts and cultural differences in landscape perception to refine these recommendations further. By prioritizing user psychology and leveraging incremental improvements, designers can create spaces that promote health, productivity, and sustained engagement. Future research should explore long-term physiological impacts and cultural variability in landscape preferences.

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