

Exploring the impacts of natural elements on relieving psychological stress in restorative virtual environments

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Abstract: With rising stress levels in modern society, restorative virtual environments (RVEs) offer promising solutions for promoting emotional well-being through immersive, nature-inspired design. However, limited research has examined which specific natural elements within RVEs most effectively alleviate psychological stress. This study involves a controlled experiment conducted within Rec Room, a virtual reality platform, to examine how both fixed green environments and natural, moving elements affect users' emotional states and physiological responses. Four indoor VR conditions were developed, manipulating the presence of plants and dynamic elements such as light shifts and wind-driven motion. Although biometric indicators showed limited differences, qualitative data revealed a clear preference for environments that mimicked natural growth patterns and incorporated familiar, calming features. Participants associated these spaces with past positive experiences, indicating that perceived realism and emotional resonance play important roles in stress recovery. Based on these findings, we propose three design principles for restorative VR environments: preserve natural forms, favor organic interactions, and anchor design in users' lived memories.

Keywords: *Biophilic design, Natural movement, Plant realism, immersion, Psychological stress, Restorative virtual environment.*

1. Introduction

In contemporary life, people are spending more time indoors than ever before—a shift that may not adequately support their psychological and emotional health. A growing amount of research highlights the positive influence of natural elements within indoor spaces on stress reduction and emotional well-being. Understanding how such elements shape emotional responses is crucial for designing indoor environments that foster relaxation, particularly in offices, residential settings, and healthcare contexts [1]. This study investigates how incorporating natural elements can help mitigate psychological stress in enclosed spaces. For example, features that reflect nature, like flowing forms or raw, natural materials, can elicit a soothing connection to the natural world [2]. By examining the impact of these sensory components, the research explores how they interact to influence both physical and psychological stress responses. The outcomes aim to inform restorative interior design strategies, especially for environments where reducing anxiety is essential to improving well-being and functional performance. By measuring the impacts of these elements, this research contributes to a better understanding of how biophilic design can create healthier, more supportive indoor experiences.

2. Related Work

2.1. Psychological Stress

The pace of life is accelerating with the advancement of modern society, and psychological stress has become increasingly prevalent due to demanding work and study schedules, fierce social competition, and growing pressure on both physical and mental well-being [3, 4]. When individuals are

exposed to—or even merely perceive themselves to be exposed to—a threat, it often leads to uncertainty and worry, particularly in those with negative affectivity [5]. Anxiety, one of the most powerful human emotions, is a major contributor to psychological stress and significantly influences behaviour, physiology, and mental states [5]. Stressful circumstances are widely believed to affect the pathophysiology of physical illness by triggering negative emotional states, which in turn influence biological processes or behavioural patterns linked to disease risk [6]. Psychological stress represents a dynamic interaction between an individual and their environment, perceived as exceeding personal resources and threatening well-being [7]. Chronic stress, in particular, is considered the most detrimental, as it may lead to lasting emotional, physiological, and behavioural changes that increase vulnerability and influence the progression of illness [6].

2.2. Restorative Virtual Environment

A Virtual Environment (VE) refers to an interactive computer simulation that immerses the user in a different, yet plausible, digital world [8]. Users engage with this environment using devices such as keyboards, mice, head-mounted displays, or data gloves. In real life, humans rely heavily on spatial reasoning to navigate spaces and interact with others effortlessly. However, virtual environments often lack many real-world sensory cues, such as shadows, ambient sounds, and tactile details, resulting in a somewhat limited, “tunnel vision” experience [9]. Despite these limitations, VEs remain a powerful and intuitive way for users to interact with digital content. Originally used in training contexts, Virtual Reality (VR) has since expanded into areas like rehabilitation centres and relaxation spaces, offering accessible, flexible, and innovative opportunities for learning, therapy, and medical applications beyond conventional boundaries [10].

Merging the ideas of VR, nature, and psychological restoration, a restorative virtual environment (RVE) can be defined as a virtual setting that replicates the calming effects of natural environments [11]. Our feelings and behaviours are closely influenced by our surroundings; for example, a walk through a tranquil forest evokes a different experience compared to navigating a noisy urban street. Identifying which environmental factors shape perception is vital for effective spatial design [12]. Yet, studying the impact of specific features in natural settings can be difficult in uncontrolled real-world contexts. Advanced tools like VR enable researchers to simulate and manipulate these features, offering deeper insight into how different elements influence environmental experience. VR has demonstrated value in reproducing the therapeutic benefits of real-world nature and virtual equivalents [13]. Studies show that realistic VR environments can help users, especially patients, shift attention away from distress, foster positive emotional responses, and reduce anxiety [14]. However, the specific contribution of natural elements in these virtual spaces remains underexplored and warrants further investigation.

2.3. Nature and Psychological Stress

Nature has the ability to enhance health and wellbeing [15]. People’s minds are at ease when seeing the motion of nature, such as leaves blowing in the breeze or water flowing. This is due to the fact that taking in the beauty of nature is typically quite carefree, calming, and fascinating and doesn’t take any effort or direct focus [2]. Yin tested participants’ stress reactions in four virtual indoor environments and found that the indoor green environment was most effective for physiological stress recovery, with participants in biophilic settings showing lower physiological stress and anxiety levels compared to those in non-biophilic environments [16]. It has also been demonstrated that realistic and artistic representations of nature have healing properties. Even with the low degree of perception of nature, people may still be able to gain from it and experience its rather strong restorative effects [17]. In addition to encouraging positive emotions and comfort, plants can lower stress, elevate mood, and foster creative thinking in humans [18]. Through the intermediary of physical health, people’s mental health is negatively impacted by a lack of greenery. There is mounting data linking greater well-being and lower levels of stress, anxiety, and depression to the quantity and quality of green space in communities.

It can improve mental health whether it is active or passive [19]. In interior design, the use of natural elements provides residents with the opportunity to connect with nature, satisfying the innate human affinity for nature and allowing people to achieve physical and mental restoration even in indoor spaces [20].

2.4. Experiment

2.4.1. Hypotheses

Biophilic design, which integrates elements of nature into built spaces, has gained attention for its potential to improve psychological well-being. While previous studies demonstrate that exposure to nature reduces stress, the specific mechanisms—such as natural movement, organic forms, or plant morphology—remain unclear. This gap in knowledge calls for a more detailed investigation of which specific nature-related elements have the greatest effect on reducing psychological stress. Understanding these elements will provide insights into how to effectively design indoor environments to alleviate stress. One study used an abstract painting environment as a control to create a virtual forest, which in turn improved participants' mood, physiological responses, and cognitive performance [13]. Another study examined how fire escape scenarios turned out when negative emotions increased during fires, providing insights into how people behave and feel in emergencies [21]. In addition, VR has been shown to lessen anxiety and depression, particularly in those who have mild to moderate mood issues [22]. Based on these studies, it can be demonstrated that conducting psychology-related experimental research applying VR may produce results that are more effective and convenient. This experiment aims to create different indoor Spaces with VR and study different nature-related elements, such as natural movement (e.g., rippling water or moving plant leaves) and many forms of green plants, impact on stress levels in indoor spaces. These elements may mimic certain characteristics of outdoor natural environments, potentially promoting psychological well-being. The study will compare physiological stress indicators (such as heart rate, and blood pressure) and self-reported stress levels before and after exposure to these elements in different conditions in a restorative virtual environment. By isolating the specific components of the biophile design, two hypotheses are proposed in this experiment:

H₁: Green plants in nature have an impact on people's emotions and psychological stress in virtual reality.

H₂: Natural movements (such as the sound of flowing water or leaves swaying in the wind) in virtual reality affect people's emotions and psychological stress.

2.4.2. Rec Room Project

In order to explore the impact of nature-related elements (such as dynamic natural movements and static greenery) on emotions and psychological stress in virtual reality, 4 experimental environments were developed using the Rec Room¹ platform.. Rec Room is a large-scale multiplayer online game that supports virtual reality, allowing players to achieve full 3D interaction through the motion capture system of VR headsets and handheld controllers. Players can freely move within physical space or teleport through the controllers to explore the virtual world. Its user-generated content (UGC) feature allows the use of the in-game "Maker Pen²" (a 3D modelling tool similar to a hot glue gun) to create custom geometries, and develop complex interaction logic through the visual programming language Circuits or the Unity engine, providing a technical foundation for building highly controllable experimental scenarios.

When building the experimental room, I first used the Maker Pen to draw a standardised cabin structure, which includes two functional areas: one is a reading area with tall bookshelves, a lazy sofa, and a hanging chair, and the other is a viewing area with large surrounding windows, a sunken sofa, and a central fireplace. Condition 1 serves as the basic control, retaining only the fundamental structure and

¹ Rec Room, a virtual reality multiplayer online game with an integrated game creation system, see more at recroom.com.

² Maker pen, a tool within Rec Room used to build and customise 3D objects and environments.

disabling all dynamic interactions. Condition 2 densely arranges 3D plant models such as vines and potted plants created with the Maker Pen on bookshelves, windowsills, and scattered surfaces, and locks the plant positions using Circuits V2³ to ensure no dynamic effects; Condition 3 achieves a day-night cycle (1-minute cycle), wind effects (driving wind chimes and hanging plants to sway), and water flow texture animations (carpet ripples, wall flow effects) through programming, while also adjusting the flicker of the fireplace; Condition 4 combines all the elements of Condition 2 and 3. Additionally, I disabled players' interaction with non-experimental objects (such as weapons and balls) through Circuits, retaining only basic movement and scene observation functions to reduce interference variables.

By comparing the physiological indicators (heart rate, blood pressure) and subjective evaluations of participants in four conditions (basic scene, pure greenery, pure dynamic, integrated environment), I aim to systematically analyze the visual recovery effects of static greenery, the immersion-enhancing effects of dynamic natural elements, and the synergistic effects of both on emotional regulation in VR spaces, providing empirical evidence for the therapeutic design of virtual environments.

To create immersive indoor environments, this study employed the Meta Quest 3⁴ VR headset in the Rec Room platform. Psychological stress was measured using a digital sphygmomanometer to record participants' heart rate and blood pressure after each VR condition.

2.5. Independent Variables

The independent variable in this study is the presence and type of biophilic elements within the virtual environment. Specifically, two independent variables were manipulated:

Static Natural Elements – including indoor plants, natural materials, and organic shapes.

Dynamic Natural Movement – including wind-driven foliage, animated light cycles, and flowing water textures.

Based on these 2 variables, four experimental conditions were designed, ranging from environments without any biophilic elements to immersive spaces integrating both static and dynamic features. These conditions are described in detail in the following section and illustrated in Figure 1.

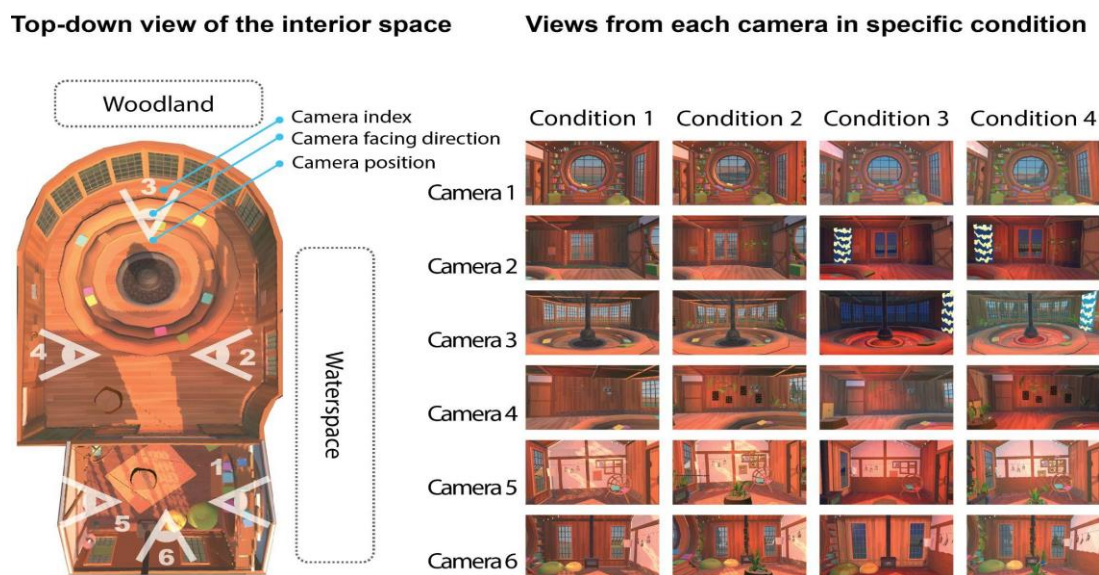


Figure 1. Top-down view of the interior space (left); Views from each camera in specific condition (right).

³ Circuits V2 is Rec Room's visual scripting system that allows creators to define object behaviours and interactions.

⁴ Meta Quest 3 is a standalone VR headset developed by Meta (formerly Oculus), supporting full spatial tracking.

Condition 1: Condition 1 served as the baseline control environment, retaining only the fundamental cabin structure with static architectural geometry. Strictly preserved the two core functional zones: a reading area with empty bookshelves, a fixed-position sofa, and a stationary hanging chair, alongside a viewing area featuring non-interactive panoramic windows, a static sunken sofa, and a deactivated central fireplace. See Figure 1a.

Condition 2: Condition 2 introduced static botanical enhancements by densely populated surfaces with Maker Pen-generated 3D plant models, including hanging vines (1.2m average length), potted ferns (0.6-1.2m height), window box planters, and epiphyte clusters. These vegetation elements were strategically distributed across bookshelves (55% density), windowsills (30%), and horizontal surfaces (15%).

Condition 3: Condition 3 focused on dynamic environmental programming while maintaining minimal decor. A compressed 60-second day-night cycle (simulating 0500-1900 daylight) synchronised wind effects (2-5 m/s simulation) animated wind chimes (15° maximum swing) and virtual foliage (40mm displacement), while fluid dynamics programming generated carpet ripple animations (3cm amplitude) and wall-mounted water flow textures. The central fireplace exhibited programmed flame height variations.

Condition 4: Condition 4 synthesised Conditions 2-3 into a multi-layered immersive environment, combining the static botanical density with dynamic systems.

2.6. Dependent Variables

In order to determine users' real-time emotional feedback on different conditions, a series of dependent variables were developed, including physiological indicators, questionnaires, and interview feedback. The dependent variables include participants' Emotional State, Cognitive Reactions, and Physical Reactions in the virtual reality environment.

i) Emotional State: Participants' emotional experiences in different conditions are assessed through a questionnaire, including the intensity of positive emotions (such as relaxation, pleasure, calmness) and negative emotions (such as anxiety, irritability, boredom). The questionnaire may use a Likert scale, asking participants to rate their emotional experiences (e.g., 0 = not relaxed at all, 4 = very relaxed).

ii) Cognitive Reactions: Measure participants' attention allocation, immersion, and environmental perception in different conditions. For example, ask participants whether they noticed specific natural elements (such as plants, flowing water, wind chimes), and their overall evaluation of the environment (such as "This condition makes me feel comfortable" or "This condition distracts me").

iii) Physical Reactions: Objectively assess participants' stress levels and relaxation through physiological indicators (such as heart rate and blood pressure). For example, heart rate variability (HRV) can be used to measure the balance state of the autonomic nervous system, while blood pressure changes can reflect emotional fluctuations.

These dimensions are comprehensively measured through questionnaires and physiological indicators. This study employs the Perceived Stress Scale (PSS⁵) and a customised stress perception scale (focusing on immediate responses to the VR environment) for comprehensive stress assessment. The questionnaire items include: (1) Emotional dimension: i) calm and at ease, ii) anxious or uneasy, iii) soothing and relaxing (2) Cognitive dimension: i) able to concentrate and think clearly, ii) feeling distracted, iii) able to enhance mental clarity

These measures were grouped into a post-session questionnaire (PSQ), as shown in Table 1, to be filled out by participants after experiencing each situation. Heart rate and blood pressure measurements were taken using a sphygmomanometer after each VR experience, and participants' subjective thoughts were collected through interviews at the end of the experiment.

⁵ The Perceived Stress Scale (PSS) is a widely used psychological instrument for measuring the perception of stress.

2.7. Experiment Procedure & Participants

Participants were recruited from the residents of the author's place of residence, totalling 20 participants (11 females, 9 males, aged 18-50, with 25% having prior VR experience, of which 15% were frequent users, and the rest had never tried VR before).

Participants were asked to avoid caffeine, alcohol, and vigorous activities for at least 24 hours before the experiment to control the external impact on stress. After reading the information sheet and signing the consent form, an experimenter will demonstrate how to use the controller to navigate and observe scenes in the virtual space. Participants will use VR headsets (Meta Quest 3) to experience all four VR environments in the rec room in a balanced random order. Each VR session lasts 10 minutes, with a 5-minute break between each session to prevent carryover effects. After each situation occurs, immediately measure: physiological indicators (heart rate, blood pressure). Self-reported stress levels use the same stress scale. Qualitative feedback on comfort, realism, and emotional impressions of the VR environment is collected in questionnaire form. Use valid scales to measure participants' heart rate, blood pressure, and self-reported stress levels. And conduct a brief interview at the end of the experiment: briefly introduce the purpose of the different conditions to the participants and discuss any discomfort they experienced. Provide participants with the opportunity to ask questions or give feedback. The interview content revolves around: Which of these four conditions do you like the most? Make a ranking. What elements attract you the most in these four conditions, what are the plant elements, what are the dynamic elements, which area of the condition do you spend the most time in, and what do you imagine doing in your favourite condition?

3. Results

3.1. Biometric Results

From the changes in participants' blood pressure and heart rate, although biometric results showed no significant differences across conditions, qualitative feedback revealed clear participant preferences, which will be detailed in the following sections.

3.2. Interview Results

Preferences - In terms of participants' subjective preferences, the interview data showed that 13 participants liked Condition 4 the most, accounting for 65% of all participants, and the remaining 3 liked Condition 3, 3 liked Condition 2, and 1 liked Condition 1. Demonstrated a clear preference for plant-based and dynamic elements in the ideal relaxing VR environment. In terms of dynamic elements, 10 participants like the change of light and shadow, 6 participants like the flow of water (such as raindrops, waterfalls), 4 participants like the fluttering of plants, and 1 participant likes the fluttering wind chimes. In addition, some participants expressed negative emotions towards some elements, with one finding the shaking of wind chimes disturbing, one expressing discomfort with mechanical movements, and two not liking moving walls. In terms of plant elements, 7 participants like hanging green plants, 5 participants like outdoor forests, 4 participants like aquatic plants, 3 participants like climbing vines, 0 participant like potted plants; In terms of regional preference, 10 participants prefer to stay in front of a window and 8 participants prefer to stay near a fire.

Scene associations - 14 participants mentioned that these conditions reminded them of a relaxing environment, including 6 participants whose associations were related to outdoor sports. 3 participants think of outdoor sports, 2 participants think of outdoor travel, 1 participant thinks of making outdoor documentaries, 5 participants think of forests, 3 participants think of happy memories of childhood, 2 participants think of friends gathering. In terms of functional associations, 5 participants wanted to meditate, 5 participants wanted to lie down, 4 participants wanted to do sports, 3 participants mentioned drinking tea, 2 participants listened to music, and 2 participants read books. One mentioned playing with their mobile phone, and one went fishing.

Emotional feedback - 5 participants felt calm, 4 responded enthusiastically, and 2 felt distracted and nervous.

Demand - Participants also put forward some additional needs, which were mentioned 14 times, about the need for immersion. Among them, 5 participants want to hear the sound of nature, 3 participants want music in space, 3 participants pursue the sense of reality, 1 participant thinks that the shape of plants is not natural, 1 participant hopes that the change of day and night is natural, and 1 participant mentions the colour authenticity. 2 participants want to have a breath of life. There are also six mentions of interactive needs, and 4 participants pursue functionality. 2 participants want to adjust the intensity of the fire, 1 participant wants the ability to switch scenery, 1 participant wants to simulate the change of the seasons and finally, three want fun, hope to increase recreational activities.

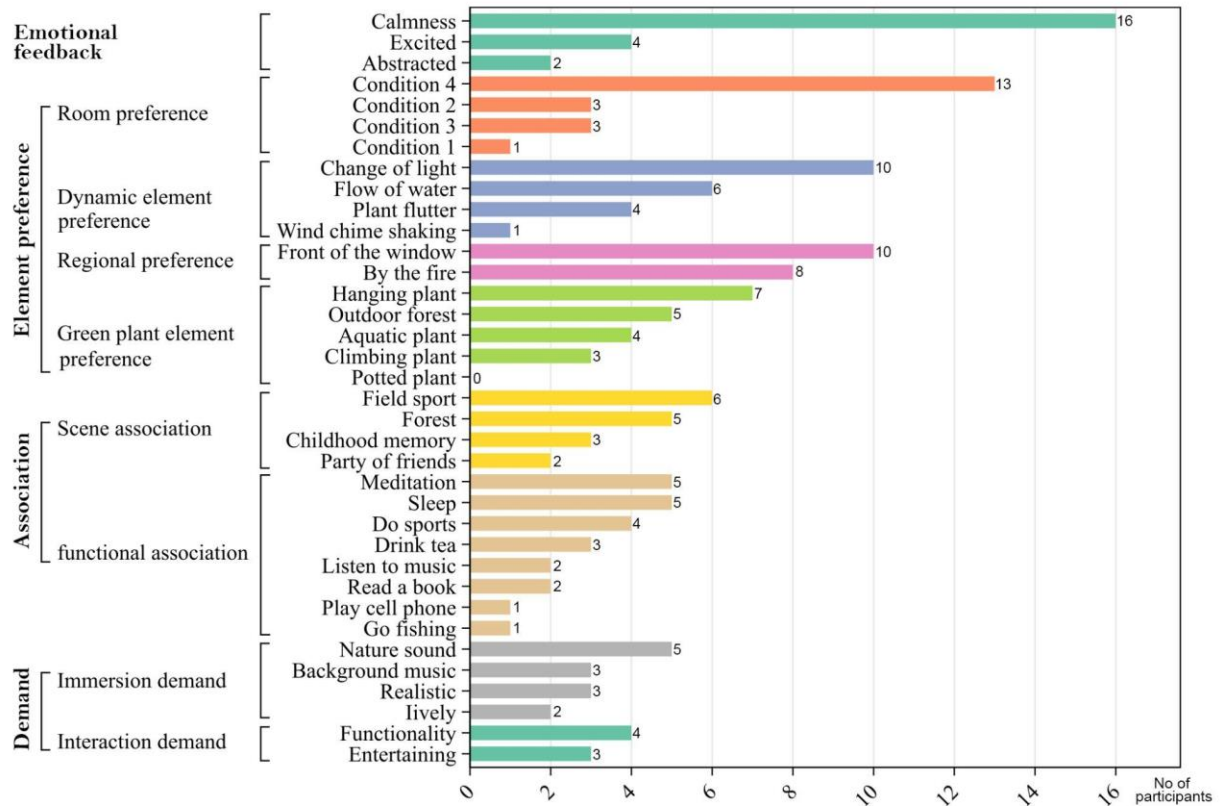


Figure 2.
Ingredients of all the coded segments of the interview, number of participants are shown along the bars.

3.3. Questionnaire Results

Participants' three-dimensional feedback on the four conditions: I calculated the mean and variance, as well as the k-value and p-value, and found no significant differences.

Table 1.
Results of the questionnaire.

Questionnaire item	Measure	C1 M(SD)	C2 M(SD)	C3 M(SD)	C4 M (SD)
1-I feel calm and at ease in this environment.	Emotional Dimension	2.8 (0.40)	3.1(0.62)	2.75(0.82)	3.05(0.92)
2-This environment makes me feel anxious or uneasy.	Emotional Dimension	1.1(0.99)	0.95(0.66)	1.25(0.86)	0.95(1.02)
3-I find this environment soothing and relaxing.	Emotional Dimension	2.5(0.74)	3.05(0.86)	2.6(0.86)	2.95(0.92)
4-I can concentrate and think clearly in this environment.	Cognitive Dimension	2.85(0.47)	2.75(0.76)	2.65(0.79)	2.8(0.81)
5-I find this environment mentally distracting.	Cognitive Dimension	1.45(1.16)	1.2(0.76)	1.35(0.96)	1.3(0.95)
6-This environment enhances my mental clarity.	Cognitive Dimension	2.25(0.59)	2.45(1.07)	2.55(1.07)	2.7(0.95)
7-I feel physically relaxed in this environment.	Physical Dimension	2.45(0.80)	3.05(0.86)	2.5(1.20)	2.8(0.92)
8-I feel any physical tension or discomfort in this environment.	Physical Dimension	0.95(1.32)	1(1.00)	1.3(1.14)	1.15(0.90)
9-This environment makes me feel energised and refreshed.	Physical Dimension	2.4(0.58)	2.45(0.97)	2.35(0.65)	2.45(0.86)

Note: Score each question(0 = Strongly Disagree, 4 = Strongly Agree).

4. Discussion

4.1. Effect of Greenery on Psychological Stress

Natural Growth Forms Enhance Psychological Relief - Respondents' fantasies about scenes involving greenery are mostly related to forests. They feel more connected to larger plants with natural survival characteristics. 7 participants said they particularly liked the climbing plants hidden in high pots on tall bookshelves. Participant 5 (hereafter referred to as P5) mentioned that walking under these climbing plants felt like strolling through a rainforest, bringing them closer to nature. Additionally, 4 participants mentioned aquatic plants in outdoor ponds that interact with swimming fish. P 20 said, "The lotus flowers outside the window, with their petals gently closing in the wind... it feels like watching a slow-motion documentary." The small potted plants placed on the windowsill are completely unmentioned in the presence of larger plants that provide a more immersive jungle experience. Even in rooms with greenery, such as Condition 2 and Condition 4, almost all the platforms in the space are filled with small potted plants. This is more in line with our living environment, as we are more accustomed to caring for small potted plants. The circular windowsill, where most participants tend to linger, is also surrounded by small potted plants. But participants' attention is on the outside of the window, not on the windowsill. Therefore, respecting the original growth form of plants, hiding pots to reduce artificial decoration traces, and arranging greenery indoors as if they were growing naturally can better attract participants' attention. This makes it easier to alleviate psychological stress and create an immersive forest-like environment.

Enhancing Relaxation Through Realistic Plant Details - In the vegetation-rich relaxation scenario (Condition 2, Condition 4), participants' preferences focused on enhancing immersion. For example, the questions that could be improved by participants focused on the sense of reality. P20 suggested that there could be more varieties of green plants, and it would be better to simulate the changes of the four seasons -- small flowers bloom in spring, and leaves turn yellow in autumn, which would be more realistic. If the sound of water in the waterscape could be softer, like the sound of running water in a distant stream, instead of being completely silent, it would be more realistic. It might be more natural. P17 suggested that although the green plant scene was beautiful, the edges of some leaves were too neat to look natural. Improve the texture and shape of plants, depict the original growth mode of plants, add more colors and structural details to make them look more real, add sounds in nature, the sound of

leaves rubbing, and the sound of small animals living in plants, which almost everyone can casually think of from the visual effect of plants. Five participants (P2, P7, P9, P11, P18) expressed the need for natural sounds. Under real conditions, it is very difficult to set up plants with natural growth in the indoor space, and it takes a lot of time and energy to maintain their state, but in virtual reality, it can be very easy to create such a space.

The association with outdoor plants opened by the window - In response to the question of which area participants spent more time in during the experiment, the window side was mentioned the most (10 participants). P14 said that the large window was particularly attractive to them; the sunlight filtering through the greenery made them feel completely healed. The outside view was the most convenient area in the entire space for interacting with plants placed outdoors. The circular windows were the best spots to observe outdoor scenes, allowing participants to see the forest and pond outside from indoors. P17 said the lotus flowers and pond outside the window were framed into a picture, which was very attractive. VR technology also provides the idea of easily switching the outdoor scene, two participants expressed this need, P13 said that Condition 4 is suitable for relaxing or thinking, if interactive elements can be added, such as the scenery outside the window can be changed manually, or the kettle can be used to make tea, it may be more interesting. The simple production and switching of outdoor scenes in VR gives participants more freedom to daydream. Switching between different scenes and different seasons is the unique freedom of the VR world. Most participants put forward a lot of nature-related expectations for the scenes outside the window.

4.2. Perceptions of Natural Movement

Disadvantages of having natural movement elements - In the experiment, the elements that elicited negative emotions from participants mostly came from dynamic elements. The repetitive nature of mechanical movements significantly affected participants' emotional stability. P8 mentioned that the ripples on the wall made them dizzy, like watching the spinning cycle of a washing machine for too long. However, the swaying shadows of the trees outside were much more pleasant, and it would be even better if they could be adjusted to slow motion. Even though the intention was to connect the movement of the waves with the walls, classic wave elements were extracted from the walls of the Casa Batlló⁶. It is clear that the classic interpretation of the Casa Batlló, where the relative movement of the walls created by human motion is more successful in simulating the effect of waves, was more effective. The movable walls in the experiment either did not attract much attention or made participants feel confused and irritated. Regarding the interaction of wind or water with non-natural elements, such as wind blowing through wind chimes, opinions were mixed. P10 said that the greenery in Condition 2 made them feel particularly relaxed, especially the climbing plants with their layered leaves, reminiscent of their grandmother's backyard when they were children. Although Condition 4 has greenery, the flowing walls and wind chimes were a bit distracting, making them feel like something was always moving. This experiment wanted to create a sense of a gentle breeze through the movement of the wind chimes, but the result wasn't very ideal; the feedback was not as comfortable as the effect of plants swaying in the wind. The movement of the wind chimes was either unnoticed or superfluous. It shows that participants still prefer natural elements like wind interacting with other natural elements like plants, rather than artificial elements like wind chimes. In the experiment, Condition 3, filled with natural movement elements, received mixed reviews. Not only was there debate about the movement itself, but some participants felt that the excessive number of natural movement elements in the environment disrupted their pursuit of tranquillity during relaxation, making them feel uneasy.

Advantages of having natural movement elements - Among all the dynamic elements, participants preferred the changes in light and shadow the most (10 participants). This change comes from a quiet visual impact. P10 said, "The atmosphere is particularly suitable for a nap, with sunlight filtering through the leaves and covering you like a warm blanket." It also includes the changes in light and

⁶ Casa Batlló is a famous building in Barcelona designed by Gaudí, known for its wave-like shapes.

shadow produced by the flames in the fireplace. P4 said, "The effect of the sky darkening in Condition 4 is quite realistic, like camping outdoors." And that big stove, the fire effect is very realistic, it looks particularly warm. The sun shines through the leaves into the room and onto the ground and the pond outside, the light and shadow changes are caused by the wind moving the leaves, and the day-night cycle effects. All of these enhance the sense of immersion and lead participants to associate with good weather environments, thereby gaining participants' preference. Although the simulated natural movements in the experiment do not include the sounds produced by natural movements, they still evoke associations about sounds, about the interaction of wind and water and natural scenes, such as the the wind shaking the leaves, the water in the pond, the rain, the fish in the water, all expressed positive attitudes.

4.3. Familiarity and Comfort in VR Environments

The fireplace in the room is often mentioned by the respondents. Although there is no temperature-sensing system, the illuminated fireplace and the naturally flickering flames in C3 and C4 create a warmer atmosphere, making participants feel comfortable. 8 participants said their favourite area is next to the fireplace. P4 mentioned the large stove, saying the flame effect is very realistic and looks particularly warm. P18 said sitting there and watching the flames makes them feel completely relaxed. P20 mentioned the central fireplace-like device, saying the warm yellow glow spreads out in circles, like the flames of a gas stove in a stew. This reminds me of the use of breathing lights; I think it's a similar principle. Simulating a more natural movement trajectory allows participants to enter a more relaxed and comfortable state. At the same time, since the residences of the experimenters and participants are located in a relatively cold region, there is a high demand for heating in winter. Elements such as hot springs, saunas, bonfires, and heated kangas are all highly characteristic of the region. Therefore, for the locals, the elements of a fireplace and a relaxing atmosphere are often correlated. The fireplace evokes a warm atmosphere, making participants want to linger nearby, even if they are not actually drawing warmth from a virtual fireplace. Keeping participants physically in a stationary state while enhancing the realism of the indoor environment can provide a more reassuring and familiar spatial atmosphere. It can even simulate conditions of a personal space that one is very familiar with. By incorporating elements of real-growing plants or dynamic elements through virtual reality, participants can experience visual restoration effects while feeling a sense of safety, maintaining a calm mood. The two are complementary to each other in soothing participants' minds.

4.4. Scene and Functional Associations

In the pre-questionnaire, during the process questionnaire, and subsequent interviews, without any questions about scene associations, almost everyone made associations related to relaxing and relieving psychological stress. Among them, 11 participants associated scenes related to forests and outdoor activities. P8 said Condition 2 was definitely the best! The room was full of greenery, making it feel like being in a forest cabin, which was very soothing for the eyes. P4 said they liked the waterfall and the fish the most! The waterfall in Condition 4 was particularly attractive to them, like being in a natural scenic area. The fish in the pond were also very relaxing to watch. P15 associated the stove with the campfire during camping. The outdoor-related associations were almost all recreational in nature, such as natural scenic spots, travel, and camping. In contrast, the scene associations connected to reality were mostly functional, involving the addition of certain items to achieve a specific function and thus meet personal needs. For example, P19 suggested adding a practical desk or tea table, placing a few books or tea sets on it to create a more homely atmosphere. More seating arrangements were desired for gathering with friends, such as placing lounge chairs. P14 wanted a few friends over for a chat. A small tea table next to the round bookshelf. Brew a pot of tea, sip it while chatting, and it feels particularly cosy. 3 participants also mentioned their happy childhood memories. P20 said the placement of those green plants is very natural, unlike the deliberate arrangements in a flower shop. Especially that hanging ivy plant, its leaves layered upon each other, like the grape trellis in my grandmother's yard

when I was a child. P10 said the greenery in Condition 2 made them feel particularly relaxed, especially those climbing plants, with their leaves layered upon each other, like the backyard of their grandmother's house when they were young. These scenes are all places where participants have previously felt relaxed. They are not fantasies but are based on the real world, real places that have actually existed. They are fragments of participants' happy past experiences. Humans have developed a preference for natural environments during the process of evolution. Elements in natural scenes, such as sunlight, colours, and life, can trigger positive emotional responses in people (Marocco, 2025). Even when people overcome difficulties in nature, it is often a process where they actively participate and can gain a sense of achievement and happiness. The scenes requiring modern people to work in nature are becoming increasingly rare, and people's interactions with nature are more for entertainment and relaxation. The various elements in nature naturally need to possess a certain purity, evoking positive emotional associations in people.

Starting from scene association, arranging greenery indoors as if it were originally there makes it easier for participants to relieve psychological stress and feel immersed in a forest-like state. Handling the changes between day and night more naturally and restoring the colours of real life more accurately also reflects that participants' fantasies about relaxing scenes in the VR world are more based on real life rather than a fantasy world. Even when wearing glasses to enter the virtual reality world, they are more looking forward to real scenes, even those they have experienced or seen through the media and other ways. This kind of scene provides a controllable sense of security. The more anticipated form of virtual environments should be those that simulate scenes that participants have experienced, are memorable, or are expected to have a relaxing effect. The goal is to evoke a sense of security and create associations with pleasant memories. For example, The Math Guru tutoring studio employs various methods such as creating a warm visual environment and flexible spaces, allowing students to associate the school with a home-like atmosphere. By incorporating natural elements, it breaks the monotony of traditional learning environments, enabling students to feel the beauty of nature indoors, just like enjoying the tranquillity brought by nature at home, thereby effectively reducing the perception of stress [23].

4.5. Functional Association

People's functional associations are often static, and the associations of what can be done here are more non-tech-related. For example, the most mentioned activities (by 5 participants) are daydreaming and meditation. P13 said, "I feel like I could stay here forever and do anything." For instance, reading a book, listening to music, or simply daydreaming. The window-side spot is particularly suitable for relaxation. Sleeping, mentioned by 5 participants, was highlighted by P5, who said the atmosphere of Condition 4 is perfect for relaxing, with the green plants and light effects making it feel very relaxing. 3 participants mentioned drinking tea, and P15 said that although there were no fish, the pond looked quite suitable for casting a few lines. Or they could invite a few friends over for tea and chat, with a tea table set up on the platform. 2 participants mentioned reading, 4 participants mentioned exercising, and only P9 mentioned playing on their phone. Playing on the phone is the most common indoor activity participants choose to relax during their leisure time in daily life. Especially under Condition 4, when environmental stimulation is sufficient, participants greatly reduce the need to fantasise about play with mobile phones.

4.6. Additional Demand for Immersion and Interactivity

Participants frequently expressed a desire for enhanced immersion and interactivity. Several mentioned the need for natural sounds or soft background music to complement the visuals, enhancing the sense of realism. For example, P2 noted that the window-side spot was ideal for relaxing but could be improved with subtle nature sound effects. Others emphasised interactive elements that simulate real-life comfort. P20 suggested adding virtual books with cosy covers near the rocking chair to create a more inviting, homely feel. These suggestions highlight that while natural elements aid stress relief, immersion and interaction are essential for enhancing engagement and creating a personally meaningful

experience in VR. These findings suggest that future restorative VR environments should not only simulate nature visually but also include auditory and interactive layers tailored to individual user preferences.

4.7. Emotional Feedback

Emotional feedback data revealed that feeling calm was the most commonly reported response across all conditions. Participants attributed this to a variety of elements, including natural greenery, dynamic light and shadow, and the warm glow of the fireplace. However, several participants found mechanical or artificial dynamic elements, such as moving walls and wind chimes, to be distracting or anxiety-inducing. For example, P10 appreciated the greenery in Condition 2 but found the moving walls and wind chimes in Condition 4 made the space feel unsettling.

These results emphasise the importance of balance in designing for psychological restoration: while sensory stimulation can support immersion, calmness and predictability are essential for emotional comfort. The healing effect of a VR environment, therefore, rests on a foundation of perceived safety and serenity.

5. Findings & Design Implications

Our study yielded four key findings:

- Natural growth forms reduce stress – In indoor environments, plants that preserve their natural growth patterns are more effective in relieving psychological stress than artificial or overly decorative greenery.
- Natural dynamics outperform mechanical motion – Movement triggered by natural forces (e.g. wind, water) is more effective at promoting relaxation when interacting with organic elements (e.g. trees, rivers) than with artificial objects.
- Visual cues evoke restorative associations – Both greenery and dynamic natural elements primarily support stress relief through visual stimulation, which triggers associations with calming, positively evaluated scenes.
- Familiarity and emotional safety matter – People tend to prefer environments that feel familiar, controllable, and emotionally resonant—especially those linked to pleasant memories. A sense of safety is crucial to achieving psychological restoration.

Based on these findings, we propose three design principles:

- Preserve natural forms – Maintain the authentic growth appearance of plants and minimise visual distractions such as visible pots or artificial containers.
- Favour organic interactions – When simulating environmental dynamics, prioritise interactions between natural forces and natural elements to avoid mechanical or distracting movement.
- Anchor design in lived experience – Use elements that are familiar to users or evoke meaningful, memory-based associations to create a safe and emotionally restorative virtual space.

6. Conclusion

This paper examined how natural elements, such as plant forms and natural movement, affect psychological stress in Restorative virtual environments. Through a controlled VR experiment involving four immersive indoor conditions, we assessed participants' emotional and physiological responses to static greenery and dynamic natural features. The findings indicate that replicating plants in their natural growth forms, using simple and unobtrusive methods, enhances users' immersion and sense of connection with nature. In contrast, mechanical movements and artificial elements were often distracting, highlighting the value of organic interactions, e.g., wind or water influencing natural elements. The study also underscores the importance of emotional safety and memory-evoking imagery in creating calming virtual spaces. Based on these insights, we propose three design principles for

restorative virtual environments. Looking ahead, we envision virtual spaces that are not only grounded in familiar real-world settings but also enriched with elements that anchor positive personal memories. Future research will explore how multisensory components interact in virtual settings to support stress reduction, with applications in education, healthcare, and workplace well-being.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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