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Mental restorative effects of streetscape vegetation: Assessment of various design strategies using virtual environments

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ABSTRACT

While numerous studies have explored the restorative effects of natural environments, a gap in our understanding remains regarding how design approaches influence urban nature, particularly streetscape vegetation. A virtual reality experiment was conducted to address this gap, aiming to assess the restorative potential of three distinct design elements within an urban environment: Accessibility (fenced or not), Arrangement (regular or random), and Diversity (high or low). The participants (N = 57) experienced eight conditions based on these three factors in two virtual environments. The evaluations were obtained via a self-report questionnaire based on three dimensions of subjective restoration. The results revealed that the conditions without fences, arranged randomly, and with higher diversity exhibited more significant restorative potential than their counterparts with fences, regular arrangements, and lower diversity. This study provides insight into the influence of design strategies on streetscape vegetation in enhancing restoration, underscoring the potential of virtual reality as a tool for assessing urban design alternatives.

1. Introduction

Recently, numerous studies have investigated the effects of nature on well-being. A wide range of effects have been studied, from positive and negative affect (Yao et al., 2021), pain reduction (Scates et al., 2020), psycho-physiological benefits (Berto, 2014), and therapeutics (Je and Lee, 2020). Most studies have relied on two main theories: Attention Restoration Theory (ART) by Kaplan and Kaplan (1989) and Stress Reduction Theory (SRT) by Ulrich (1981).

According to the ART, humans have a limited capacity of directed attention that is exhausted by performing daily tasks in urban life. In contrast, nature has the potential to restore the directed-attention capacity in humans based on four dimensions (Kaplan, 1995): fascination (capturing attention in a non-exhaustive way), extent (feeling of being in a whole other world), being away (disengaged from everyday worries and concerns), and compatibility (matching needs and desires;). SRT refers to evolutionary psychology and states that exposure to environments containing natural elements results in reducing mental stress responses (Hartig and Mang, 1991; Ulrich et al., 1991).

Based on both theories, an environmental, particularly a natural setting, which exhibits characteristics that mitigate stress levels or facilitate the replenishment of physical and psychological resources, qualifies as a "restorative environment" (Berto, 2014; Hartig, 2004; Herzog et al., 2003; Kang and Kim, 2019; Takayama et al., 2022). The concept of urban nature could also be considered a restorative environment. It may not be easy to define urban nature because the definition of nature is quite different around the world based on cultural and geographical backgrounds. Urban nature can be assumed as all elements of nature distributed inside cities, which can be either formed by the spontaneous action of flora or fauna or from the human design and be used or unused by humans (Breuste, 2021). In many experiments, urban spaces are often placed in opposition to natural spaces; thus, “urban nature” seems to be a self-contradictory term. In experiments that aim at finding the benefits of nature for human well-being, the urban environment is considered a counterpart to the natural environment (Bratman et al., 2015; Hartig et al., 2003; Li et al., 2022; Mostajeran et al., 2021; Ulrich, 1981). However, the history of urban planning reveals that the integration of nature into urban environments has often

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gone beyond this binary opposition (Sijmons, 2020). Furthermore, in an increasingly urbanized world, urban nature represents the daily relationship with nature for the urban population.

It is important to consider streetscape vegetation as a significant aspect of urban nature. About a quarter of all developed urban areas are streets, a significantly higher percentage than parks and public spaces (Jacobs, 1997). Moreover, streets are environments where people spend most of their time for commercial, social, and political activities or just moving inside cities. Nevertheless, most studies on pedestrian experiences with urban nature have been conducted in urban parks or large public spaces (Carrus et al., 2017; Masullo et al., 2021; Ojala et al., 2019; Pratiwi et al., 2020). Research experiments on streetscape vegetation and sidewalks are scarce (Jiang et al., 2015; Lindal and Hartig, 2015). Natural elements, such as individual trees at the corners of streets or vegetation on the edges of sidewalks, cannot be neglected as a frequent exposure to nature (see Fig. 1). Based on previous studies, evidence suggests that even tiny areas of nature can improve well-being and restoration (Allard-Poesi et al., 2022). The restorativeness of small parks depends on their design, not just their size (Nordh et al., 2009; Nordh and Østby, 2013).

1.1. Effects of different natural environment types

Not all natural environments have the same features—many differences exist in shape, size, scale, color, density, and type of natural elements. Moreover, spaces inside cities can rarely be entirely natural or thoroughly urban but rather a mix of natural and urban elements in different proportions and structures. The integration of these elements has become increasingly prominent in emerging urban districts that prioritize sustainable design, focusing on such aspects as soil, water, local microclimates, and plant richness (Monti, 2020).

Some studies have aimed to investigate the effects of various elements in natural environments such as vegetation type, presence of water, street furniture, flowers or animals (Maurer et al., 2021; Pals et al., 2014; Wang et al., 2019). Diverse types of vegetation can have varying effects on well-being. For example, grassy environments may improve positive affect more than trees (Huang et al., 2020). In contrast, in another study, the presence of grass and the size of trees along the street did not affect the judgment of restoration (Lindal and Hartig, 2015). Comparing virtual walks in two green areas, a pine forest and a farmed field, displayed more restorative effects for the former (Brancato et al., 2022). Another experiment investigating the restoration effects of urban park pavilions revealed that serenity and plant richness are critical factors for restoration effects. However, the pavilion enclosure does not affect this (Luo et al., 2022). Evidence also reveals that human structures inside nature do not diminish the restoration effects of virtual nature (Reese et al., 2022a).

In a study evaluating the subjective well-being of urban green spaces, significant positive effects of biodiversity were exhibited (Carrus et al., 2015). Another similar study concluded that restorative benefits perceived from parks were primarily determined by biodiversity and not by non-natural site facilities, such as benches and lighting (Wood et al., 2018). An experiment conducted in three locations of a forest at three levels of density indicated that the forest interior condition led to significant stress reduction, and higher density exhibited better attentional performance (Chiang et al., 2017). Analyzing the relationship between the characteristics of pocket parks and restorative effects revealed that naturalness plays a crucial role, which is increased based on a higher green ratio, the existence of water, and more plant diversity (Peng et al., 2023).

Other factors in green spaces, such as distinct types of trees (Elsadek et al., 2019), plants colors (Elsadek et al., 2017), brightness levels (C. Li et al., 2020), climates (Bielinis et al., 2021; Yin et al., 2022), enclosures (Tabrizian et al., 2018), and per capita area (Lin et al., 2019), were also investigated in recent studies. As urban design evolves and shifts toward the creation of sustainable cities, numerous design approaches have undergone significant transformations in recent decades, particularly in Western countries. These transformations have introduced new factors and features concerning the design of urban nature, including ecological aspects and the maintenance of biodiversity (Monti, 2020). Consequently, further research is essential to examine how these changes may influence the well-being of urban residents.

1.2. Using virtual environments to evaluate nature effects

While it is impossible or very challenging to create a control condition in real-life experiments that matches the experimental condition in all aspects except the element of nature, Virtual Reality (VR) allows researchers to manipulate natural environments, create identical scenes, and investigate each variable separately. Moreover, VR presents advantages over using images, videos (e.g., by offering a higher sense of presence), or real environments (e.g., by being easily accessible to anyone anywhere). All these aspects have made VR a popular medium in recent years to study the effects of nature on mental health and well-being (Frost et al., 2022; Nukarinen et al., 2022; Spano et al., 2023).

There are many studies regarding the validity of using virtual nature (i.e., natural elements represented in VR) to evaluate perception in natural environments. For example, Mattila et al. (2020) found that a VR environment presenting a forest was perceived as restorative as the physical forest. A similar study, which compared a VR forest with a physical one, demonstrated that there was no significant difference between the two environments with regard to their impact on well-being (Reese et al., 2022b). Chirico and Gaggioli (2019) observed similar positive and negative emotions from a real panoramic view of a lake and an immersive 360-degree video of the same environment. A further study has put forth the proposition that virtual simulations of natural and urban environments evoke effects that are analogous to those experienced in the actual physical counterparts of these settings (Ünal et al., 2022).

Nevertheless, other studies have indicated that virtual nature does

Fig. 1. Examples of urban nature in the design of contemporary urban developments.

not appear to have the same mood-enhancing effects as the real environment (Browning et al., 2020). Calogiuri et al. (2018) were unable to reproduce psychophysiological responses comparable to those experienced during green exercise in a natural environment due to the limitations of the available VR technology. As they observed, the occurrence of cybersickness, poor image quality, and a lack of holistic engagement with the natural environment were the primary factors impeding positive psychophysiological responses (Calogiuri et al., 2018). The efficacy of a virtual environment is contingent upon its degree of realism and the extent to which it engenders a sense of presence. Accordingly, more realistic virtual reality environments elicit more favorable responses related to serenity and positive affect (Newman et al., 2022). Although there are still considerable limitations in comparison to a real-world experience (such as the absence of multisensory experiments), previously cited findings indicate that the utilization of a virtual environment that offers a high degree of presence and immersion can serve as a valid instrument for evaluating the psychological impact of natural environments. Consequently, there has been a notable increase in the utilization of VR for the assessment of the restorative potential of urban natural environments (Luo et al., 2022; Zhu et al., 2023).

1.3. The present study

The majority of research on the restorative power of green spaces depicts nature as either wild nature (e.g., forests) or large-scale urban nature (e.g., parks). As previously stated in the introduction, the type of nature that is typically encountered in everyday life is different and primarily includes small green spaces and streetscape vegetation. The impact of these natural elements in urban environments may vary based on numerous factors, including the size and type of vegetation, their configurations or distributions, and the manner in which the natural elements interact with other urban elements.

As mentioned, studies have demonstrated that exposure to nature has mental benefits for humans, and urban designers are increasingly trying to integrate nature into cities and add more natural elements to urban areas. However, it is not certain that all design principles aimed at making cities greener have the same restorative effects. Consequently, VR can be an effective tool for assessing these elements in accordance with established regulatory frameworks, thereby facilitating the examination of a range of prospective design options in a prompt and efficient manner.

Many different parameters apply when designing urban green spaces. Based on observations in new urban neighborhoods of the city of Nantes, which are already populated with various types of sidewalks and small vegetation (see Fig. 1), three elements regarding the level of naturalness were explored in this study: Accessibility, Arrangement and Diversity. These three elements are observed to have a strong influence on the degree to which a green space appears to have been altered by humans or to resemble an unaltered natural environment. Furthermore, these elements can be readily controlled by the designer from the outset of the design phase and remain consistent after the design is complete, unlike other characteristics such as brightness, color, foliage density, and cleanliness, which can vary significantly over time.

Accessibility: A green space can be designed to be accessible (e.g., people could step into the green space and move close enough to the natural elements to feel as if they could touch or move the leaves or branches) or inaccessible (a fence or barrier separates people from the green space). There may be assorted reasons for urban designers to add fences to green spaces. Fences can separate public and private spaces while providing the desired visual porosity between the two. Moreover, they can play a protective role, preventing people and animals from stepping on and damaging natural elements. Fences also contribute to the design as part of the street furniture.

In large urban green spaces such as parks, the presence of fences may be of limited importance, particularly when situated within these environments. This is because people would be surrounded by continuous green spaces, and a fence between them and natural elements would not be perceived as a border between green and non-green environments. In contrast, in smaller urban green spaces, particularly streetscape vegetation, the absence or presence of fences could have a considerable impact on both the visual and physical experience of pedestrians. Even a modest fence could effectively delineate the boundaries between green and non-green spaces.

The presence of a physical obstacle between people and natural elements does not inherently impede the positive effects of these elements. Indeed, previous studies have demonstrated that even viewing nature through windows or viewing images and videos of nature can be restorative (Ohly et al., 2016; Ulrich, 1984). However, to the best of our knowledge, no studies have investigated whether fenced or not fenced green spaces have different effects on the restorativeness of urban nature.

Arrangement: In real nature, it is atypical to observe a regular, ordered arrangement of trees or shrubs. The dispersion of natural elements in nature can be described as either uniform, clumped, or random. With the exception of fractal geometries (Robles et al., 2021; Joye and Van den Berg, 2011), natural elements in non-manipulated nature do not follow a geometrical pattern, particularly rectangular shapes and straight lines. However, in green spaces designed and created by humans, regular and geometrical patterns of natural elements are frequent, which is a legacy of classical urbanism where plants follow the alignment of streets and trees are significant elements of aesthetics. For instance, consider the baroque boulevards of France, which employ meticulously arranged rows of trees as a symbolic representation of the ruler's authority over the land (Lawrence, 2008). The organized formations of trees serve to illustrate that these green spaces have been constructed by human intervention, rather than developing naturally. In consideration of these differences, a potential discrepancy may also exist in terms of the restorative quality between a row of equidistant plants and a more randomly distributed green space. As far as we are aware, no previous study has examined the distinction in the impact of these arrangements on restoration and preference.

Diversity: The pursuit of biodiversity often leads to a combination of vegetation species in contemporary urban design. As mentioned, evidence indicates that a higher degree of biodiversity in an environment can have a different effect on restoration than an environment containing limited species. Most studies that have investigated this effect include flora and fauna biodiversity (Schebella et al., 2019; van Vliet et al., 2020; Wang et al., 2019), which is a larger category than vegetation diversity or plant richness. Unlike biodiversity in real nature, vegetation diversity can be defined completely by the designer of an urban green space. In the present study, we aimed to utilize the potential of digital environments to compare environments that are similar in regard to the number of trees and the density of vegetation, but differ in diversity and arrangement. To the best of our knowledge, a comparable controlled experiment has not been conducted previously.

Our own visual observations of unaltered nature (particularly in Europe), which would be experienced by typical visitors as a form of natural exposure, reveal that vegetation in these environments is not typically separated by fences. Furthermore, the plants do not tend to follow a grid-like pattern or linear arrangements. Finally, these elements generally display a high degree of diversity, with a variety of vegetation types present within a single region. In alignment with the premise that unaltered natural environments are highly restorative, it is postulated that human-made green spaces that are more analogous to authentic natural settings in these attributes may be correspondingly more restorative. In accordance with this concept, three hypotheses have been put forth:

H1. Not fenced, accessible nature in urban environments has a higher positive influence on subjective restoration.

H2. Randomly arranged elements of nature have a higher positive influence on subjective restoration than regularly arranged natural elements.

H3. Green spaces with higher diversity have a higher positive influence on subjective restoration than less diverse spaces.

2. Methods

2.1. Participants

A total of 57 participants from the city of Nantes in France were recruited via emails, posters, and word of mouth. The mean age of the participants was 28.00 (SD = 10.04), and the gender ratio was nearly equal (29 females and 28 males). Around two-thirds of the participants (38, 66 %) had zero or very limited previous experience with VR, and almost half of the participants (28, 49 %) had very limited or no experience regarding three-dimensional (3D) video games. The experiment was conducted with the approval of the Ethics Committee of the University of Nantes.

2.2. Materials and environments

Two nearby locations in the city of Nantes were selected. A mixed procedure of photogrammetry and 3D modeling was employed to create two simulated 3D environments based on these real environments, using Blender 3.2 and Unity 2021.3. The first environment (*Street*) was a street containing a small portion of greenery in a concave outdoor space in front of a building. Participants stood on the sidewalk of this street close to the green space but could not enter it. The second environment (*Alley*) was a pedestrian-only alley that contained linear patches of trees and bushes on both sides of the walkway. The participants stood in the center of the area, at a similar distance (approximately two meters) to the green patches surrounding them. It should be noted that the aim was not to compare the restorativeness of streets and alleys but to assess the effect of the factors manipulated in various urban contexts. There are numerous types of streetscape vegetation, which can be classified based on a range of characteristics (Peschardt et al., 2012). However, evaluating these diverse types in a single experimental setting with multiple factors is not feasible. To ensure that the findings are not limited to a

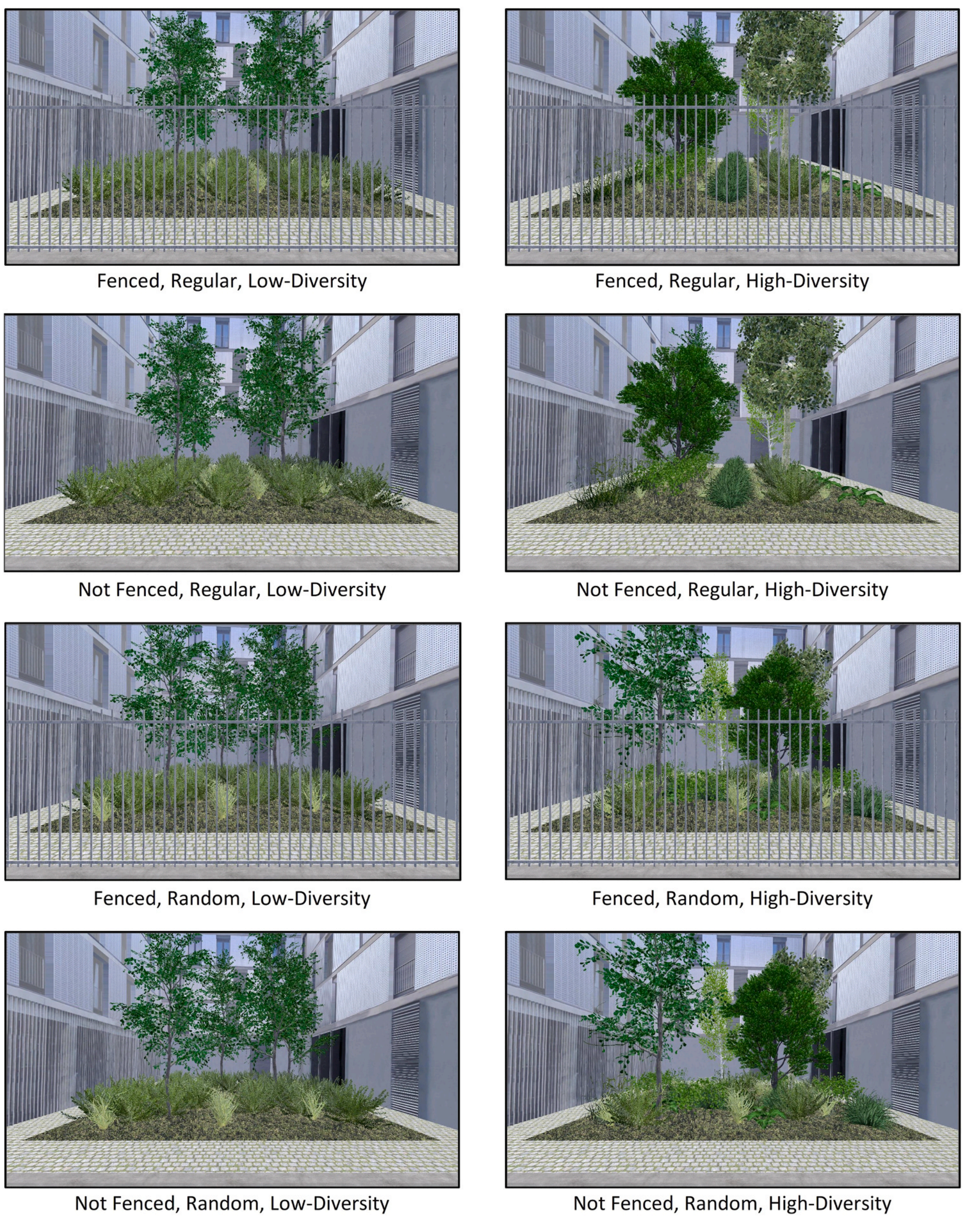

Fig. 2. Eight conditions in the Street environment.

specific type or category of vegetation, two dissimilar settings were selected for this study. If comparable outcomes are identified in two distinctly disparate contexts, it is more prudent to extend the findings to other categories of streetscape vegetation. Thus, the environment type should not be considered an independent variable; we only used *Street* and *Alley* as labels for the sake of clarity and readability. For each environment (*Street* and *Alley*), eight conditions were created by crossing two degrees of Accessibility, Arrangement and Diversity (see Figs. 2 and 3). Therefore, each participant visited 16 experimental scenes in total.

For Accessibility, two conditions were named as “Fenced” and “Not fenced”. In the *Street* environment, the fence consisted of high metal bars at the edge of the sidewalk, preventing the observer from accessing the green space (see Fig. 2). In the *Alley* environment, the Fenced condition included low wooden fences located at the exact edge of the green space. In both environments, the “Not-fenced” condition lacked any form of fencing (see Fig. 3). The selection of these alternative fence types is analogous to the approach taken in selecting the two contrasting environments. Two distinct fence types, distinguished by height, material, and design, were chosen to preclude the possibility of concluding that the accessibility effect was a consequence of a single fence type. Moreover, the suitability of each fence type is contingent upon contextual considerations and is based on actual instances observed in the real world.

For the Arrangement factor, the two opposing conditions were “Regular” and “Random”. In both environments, the “Regular” condition was created in such a way that the distribution of natural elements in the area followed a geometric pattern or grid. The distances between natural elements were almost equal and aligned in rows and columns (a small misalignment was added to avoid a sense of artificiality because it is almost impossible to have perfect equality and alignment even in organized plantations in the physical world). In contrast, the “Random” condition was created in such a way that natural elements were distributed arbitrarily in the area without following any rules or patterns.

Last, for the Diversity factor, there were also two contrasting conditions: “Low-diversity” and “High-diversity”. In the *Street* environment, the “Low-diversity” condition included two species of plants and only

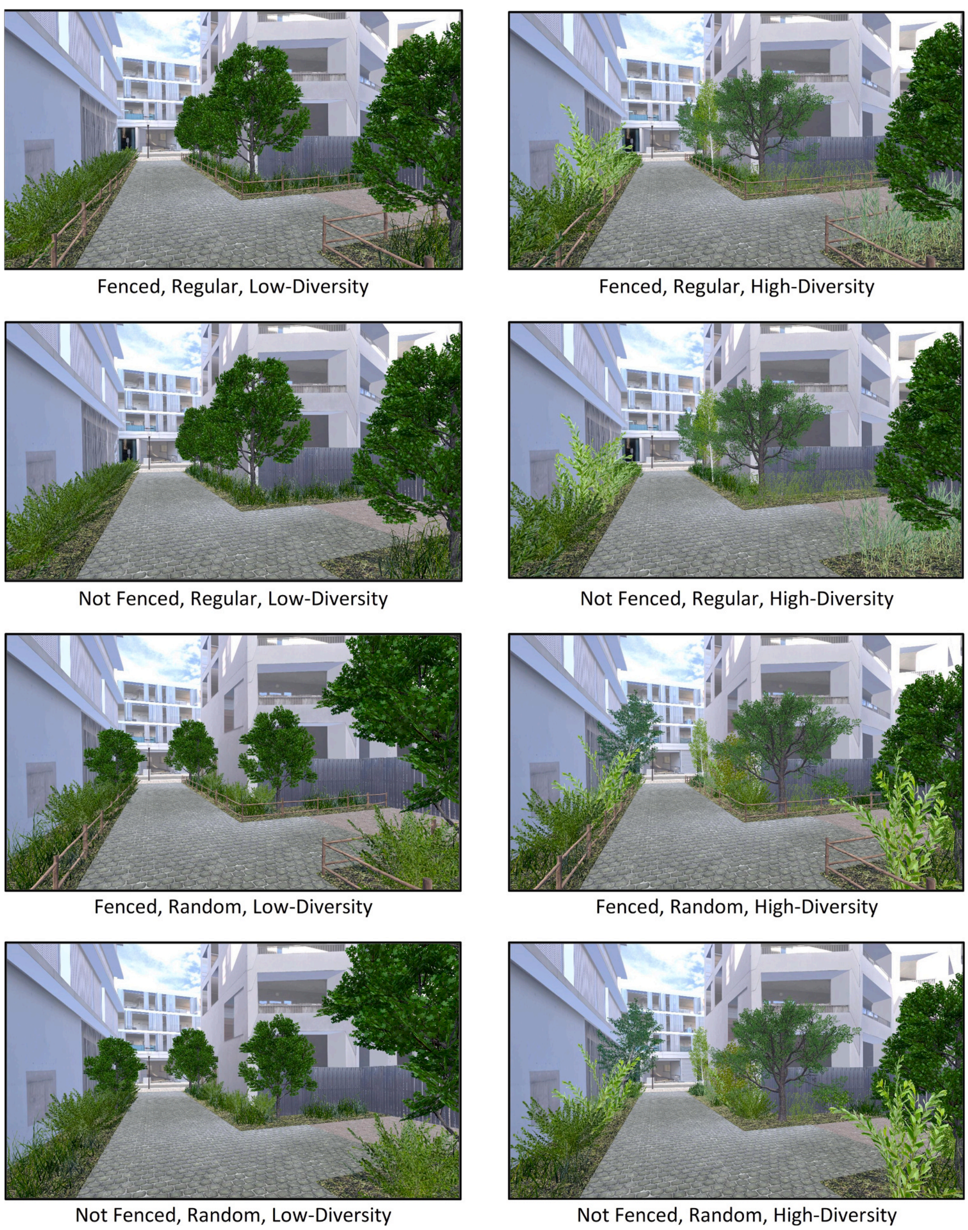

Fig. 3. Eight conditions in the Alley environment.

one species of tree. In contrast, the “High-diversity” condition included six different species of plants and four different trees. Similarly, in the *Alley* environment, there were two species of plants and only one species of tree in the “Low-diversity” condition, in opposition to seven different species of plants and six different trees in the “High-diversity” condition. Despite the differences in diversity, the counts of trees and plants were equal in the two conditions (see Figs. 2 and 3).

The experiment was conducted at the Nantes School of Architecture and Ecole Centrale de Nantes. Both rooms contained an empty area of 2 × 2 m for participants to safely walk around during the experiments. For viewing the environments, an HTC Vive Pro Eye 2 head-mounted display (HMD) was employed. For rendering, a Dell desktop computer (Core i7 10700 at 2.9 GHz) with an NVIDIA GeForce GTX 3060 graphics card was used. The questionnaires before and after the VR experience were also conducted in the same rooms using a laptop computer. With this setup, the virtual environment was displayed at a steady refresh rate of 90 Hz in the HMD.

2.3. Measurements

Subjective Restoration: Various self-report questionnaires have been used in related research experiments to evaluate and compare the restorativeness of environments, including the Restorative Outcome Score (Hartig et al., 1998; Korpela et al., 2008), Positive Emotions (Pasanen et al., 2018) and Perceived Restorativeness Score (Hartig et al., 1997). A short questionnaire considering the three dimensions (restorative experience, positive emotions, and stress reduction) has been used in recent studies containing ten (Wan et al., 2020) or eight items (Luo et al., 2022) rated on a 5-point Likert scale questionnaire from 1 (completely disagree) to 5 (completely agree).

As each participant was required to respond to the questionnaire on 16 occasions, the principal rationale for the removal of items was to ensure the questionnaire was as concise as possible. However, efforts were made to maintain the questionnaire’s structural integrity. As the original questionnaire comprised three dimensions, two items were retained from each dimension in this study to ensure a balanced representation. Consequently, the final questionnaire comprised six items, as indicated in Table 1. The subjective restoration score of each condition is calculated as the average value of all items.

Simulator Sickness Questionnaire (SSQ): This questionnaire measures the symptoms in participants after experiencing VR to evaluate cybersickness from VR. It contains 16 items rated on a 5-point Likert scale ranging from 0 (very slightly or not at all) to 4 (extremely; Kennedy et al., 1993). If the average cybersickness symptoms are extreme, the experiment results could be affected.

2.4. Procedure

First, the participants signed the consent form, upon which they were informed that they had the right to stop at any time without any justification. They also completed a demographic questionnaire consisting of age, gender, and two questions about their previous experience with VR and video games. Afterward, they put on the VR headset and learned how to walk around and use the controllers to answer questions in a neutral 3D environment: a virtual room with white walls that was empty and included text encouraging the participants to look around when they will be transported to the other environments. Subsequently, as the study was designed as a within-subjects experiment, all participants visited all 16 experimental conditions in random order. They began with one randomly selected condition from the street environment and then proceeded to one randomly selected condition from the alley environment, alternately visiting the two environments in succession (Fig. 4).

Table 1
Subjective restoration questionnaire.

Dimension	Item	Scale				
Restorative experiences	I forget everyday worries after passing here.	1	2	3	4	5
	Passing here gives me a break from my day-to-day routine.	1	2	3	4	5
Positive emotions	Passing here makes me happy.	1	2	3	4	5
	I feel energized after passing here.	1	2	3	4	5
Stress reduction	I feel relaxed after passing here.	1	2	3	4	5
	Passing here helps me reduce stress.	1	2	3	4	5

In each condition, participants started on a spot marked by a green circle under their feet. After 30 s they heard a beeping sound and saw another circle in another spot less than two meters away from them, which they reached by physically walking in the real world, and then stood there for another 30 s. During this time, they could freely turn around and view the environment. The reason behind this procedure was to make participants move as much as possible to increase their immersion and sense of presence, yet prevent very rapid movements or leaving the VR safe zone. This procedure was repeated three times, and after the last beeping sound, participants saw a white circle in the location of the first circle, from which they could answer the questions in a panel that appeared. The order of appearance of the six questions was random, and after participants answered all of them, the environment faded to black, and the following condition appeared.

After finishing all 16 conditions, participants took off the HMD and answered the post-experiment questionnaire (SSQ). The whole experiment took around 45 min per participant, including about 30 min of exposure to the virtual environments, which was found to be tolerable based on preliminary tests. However, participants were informed that they could request a break if they felt fatigued, yet none of them opted for a break.

2.5. Data analysis

The data from the experiment were compiled and analyzed using JASP (v 0.17.2; JASP Team, 2023). For each condition, the average value of the answers to the six questions was used as the main subjective restoration score. Based on the three factors, a 2x2x2 (Accessibility: fenced vs. not fenced; Arrangement: regular vs. random; Diversity: low vs. high diversity) repeated measures analysis of variance (ANOVA) was performed for each environment, with a significance level of $\alpha = 0.05$. The partial eta squared (η^2_p) was reported to measure the effect size.

3. Results

Fig. 5 represents the mean subjective restoration score in all conditions. Initially, the highest score corresponds to the condition with no fence, a random arrangement, and higher diversity in the *Street* (M = 3.07, SD = 0.85) and *Alley* (M = 3.30, SD = 0.78) environments. Table 2 reports the results of the repeated measures ANOVA.

Street environment: The results indicate a significant difference between “Fenced” and “Not fenced” conditions in the *Street* environment with a considerable effect size. In this environment, the restoration score was significantly higher for the “Not fenced” conditions (M = 2.89) compared to the “Fenced” conditions (M = 2.32). Regarding the Arrangement, the restoration score for the “Random” conditions (M = 2.66) is significantly higher than the “Regular” conditions (M = 2.55). For diversity, the score for “High diversity” was significantly higher (M = 2.68) than for “Low diversity” (M = 2.54). No significant interactions occurred between factors in the *Street* environment.

Alley environment: In this environment, although the average score for the “Not fenced” conditions (M = 3.07) was higher than the average score for the “Fenced” conditions (M = 2.93), the effect size is small, and the difference failed to reach statistical significance. The two other factors (Arrangement and Diversity) have significant differences in this environment. The mean score for the “Random” conditions (M = 3.07) is significantly higher than the “Regular” conditions (M = 2.93). In this environment, conditions with “High diversity” obtained a higher

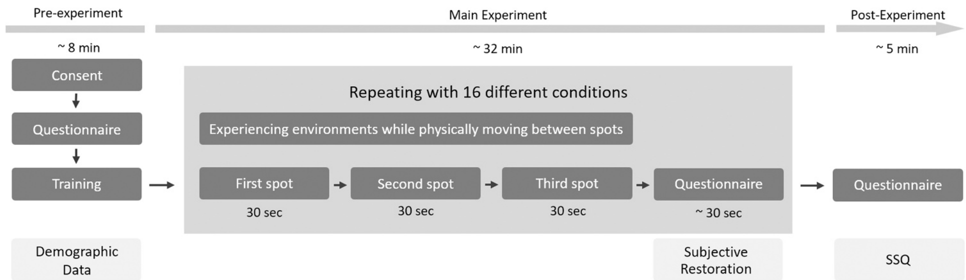

Fig. 4. Experimental procedure.

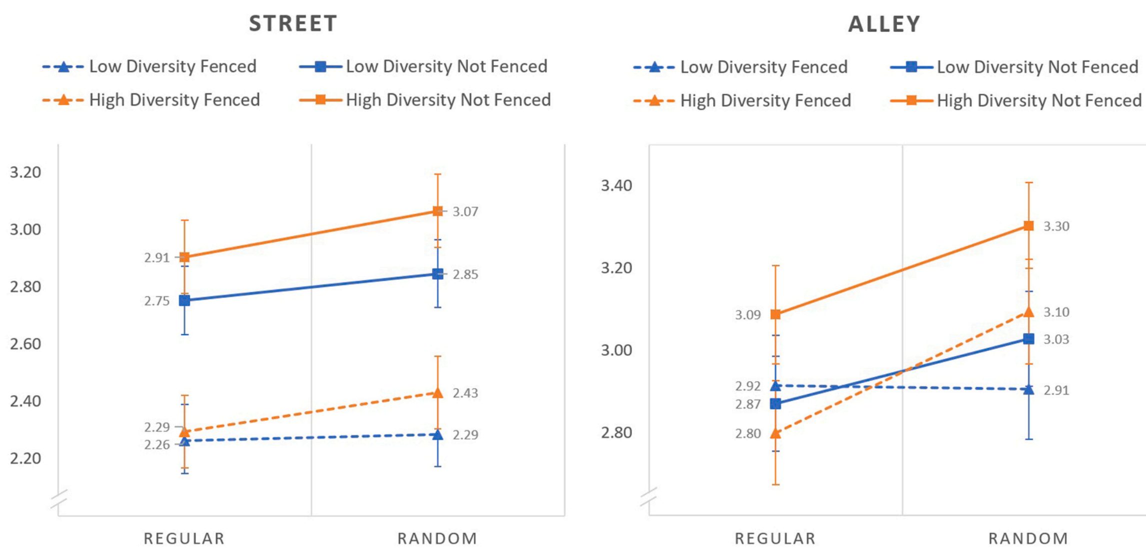

Fig. 5. Three-way interaction between accessibility, arrangement, and diversity for the subjective restoration score.

Table 2
Repeated-measure ANOVA results for the subjective restoration score.

Environment	Factors	F	p	η^2_p
Street	Accessibility	51.340	<.001***	0.483
	Arrangement	5.866	0.019*	0.096
	Diversity	5.235	0.026*	0.087
	Accessibility * Arrangement	0.019	0.890	0.353
	Accessibility * Diversity	0.409	0.525	0.007
	Arrangement * Diversity	0.446	0.507	0.008
	Accessibility * Arrangement * Diversity	0.040	0.842	0.727
Alley	Accessibility	3.317	0.074	0.057
	Arrangement	9.257	0.004**	0.144
	Diversity	8.422	0.005**	0.133
	Accessibility * Arrangement	4.959	0.030*	0.083
	Accessibility * Diversity	0.133	0.717	0.002
	Arrangement * Diversity	2.261	0.138	0.039
	Accessibility * Arrangement * Diversity	1.288	0.261	0.023

Note. * p < .05, ** p < .01, *** p < .001.

average score (M = 3.08) than conditions with "Low diversity" (M = 2.92). Significant interaction occurred between the Accessibility and Arrangement variables in the *Alley* environment. In the "Fenced" conditions of this environment, the subjective restoration score is higher for the "Random" arrangement (M = 2.95) than for the "Regular" arrangement (M = 2.91). Similarly, in the "Not fenced" conditions, the subjective restoration score is higher for the "Random" arrangement (M = 3.2) than for the "Regular" arrangement (M = 2.95).

In a separate repeated measures ANOVA, comparing the restoration score of only two conditions, "Fenced", "Regular" and "Low diversity" (as a combination of all negative factors based on the hypotheses) and the "Not fenced", "Random", "High diversity" (as a combination of all positive factors based on the hypotheses) also indicates significant differences in both environments (F_S (1,55) = 47.024, $p < 0.001$), (F_A (1,55) = 10.666, $p = 0.002$).

Simulator Sickness: The average score for cybersickness was calculated (M= 14.05 SD = 9.93) based on the scoring procedure for the SSQ, which is considered minimal symptoms (Kennedy et al., 1993). The most frequently reported symptoms were fatigue, eye strain, and fullness of the head.

4. Discussion

4.1. Effects of design factors on subjective restoration

This study investigated the restorative effects of three factors considered while integrating small green spaces, particularly streetscape vegetation, into the everyday living spaces of urban environments. From the contemporary urban design perspective, urban designers have ensured the sustainability of nature to re-nature cities by planting local species adapted to the soil and promoting biodiversity. This approach to sustainable design has the potential to result in green spaces that more closely resemble their natural counterparts outside of urban areas. This assumption is based on a greater emphasis on biodiversity and ecological aspects, which contrasts with the traditional Western urban planning approach that has fostered a culture of domestication and domination of nature (Forman, 2014). Some studies have investigated wild vs. tended nature effects on the mental well-being of humans (Chiang et al., 2017; Martens et al., 2011; McAllister et al., 2017; McMahan and Estes, 2015). However, there is still a lack of research on the parameterization of the elements of difference between these environments. The aim of this study was to fill this gap by taking advantage of the possibilities offered by VR. Among the many different design elements, this study explored three important ones that are easily controlled by the designer and can greatly influence the level of naturalness in these environments. These three elements were accessibility, arrangement, and diversity.

For all three factors, the results support the related hypotheses, which state that a more accessible, diverse, and random arrangement provides a more restorative experience, with some nuances depending on the considered environment. In the *street* environment, no interaction between factors was observed. Regarding Accessibility, the condition with fences between participants and the natural elements provided a significantly lower restoration effect than the condition without fences. However, in the *Alley* environment, the presence of a fence altered participants' perceptions only in the case of a random arrangement, suggesting that the addition of a barrier did not alter an already unfavorable perception of artificially arranged vegetation. Each factor is discussed in the following paragraphs.

In both fenced and not fenced conditions, the position of the participants and their distance to the natural elements was equal. Participants could not move closer to the vegetation even in the not fenced conditions (due to the limited space of the experiment room); however, in this entirely visual simulation, the absence of fences created a higher restorative perception in participants. This result supports the findings of a previous study on the effects of accessibility and density in a forest, indicating that higher accessibility could increase pleasure and arousal in visitors (Staats et al., 1997). Although the term "accessibility" in the referenced study did not have the same meaning as it had in the current study, one aspect common to both studies was the existence or absence of any barriers (passableness).

In the *Alley* environment, the difference between the fenced and not fenced conditions was not significant. Further investigation is necessary, as there are numerous differences between the two environments and the types of fences associated with each of them. Nevertheless, potential explanations for the observed outcome may be sought in the private or public character of the green space, the distance between observers and natural elements, and also the differences in height and material of the two fence types.

For the second factor, Arrangement, the results in both environments supported H2. The conditions in which natural elements are distributed randomly in the environment displayed higher subjective restoration than the conditions in which they were distributed regularly and in geometric patterns. The results suggest that it is better to avoid geometric plans and equidistant placement of vegetation to achieve better restorative values in urban green spaces. This finding is a critical difference between natural elements in wild nature and tended nature, which is discussed further in the subsequent section.

Last, the results for the Diversity factor indicated that higher subjective restoration was positively related to higher plant diversity in both environments, validating H3. This result confirms the findings of previous studies demonstrating that higher diversity in plant species (and biodiversity in general) increases perceived restorativeness (Carrus et al., 2015; Fuller et al., 2007; Mavoa et al., 2019; Meyer-Grandbastien et al., 2020; Wood et al., 2018). However, no consensus exists regarding how biodiversity affects psychological restoration (Dallimer et al., 2012; Hough, 2014; Shanahan et al., 2016; Southon et al., 2018). Moreover, studies have mentioned that, in addition to considering objectively measured values, examining the consequences of perceived biodiversity is also essential. Indeed, not all different species might be noticed by visitors, and real diversity may highly differ from what is recognized and observed by people (Beute et al., 2020; Marselle et al., 2019). A recent study has also found that a single approach is not universally applicable when examining the connection between mental well-being and biodiversity, and connectedness to nature plays a crucial role in moderating this relationship (Shwartz et al., 2023).

Increased diversity in plant richness and a less predictable arrangement of natural elements can be interpreted as signs of higher complexity within a natural scene (Hunter and Askarinejad, 2015; Zhao et al., 2013). Nevertheless, the relationship between complexity and the human preference for natural and urban scenes is not straightforward. Some studies suggest that preference may not increase in a linear manner with complexity, but rather in an inverted-U shape. (Hunter and Askarinejad, 2015; Ulrich, 1983). Consequently, it remains uncertain whether our study aligns with the existing findings on complexity or not. To gain a more comprehensive understanding, further studies incorporating a wider range of intermediate levels of diversity and arrangement are necessary.

4.2. Level of naturalness

In each factor of the current study, one degree represents a state more similar to classic urbanism, and the other degree would represent a state more similar to real natural environments. In classic urban design, human-made environments often include fences separating the green elements from the outside, and these elements are often cultivated in geometric patterns with few plant species. In contrast, in wild nature, there are no fences or grid-like patterns, and the environments comprise many distinct plant species. Thus, from another viewpoint, the differences regarding Accessibility, Arrangement and Diversity can also be discussed as different levels of domestication and modification of nature. Accordingly, more naturalness could be defined as less domination of nature by humans.

Based on the study findings, conditions characterized by a greater degree of naturalness exhibited higher subjective restoration scores than those with lower levels of naturalness. This finding is consistent with previous studies that have demonstrated higher restorative values for more natural or wilder environments (Allard-Poesi et al., 2022; Brancato et al., 2022; Hoyle et al., 2019; Tyrväinen et al., 2014). However, the literature presents conflicting results, with some studies reporting insignificant differences in restoration based on naturalness or wildness (Martens et al., 2011; Samus et al., 2022; Van den Berg et al., 2014). These discrepancies may be attributed to methodological differences, participant characteristics, or the specific environments under investigation. Our findings contribute to the ongoing debate by reinforcing the link between naturalness and restoration. However, further research is necessary to gain a more comprehensive understanding of the complexities of this relationship.

4.3. Limitations and future research

While the results provide novel insight into how attributes of urban green spaces affect restoration, acknowledging the limitations of this research is critical. Though the experimental environment was created to be as realistic as possible, many differences exist between these virtual and real environments (e.g., passing cars and people, weather conditions, and sounds). Only vision was stimulated in this study; no sounds, either urban or natural, were included in the environments. Specifically, to evaluate the effects of biodiversity in flora and fauna (and not only in plant richness), future studies should also consider comparing diversity in animal sounds (e.g., birds) in the environment.

In the current study, only self-reported results were measured. Although a strong association exists between subjective and objective measurements (Bolouki, 2022; Han, 2021, 2018), future research should conduct experiments using both psychological and physiological measurements to verify the results. Physiological measurement data can provide implicit measures that offer access to cognitive processes underlying the subjective evaluation (Huang et al., 2020; Yu et al., 2018). Eye-tracking also has the potential to assess how people distribute their attention in the urban scene (J. Li et al., 2020; Liu et al., 2022).

While the participants could physically walk in the environment and observe the elements from various angles (making the experience more immersive than 360° videos or panoramic images), the lack of interaction with objects makes it less tangible than real experiences. Some participants wanted to touch or move the leaves or branches of the trees but failed because such interactions were not programmed in the virtual environment. Evidence indicates that interactivity inside virtual nature improves the relaxing effect of the environment (Liszio and Masuch, 2019); therefore, evaluating the factors of the current study while allowing the participants to interact with natural elements is a recommended topic for future research.

The representation of the urban environment was created in ideal conditions: in a temperate season, with a clear sky and perfectly developed vegetation. As the actual conditions are not always ideal, the restorative qualities of the environment may be different in other seasons and weather conditions (e.g., rainy days in autumn or with bare vegetation in the winter).

The sample population of the present study was predominantly comprised of young individuals; however, age was not a specific focus of the study. While this could be regarded as a limitation, it should be noted that the majority of extant literature concerning preference and restoration in nature also involves participants within similar age ranges (Browning et al., 2020; McMahan and Estes, 2015). This issue was also examined in the study by Nordh et al. (2011), which found only minor differences between age groups regarding preferences for park components. Similarly, for restoration effects in virtual nature, Mattila et al. (2020) compared age groups and found no significant differences between them.

5. Conclusion

The present study employed VR to replicate the experience of exposure to streetscape vegetation, enabling the assessment of the restoration outcomes across various design approaches. The VR environment created an opportunity to investigate nuanced distinctions while keeping every other element identical in the compared environments. The results indicated that Accessibility, Arrangement and Diversity of designed green spaces in urban environments are important factors at the restoration level. Accordingly, more similarity to real nature could have higher benefits for the mental well-being of urban dwellers. Further efforts in this field are recommended to explore the influence of various elements of green spaces on the citizen's experiences and establish evidence-based guidelines for urban designers.

CRediT authorship contribution statement

Pooria Baniadam: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Franck Mars:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Jean-Marie Normand:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation. **Ignacio Requena-Ruiz:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Conceptualization. **Daniel Siret:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

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

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