Small Urban Green Spaces: Insights into Perception, Preference, and Psychological Well-being in a Densely Populated Areas of Tehran, Iran

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ABSTRACT: In metropolitan areas worldwide, abandoned properties are prevalent, prompting a need for small urban green spaces (SUGS) to meet the growing demand. Understanding residents' preferences and perceptions of transformed spaces is vital for effective urban design. This study delves into residents' preferences and perceptions regarding the transformation of such spaces into SUGS and their impact on psychological well-being. By examining how these preferences and perceived health benefits shape the value of transformed spaces, the research aims to inform effective urban design strategies. The participants underwent visual stimulation, with psychological reactions recorded through Electroencephalogram (EEG) readings and assessed via Questionnaire. Machine learning techniques analyzed EEG sub-band data, achieving an average accuracy of 92.8% when comparing leftover and designed spaces. Results revealed that different types of transformed spaces provoke distinct physiological and preference responses. Specifically, viewing SUGS was associated with significant changes in gamma wave power, suggesting a correlation between enhanced gamma activity and increased feelings of empathy. Moreover, participants also reported enhanced comfort, relaxation, and overall mood, and a strong preference for SUGS over untransformed spaces, emphasizing the value placed on these areas for their health benefits. This research highlights the positive impact of even SUGS on mental health, using EEG data to assess emotional states triggered by urban spaces. The study concludes with a call for further research to investigate the long-term benefits of SUGS on well-being, alongside an exploration of the gamma band as a neural marker for emotional restoration in urban green spaces. This research highlights the crucial role of urban design in fostering psychological well-being through the strategic development of green spaces, suggesting a paradigm shift toward more inclusive, health-promoting urban environments.

KEYWORDS: Leftover space, health, perception, brain activity, emotion

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Introduction

In numerous metropolitan areas globally, the prevalence of derelict and abandoned properties remains a pressing issue.[1-4] As population growth rates have increased worldwide, factors such as aging populations,[5] population migrations,[6] and increasing urban density[7] have contributed to the abandonment and vacancy of many urban areas. The impact of post-industrial economic collapse, real estate financial miscalculations, and natural disasters has rendered entire cities affected in various regions across the world.[8] Consequently, the presence of abandoned spaces within urban environments has become a prevalent concern with implications for urban planning and design.

Moreover, in an era marked by diverse urban challenges, sustainable development strategies are increasingly emphasizing the importance of parks and public spaces.[9] These areas are now recognized as pivotal in the revitalization and transformation of urban landscapes, highlighting their vital role in promoting urban life and sustainability.[10]

The presence of high vacancy rates in urban areas provides a unique opportunity for transdisciplinary exploration in the fields of recreational space, urban ecology, design, and planning. Today, individuals are exposed to personal safety concerns and environmental issues in areas marked by high levels of abandonment, necessitating the management of demolitions, gardens, and the formation of new ecosystems.[1] Abandoned spaces, often characterized as unmanaged and informal greenspaces, can hold significant ecological value within urbanized landscapes.[2]

The health implications of these urban voids are of paramount concern. Studies indicate that natural features like urban green spaces and water bodies are beneficial for the physical[11] and mental health[12-14] of city residents. Integrating natural and artificial elements within these spaces plays a crucial role in fostering community health and well-being. The design, diversity, quality, and maintenance of these spaces significantly impact their health benefits and appeal.[15] Yet, there is a notable knowledge gap regarding which specific elements are most valued by users, especially in terms of health benefits and preferences.[16,17]

Nassauer et al[18] explored the impact of microscale landscape elements on the design and upkeep of neighborhood green spaces. These microscale elements, which reflect local cultural and social norms play a key role in revitalizing neighborhoods affected by vacancy,[19-22] enhancing their appeal and public health,[23] and having broad implications for community well-being.

In the face of urban growth and the potential for densely populated areas, small urban green spaces (SUGS) present city planners with the opportunity to enhance living environments, connecting residents with nature through initiatives like tree planting.[24] SUGS meet human needs[25] and contribute to better public health by improving the quality of existing SUGS landscapes,[26] which provide natural environments.[19,27,28] The surrounding environment, including leisure and transport options, significantly affects health and well-being.[29] These spaces can also positively impact individual characteristics such as lower neuroticism, enhanced creativity,[30] self-regulation,[31] well-being,[32] and emotional and behavioral resilience.[27] Furthermore, SUGS offer residents affordable opportunities to enjoy nature,[33] while benefiting local economies and potentially attracting tourism.[34,35]

The built environment bridges individual needs and their surroundings,[36] reflecting the challenges architects and urban designers face in addressing psychological needs due to their intangible nature and the subjective nature of judgment.[37] Environmental psychology aims to enhance the physical conditions for better human-nature interactions. The terms "preference" and "perception" frequently arise in discussions within the field of environmental psychology.[38] Experience, as a dynamic interplay between intuition and previously formed judgments, varies among individuals, contributing to social differences. Perception, on the other hand, involves the recognition and interpretation of information through various senses. Rapoport[39] underscores the fundamental link between an individual's interdependence with the environment and sensory sensations and perception. This interplay highlights how our sensory experiences are deeply intertwined with our surroundings. Gibson[40] extends this concept, proposing that human perception in green spaces is not just about the environment in its static form but also encompasses an understanding of its potential benefits and uses, further elaborating on the perceptions and activities of visitors regarding physical health in green areas.[41]

Furthermore, Brebner[42] emphasizes the profound impact of the environment on human psychology, proposing that our mental states are significantly shaped by our surroundings, not just influenced by them. This highlights the environment as an active element in shaping our psychological experiences, suggesting that green spaces contribute significantly to our well-being beyond their aesthetic appeal.

The concept of landscape visual quality (LVQ) involves understanding how landscape features affect human observers[11] and their perceptions,[43] which is crucial for evaluating the impact of green spaces on well-being. Understanding human perceptions, preferences, and quantifying the defining characteristics of LVQ are essential in unraveling these interconnections. The relationship between human perceptions and preferences regarding landscape visual quality has been the subject of extensive study across multiple disciplines. However, previous research has seldom encompassed both perceptions and preferences, including both human emotions and visual information to predict human desires related to LVQ. According to Romagosa,[41] there is scant evidence about the key features of parks that promote social interaction in park settings.

In exploring people's perceptions of Urban Green Spaces (UGS) landscapes, researchers have employed various approaches, including single indicators or multi-indicators.[43] Some studies have utilized multiple indicators, such as safety, attractiveness, wealth, and liveliness, to capture human emotions in relation to streetscapes.[44,45] Other researchers have employed multiple perceptions to analyze the emotional aspects of urban parks and predict the appropriate Landscape Visual Quality (LVQ).[43,46,47] These investigations have utilized a range of methods, including subjective perception assessments, systematic observation, and landscape rating,[48] physiological monitoring,[49,50] laboratory experiments,[51,52] computer-assisted evaluation,[53] and mixed approaches.[45]

People's perceptions of UGS are not only shaped by the characteristics of the spaces themselves but also by the overall presentation of the landscape.[47] The degree to which a park aligns with the subjective preferences expressed by its main user groups, both currently and in the future, plays a significant role in determining its acceptance among the public. If the expectations of park users diverge from those of planners, tensions, and conflicts between different groups may arise. Therefore, it is crucial to have a comprehensive understanding of people's subjective preferences and perspectives on urban parks to establish design and development patterns that cater to their needs. As highlighted by Suhardi,[54] designers can create more effective urban parks by gaining insights into people's needs and behaviors when they engage with their surroundings. A key challenge lies in quantifying human perception, which encompasses both people's perceptions and preferences of the existing landscape, as well as identifying appropriate management approaches to align the existing UGS with the desired landscape. This entails bridging the gap between the present landscape and the envisioned landscape, incorporating user perspectives and preferences into the planning and management processes.

This study aims to explore the potential value of redesigning small vacant lands in more creative ways based on users' preferences and perceptions. While the positive benefits of incorporating green spaces into urban planning and design have been widely acknowledged,[55] there is a need to integrate this knowledge with the explicit goal of maintaining green areas in neighborhoods. Although the positive impact of green spaces,[56] and especially SUGS on the well-being of urban dwellers has been studied to some extent,[29,57] there has been limited research comparing the different types of SUGS. Therefore, this study seeks to investigate how an emotional design approach can be applied to meet users' long-term environmental usage requirements. To achieve this, we employed measures such as Electroencephalography (EEG), as well as psychological reactions assessed through semantic differential (SD) and profile of mood states (POMS) questionnaires, along with a preferences questionnaire. The results of this study will enhance our understanding of how SUGS can influence the physiological and psychological states of residents. It is hypothesized that viewing SUGS will elicit different physiological and psychological effects compared to viewing leftover spaces.

In the upcoming sections, we will delve into the various aspects of this study. The materials and methods section will provide a comprehensive overview of participant selection, data collection, preprocessing techniques, and the classification methodology. Furthermore, we will present the specific features used for classification and discuss the validation approach adopted for our analysis. Subsequently, we will present the results obtained from our study, followed by an in-depth discussion of their implications. Through this, we aim to shed light on the preferences and perceptions of urban residents regarding vacant lands, and to provide valuable insights for future research and practical applications in the effective reuse and management of such spaces. By adopting this systematic and comprehensive approach, we strive to contribute to the advancement of sustainable urban design and planning practices.

Material and Methods

Methodology

The methodology employed in this study involved a comprehensive methodological framework to explore the resilience potential and opportunities for leftover spaces, assess intervention principles, and present resilience strategies. Both qualitative and quantitative research methods were applied to gather data and insights. The evaluation of concepts was based on public preferences, utilizing tools such as the EMOTIV system and visual questionnaires to capture how individuals perceive and observe landscapes. A mapping approach was employed to determine the alignment of subconscious visual behaviors with descriptive design intentions. The procedure was divided into 3 distinct phases: (1) selection of experimental images, (2) conducting experiments, and (3) analysis of EEG results data and survey responses. This methodology provides a systematic and rigorous approach to investigate the various aspects of leftover spaces and understand their potential for transformation into SUGS (Figure 1).

Phase 2, which comprises 9 sub-phases of experiments, began after providing the participants with a thorough explanation of the study's purpose, protocols, and the utilization of the equipment. The participants provided signed consent to participate after receiving a thorough explanation of the techniques. Participants were asked to sit in a chair while attaching the sensors and electrodes for physiological assessments. To test the reliability and stability of electrode recordings, participants were instructed to alternate between opening and closing their eyes in four 1-minute cycles. Prior to commencing the simulation, each participant was instructed to comfortably lie down with their eyes closed for 2 minutes to acclimatize their mood to the experimental environment.

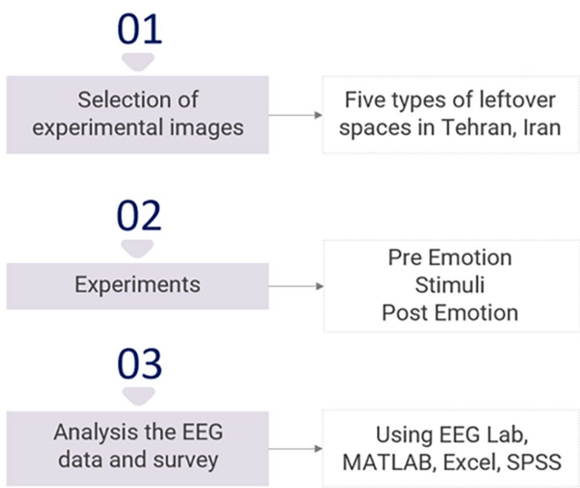


Figure 1. A schematic illustration of research process.

Additionally, the participants were guided to limit their bodily motions (to decrease the potential interference of irrelevant signals in the EEG measurements) and focus on the visual stimuli of a pre-defined scene or vacant land (control). Following the recording of physiological reactions, the participants were then instructed to fill out the Stroop and Profile of Mood States (POMS) questionnaires to assess their personal emotional and psychological reactions. The participants were first asked to view the leftover spaces, then they took a break before being asked to view the designed scenes. They were also asked to rate the intensity of their preferences on a 5-point Likert scale. Figure 2 illustrates the research procedure. The study was conducted on a within-subject basis, and each subject was exposed to both experimental conditions. The entire duration of the experiment lasted around 23 minutes.

Case study

An important focus of this study is the examination of leftover green spaces in Tehran, Iran, with a specific emphasis on managing small urban green spaces (SUGS). Given the limited availability of space in densely populated cities, adopting a resilience approach toward vacant lands becomes crucial. This research aims to investigate the effects of upgrading interventions at both the neighborhood and city scales, with the potential to apply these findings to other contexts.[58] The selected leftover spaces for this study are located in Tehran, the capital city of Iran. Geographically, Tehran is surrounded by the Alborz Mountains to the north and the central desert to the

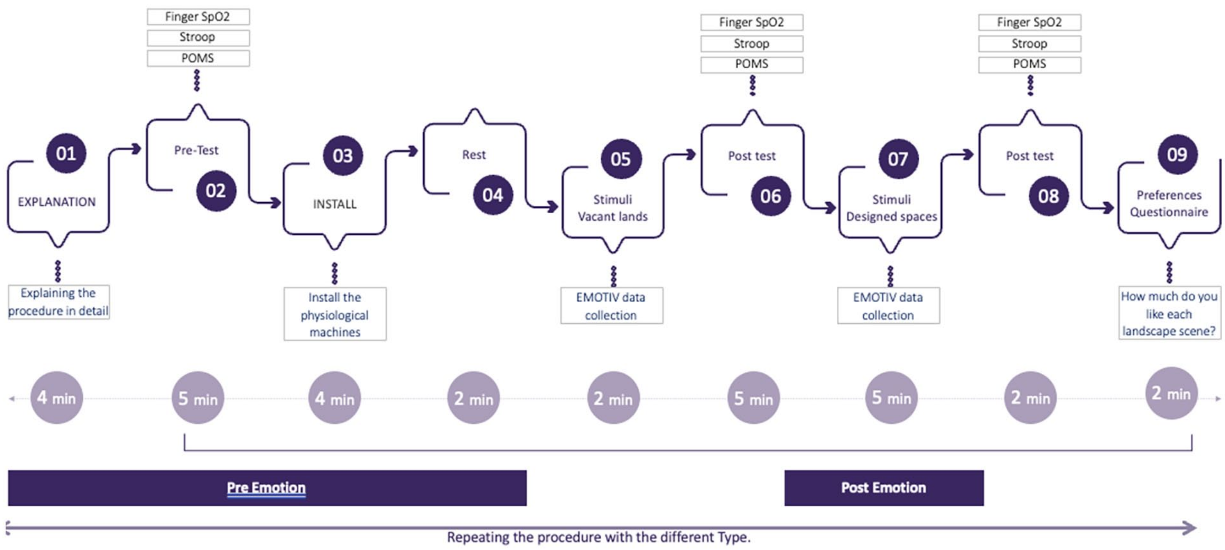


Figure 2. Research protocol.

Figure 3. The location of the case studies was conducted in Tehran, Iran.

south. With an estimated population of 8.7 million residents living in a metropolitan area of approximately 15 million people, the city of Tehran experiences rapid growth, leading to voids in the urban fabric due to uneven development. These undeveloped land parcels may remain vacant due to various reasons, including limited resources, absent owners, or challenging terrain and form. Understanding the dynamics of these leftover spaces in Tehran will contribute to the broader exploration of effective strategies for their management and transformation into vibrant SUGS (Figure 3).

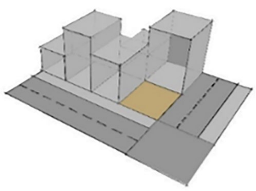
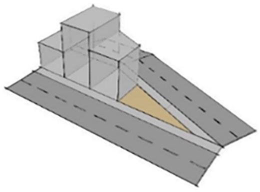
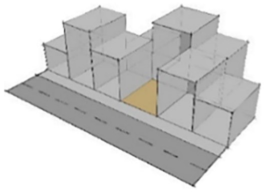
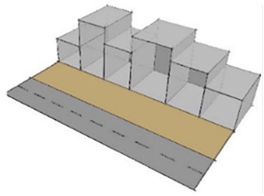
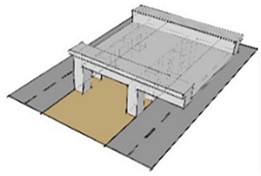
This study carefully selected a case based on several criteria, including the presence of vacant lands, proximity to the neighborhood, perception of being a leftover space by the residents, and uncertainty regarding its use. The site selection process involved conducting interviews with both citizens and experts to gather valuable insights. As indicated in Table 1, the chosen case studies encompassed various types of spaces, such as marginal areas, in-between spaces, spaces under bridges, and vacant lots. These specific case studies were deemed suitable for in-depth examination and analysis within the context of this research.

The study focused on 5 types of leftover spaces, each characterized by specific landscape elements and design interventions. These types included areas for planting, encompassing various tree species, bushes, and grass; spaces with furniture installations; locations with waterbodies, which could be either dynamic or static in nature; and sites featuring different landscape styles, ranging from regular to erratic designs. These design interventions served as reference points for evaluating and analyzing the impact of various elements on the leftover spaces under investigation (Figure 4).

Participants

Out of 386 participants who were engaged in the survey, a total of 33 healthy urban residents voluntarily participated in the EEG test for this study, in response to recruitment advertisements on social media platforms. However, after excluding 8 participants due to poor data quality, the final sample consisted of 25 valid participants (15 male, 18 female) with a mean age of 22.84 years (SD 1.50), after carefully evaluating the quality of the EEG recordings. The participant group was predominantly within the age range of 31 to 40 years, accounting for approximately 48.48% of respondents, followed by equal representation in the 41 to 50 and 51 to 60 age brackets at 21.21% each, and a smaller percentage (9.09%) aged 61 to 70. The vast majority of participants (81.82%) were not professionals.

Table 1. Leftover spaces in Tehran, Iran: a selection of types.

LOTS (REGULAR SHAPE)	LOTS (IRREGULAR SHAPE)	IN-BETWEEN SPACE	MARGINAL SPACE	UNDER BRIDGE
				
				

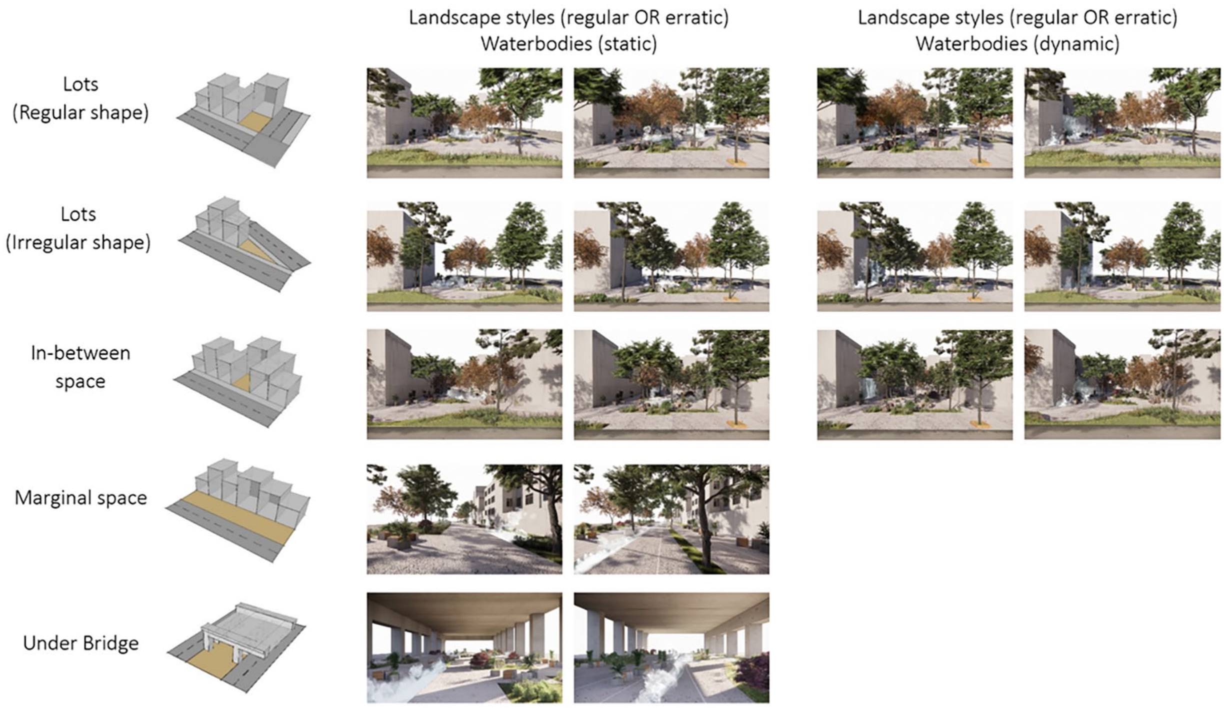


Figure 4. Design sixteen scenes for testbeds.

Just using data that was higher quality might lead to forms of bias associated with selection of certain types of participants with certain types of responses. The decision to exclude participants from the analysis was made after meticulously examining the data using the EEGLAB toolbox. Participants with significant artifacts in their EEG recordings, such as frequent eye blinks or muscle activity, were excluded to ensure data integrity. These exclusion decisions were made after a careful examination of the EEG data using independent component analysis to identify and remove artifacts.

Prior to the experiment, participants were provided with detailed information regarding the inclusion criteria and precautions, as established in previous studies.[59,60] These criteria ensured that participants did not have any cardiovascular or neurological disorders, metallic implants, potential chances of pregnancy, or a history of consuming street drugs. Furthermore, participants were required to abstain from consuming coffee, alcohol, and nicotine for 24 hours before the testing session. Participants who were undergoing treatment for any medical condition, experiencing their menstrual period during the study, or had habitual alcohol consumption were excluded from the study. All participants had normal or corrected-to-normal vision.[61]

Measurements

EEG-based emotion recognition for landscape assessment. Emotional responses play a significant role in various aspects of human daily life, including cognition, social interaction, perception, decision making, and behavior.[62] In this study, we utilized EEG equipment that has been extensively validated for landscape assessment[60] and emotion recognition[63] and has been employed in previous research studies.[61,64-66] EEG provides a non-intrusive and relatively high-resolution method for examining the brain's responses to external visual stimuli.[67] By measuring brain activity, EEG allows us to assess participants' emotional states and their responses to different landscape stimuli.

Assessing attention and psychological stress. Attention and psychological stress levels of the participants were evaluated using 2 psychological scales: the Stroop task[67] and the Profile of Mood States (POMS).[68] The Stroop task is a well-established and reliable measure of selective attention.[69] It requires participants to demonstrate high levels of attention, suppression, and task-switching abilities.[70] In this study, the color Stroop task was employed to assess participants' attentional ability. During the task, color names were presented on the screen in different font colors (e.g., the word "blue" displayed in red ink). Participants were instructed to identify the ink color while ignoring the word itself. The accuracy of their color identification was recorded, with higher scores indicating better attentional focus.

The 'POMS-SF questionnaire, a valid and reliable measure of mood states,[71] was used to assess participants' emotional states following visual stimuli. The POMS-SF is a shortened version of the questionnaire, designed to reduce the participant burden. Its content is easily understandable, adding to its advantages. The questionnaire consists of multiple subscales, allowing for the examination of participants' emotions across various dimensions. The subscale scores can then be grouped into categories such as "positive mood," "negative mood," and "total mood disturbance" (TMD), providing insights into participants' psychological well-being.

By employing the Stroop task and the POMS-SF questionnaire, attentional abilities and psychological stress levels of the participants were assessed, contributing to a comprehensive understanding of their cognitive and emotional states during the study.

Blood pressure, finger SpO2, and finger pulse rate. These physiological indicators were assessed to gain insights into participants' cardiovascular responses to the experimental conditions. A pulse oximeter, a non-invasive and harmless device,[72] was used to measure blood pressure, finger SpO2, and finger pulse rate. This device provides accurate and real-time readings of these cardiovascular parameters. Blood pressure measurement offers information about the force exerted on arterial walls, while finger SpO2 indicates the level of oxygen saturation in the blood. The finger pulse rate reflects the number of heart beats per minute. By employing the pulse oximeter, the study aimed to capture participants' physiological responses and examine any potential changes in blood pressure, finger SpO2, and finger pulse rate during the experimental procedures.

These physiological indicators were assessed to evaluate participants' cardiovascular responses before and after the to experiment. These measurements help to show that participants were in a normal situation and provide valuable insights into the impact of the experimental conditions on their cardiovascular system. Changes in cardiovascular responses, such as heart rate, blood pressure, and heart rate variability, can reflect the level of physiological arousal or stress experienced by participants during the experiment. By examining these indicators, researchers gain insights into the participants' overall physiological state and how it is influenced by the experimental conditions.

Preference. In this subsection, the measurement of participants' preferences for different image types is described. The aim was to gather information about the enjoyment level of the scenes presented to the participants. Participants' preferences were assessed using a five-point Likert scale question: "How much do you enjoy the scene?" The Likert scale ranged from 0 to 4, with 0 indicating "not at all" and 4 indicating "very."[67] This scale allowed participants to express their level of enjoyment or preference for each scene. By collecting data on participants' preferences, the study aimed to understand their subjective responses to the presented images. This information would provide insights into which image types were more preferred or enjoyable to the participants.

Experimental procedure

The study took place during the autumn (in October) of 2021 spanning over a period of 2 weeks. The timing of the experiment was determined based on participants' availability, allowing the experimental sessions to align with their schedules. In addition, participants were granted the option to modify or cancel their participation times in the study as per their convenience. In this study EEG signals were captured by the

Figure 5. EMOTIV EPOC+ 1.1 device used in this study (Emotiv Main Homepage. Available online: https://www.emotiv.com/ (accessed on 2 September 2021).

Emotiv Epoc Headset devices. Visual stimuli were presented on a 15-inch LCD monitor. Neuronal activity was recorded using a wireless EEG acquisition system (Emotiv EPOC). The device has a resolution of 14 channels (plus 2 reference channels) with a sampling frequency of 128 samples per second. The Emotiv EPOC has many advantages, including a low cost, a good signal-to-noise ratio, and ease of use.[73] Furthermore, the EPOC system has demonstrated satisfactory outcomes in various research investigations involving emotion recognition,[74] brain-computer interface,[75] and cognitive workload assessment.[76] The electrode positions are aligned with AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4, M1, and M2. M1 serves as the reference ground channel for measuring voltage across the other channels, while M2 functions as a feed-forward reference point to minimize external electrical interference. To ensure efficient conductivity between each electrode and the scalp, a saline solution was employed to reduce electrode impedance and enhance sensitivity, following the approach outlined by Duvinage et al.[73] Figure 5 presents the headset and the channel positions based on the international 10 to 20 EEG system of electrode placement (F3 and F4 of the frontal lobe control complex for cognition, language, emotion and behavior; T7 and T8 of the temporal lobe control audio and visual memory and language processing functions; P7 and P8 of the parietal lobe control sensory connection and reception; and O1 and O2 of the occipital lobe control all visual information).[77] On each experimental test, a spot from which the participants viewed the screen and took measurements was established before the experiment. The distance from the participants' eyes to the visual stimuli was 0.6 m.

Participants in this study were allowed to gaze freely while viewing a series of images representing either a designed park or a leftover space (control). The images were carefully selected to provide visual stimuli that captured the essence of each environment. To ensure a manageable testing time for participants, the images were presented in 2 sequences, depicting leftover spaces and designed scenarios of those locations. Each photo was displayed for a duration of 15 seconds. A blank blue slide was displayed for 5 seconds between each photo to reduce the carryover effect of the previous photo on participants' brain waves. During the image presentation, participants' brain activity was recorded using electroencephalography (EEG). The EEG signals were captured using electrodes placed on the scalp. To minimize irrelevant artifacts in the recording signal, such as blink and muscle artifacts, participants were instructed to avoid body movement and eye blinking during the image presentation.

Preprocessing and feature extraction

The recorded EEG signals were further processed to ensure high-quality data for analysis. The EEGlab, an advanced MATLAB toolbox, was used for preprocessing and artifact removal. Techniques such as Independent Component Analysis (ICA) were employed to identify and remove unwanted artifacts, such as eye blinks, from the EEG signals. This step aimed to enhance the reliability and accuracy of the recorded brain activity data (Figure 6).

After preprocessing, the 15-second signal for each image was divided into 7 disjoint intervals, each with a length of 2.5 seconds and the same label. This segmentation allowed for a more detailed analysis of brain activity patterns associated with emotion recognition in response to different environmental stimuli. The power of the EEG signal in each time interval was calculated for 5 frequency bands: Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta (13-30 Hz), and Gamma waves (30-45 Hz). This frequency band analysis provided valuable insights into the specific oscillatory activity patterns associated with emotional processing.

Classification

The extracted brain features were then subjected to *k*-fold cross-validation ($K = 10$), with ReliefF feature selection algorithm applied to select the top 20 features for each training set. The selected features were used to train an SVM classifier, with

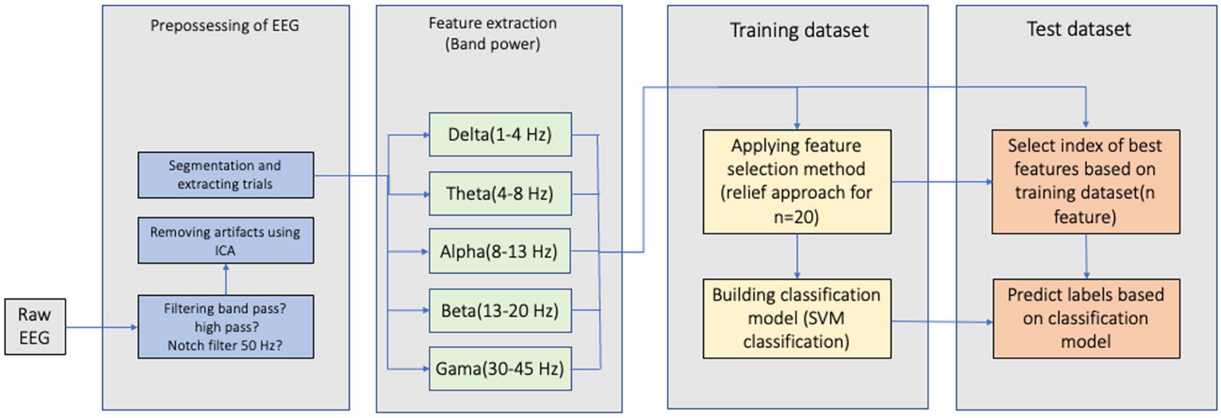


Figure 6. The unsupervised learning-based EEG decoding system.

each subject classified separately. During the classification, the confusion matrix was calculated to assess the discrimination of brain activity for emotion recognition between different groups. The confusion matrix presented the predicted and actual labels as percentages of the total number of images presented, allowing us to evaluate the performance of the classification algorithm in a more easily interpretable manner. In the representation of the confusion matrix plot, the rows depict the projected class (Output Class), while the columns depict the actual class (Target Class). Cells along the diagonal signify accurately categorized observations, whereas cells of the off-diagonal correspond to incorrectly classified observations. The percentage of correctly and incorrectly classified observations is shown in each cell. The column on the far right of the plot shows the percentages of all the examples predicted to belong to each class that were correctly and incorrectly classified. These metrics are often called the precision (or positive predictive value) and false discovery rate, respectively. At the base of the plot, the last row presents the proportions of all instances within each class, indicating the accuracy and inaccuracy of their classification. These metrics are commonly referred to as recall (or true positive rate) and false negative rate, respectively. The cell located in the bottom right of the plot signifies the comprehensive accuracy of the classification algorithm.

Additionally, the number of times each feature was selected during *k*-fold cross-validation was counted and normalized by the total number of folds in the cross-validation. This procedure resulted in a quantity for each of the 70 power-based features, indicating their importance in classification or discrimination between classes. The use of machine learning approaches, specifically the SVM classifier, allowed us to analyze complex patterns of brain activity and identify features that differentiate brain activity patterns in response to designed parks versus leftover spaces. The machine learning approach offers a fresh lens through which to understand how human perception influences urban vitality, as highlighted by Wu et al.[78] Consequently, this analysis provides new insights and understanding of the relationship between brain activity and emotional responses to different environmental stimuli, such as urban parks. The results of this study have the potential to inform the development of new strategies for creating urban environments that promote positive emotional experiences and overall well-being.

In addition to analyzing brain activity patterns in response to designed parks, we also applied a similar classification approach to assess the emotional impact of different types of leftover spaces. Specifically, we extracted power-based features from the EEG signals of participants who viewed images of Lots, In-Between spaces, Marginal areas, Micro Lots, and Under bridges. We then used the same *k*-fold cross-validation procedure with ReliefF feature selection to identify the top 20 features for each training set and trained an SVM classifier on these features for each subject separately. The resulting confusion matrix, presented in Figure 7, reveals distinct brain activity patterns associated with emotional responses to different types of leftover spaces. These findings shed light on the potential emotional impact of urban environments that are often overlooked or neglected in urban planning and design.

Results

Mood and emotions

To evaluate the impact of observing the leftover urban spaces, we conducted Wilcoxon signed-rank tests to compare the Profile of Mood Questionnaire scores before and after viewing the images. The test results revealed a statistically significant difference in the residents' Total Mood Disturbance (TMD) scores before and after observing the leftover spaces ($P < .01$). This indicates that the participants' moods significantly changed after viewing the leftover spaces. The paired-samples t-test between the positive emotions of the individuals also showed a significant increase after viewing both the leftover spaces ($P < .05$, Mean1 = 7.44, Mean2 = 8.43) and the designed parks ($P < .05$, Mean1 = 7.44, Mean3 = 6.58). However, no significant changes in negative emotions were observed after viewing the leftover spaces ($P > .05$, Mean1 = 3.39, Mean2 = 3.29). In contrast, there were significant changes in negative emotions after viewing the designed spaces ($P < .05$, Mean1 = 3.39, Mean3 = 3.89).

These findings suggest that observing the leftover urban spaces had a significant impact on participants' mood, leading to changes in both positive and negative emotions. The designed parks also influenced participants' positive emotions, but not to the same extent as the leftover spaces. The absence of significant changes in negative emotions after viewing the leftover spaces may indicate a different emotional response or a potential buffering effect of the environment. Further analysis is needed to explore the underlying factors contributing to these emotional responses in different urban environments (Figure 8).

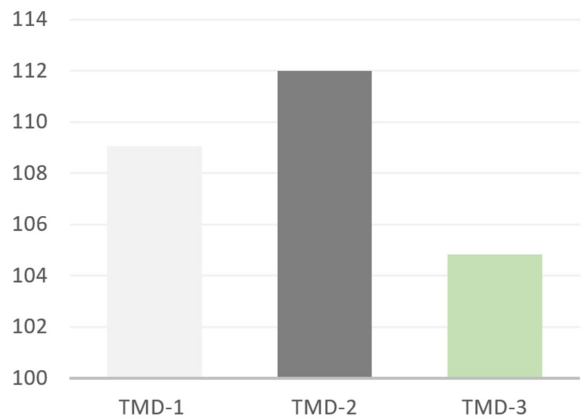


Figure 7. Total score of POMS in three stages: TMD-1 before start of the experiment, TMD-2 after observing the leftover spaces, TMD-3 after observing the designed spaces.

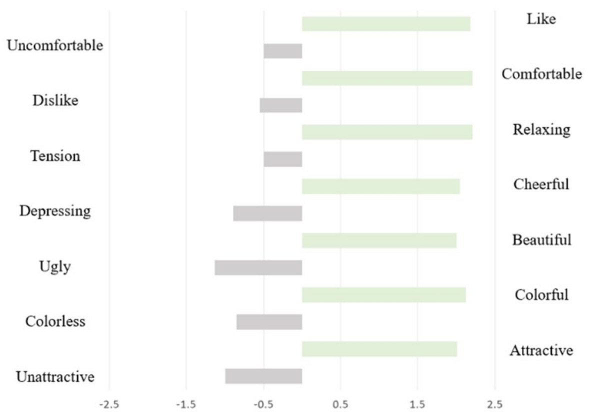


Figure 8. Comparison of subjective scoring for "attractive", "colorful", "beautiful", "cheerful", "relaxed", "comfortable", and "like" feelings between viewing a leftover space and green space.

Semantic differential questionnaire

The Semantic Differential (SD) questionnaire was used to assess participants' perceptions of the leftover spaces and green areas. Wilcoxon tests were conducted to compare the concepts and attributes for each pair before and after observing the different environments. The results revealed significant changes in all concepts and attributes after viewing both the leftover spaces and green areas. In comparison to the abandoned spaces, the green spaces received significantly higher scores for being "attractive," "comfortable and convenient," "beautiful," "colorful," "relaxing," and "cheerful" ($P < .01$). Participants expressed a preference for seeing more green spaces rather than leftover spaces ($P < .01$) (Table 2).

Furthermore, the comparison of mental emotions based on the Semantic Differential questionnaire indicated that participants reported more positive feelings and a greater sense of relaxation and comfort after viewing the green spaces as compared to the leftover spaces ($P < .01$). The data presented in Figure 9 demonstrates the favorable impact of viewing green areas on participants' emotional experiences.

These findings highlight the perceived differences in attributes and emotional responses between the leftover spaces and green areas. The green spaces were rated more positively in terms of attractiveness, comfort, beauty, colors, relaxation, and cheerfulness. Participants' preference for more green spaces further emphasizes the importance of incorporating natural elements in urban environments for promoting positive experiences and well-being.

Preference questionnaire

The internal consistency of the Preference Questionnaire was assessed using Cronbach's alpha coefficient, which measures the reliability of the questionnaire by examining the mean covariance or correlation among its items. The alpha coefficient was calculated separately for each subscale, and in all cases, it indicated high reliability of the questions ($\alpha > .84$).

Participants' preferences were analyzed based on the different types of designed spaces. A Likert scale was employed to score each question, ranging from −2 to 2, reflecting the degree of emotion experienced. Higher scores indicated stronger emotional reactions. The results showed that scenes 6 and 16 received the highest mean score (Mean = 4.27) among all the other scenes, as presented in

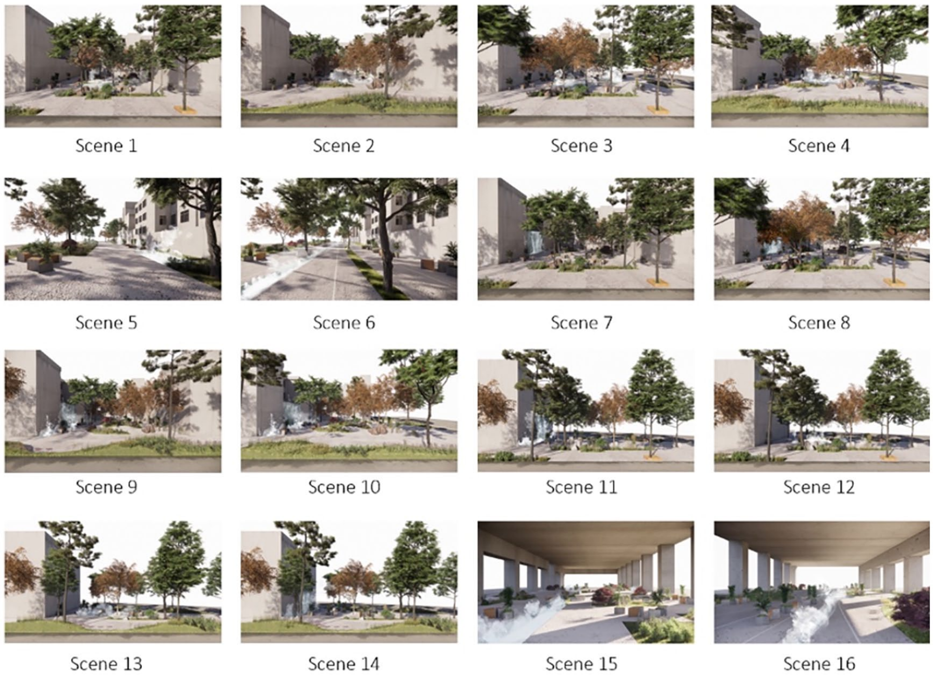
Table 2. The Wilcoxon between each pair of observations.

ATTRACTIVE – UNATTRACTIVE	COLORFUL – COLORLESS	BEAUTIFUL – UGLY	CHEERFUL – DEPRESSING	RELAX – TENSION	COMFORTABLE – UNCOMFORTABLE	LIKE – DISLIKE	
−5.121	−5.114	−5.155	−4.980	−4.587	−4.466	−4.905	Z
0.000	0.000	0.000	0.000	0.000	0.000	0.000	Asymp. Sig. (2-tailed)

n = 33, mean ± SE, $P < .01$ determined by the Wilcoxon signed-rank test.

Table 3. The Friedman test results of scenes preferences.

SCENE	MEAN	MODE	SD	DESIGNED PROTOTYPES
Scene 1	3.70	4	0.883	
Scene 2	3.73	5	1.069	
Scene 3	3.58	3[a]	1.091	
Scene 4	3.97	5	1.104	
Scene 5	3.67	4	1.109	
Scene 6	4.27	5	0.839	
Scene 7	3.06	3	0.933	
Scene 8	3.55	3	0.971	
Scene 9	3.73	4	1.126	
Scene 10	3.94	4	0.864	
Scene 11	2.88	2	1.166	
Scene 12	2.94	3	0.899	
Scene 13	2.97	3	0.918	
Scene 14	3.45	3	0.754	
Scene 15	3.76	4	1.173	
Scene 16	4.27	5	1.098	



[a] Multiple modes exist. The smallest value is shown.

Table 4. Compare means – independent-samples *t* test.

TYPES	TES VALUE = 0					
	T	DF	SIG. (2-TAILED)	MEAN DIFFERENCE	95% CONFIDENCE INTERVAL OF THE DIFFERENCE	
					LOWER	UPPER
In-between space	29.683	32	0	7.42424	6.9148	7.9337
Lots (regular shape)	21.327	32	0	7.54545	6.8248	8.2661
Marginal space	27.522	32	0	7.93939	7.3518	8.527
Lots (irregular shape)	28.091	32	0	5.90909	5.4806	6.3376
Under bridge	23.532	32	0	8.0303	7.3352	8.7254

Table 3. On the other hand, scenes 11 and 12 (Mean = 2.88, 2.94) were rated as less preferred compared to the other scenes.

To further analyze the data, a comparison of means was conducted using the independent samples t-test. The average scores of the 5 types of spaces were compared. The obtained significance level, which was less than 0.001, indicates that there is a significant difference between the means. The results confirm a significant difference between the means ($P < .001$).

These findings provide insights into participants' preferences for different types of designed spaces. Scenes 6 and 16 were the most preferred, while scenes 11 and 12 were relatively less favored. The significant difference in means suggests that individuals' preferences vary based on the characteristics of the designed spaces.

The pronounced preference for Scene 16, an under-bridge space characterized by its organic design, curved shapes, and winding paths, invites a focused exploration into the factors contributing to its appeal among participants. The "tunnel vision" in this scene—where the structural and landscape elements constrict and then expand the viewer's field of vision—plays a pivotal role in directing attention and creating a dynamic visual experience. The naturalistic features present in Scene 16 align closely with the principles of biophilic design, which emphasize human connections to nature through organic shapes, natural materials, and the mimicry of natural forms in the built environment. Designs incorporating biophilic principles have been shown to reduce stress, enhance creativity and clarity of thought, and improve well-being and expedite healing.

The curved shapes and paths in Scene 16, alongside the strategic narrowing and widening of the visual field, might subconsciously mimic the randomness and fluidity of natural landscapes. This offers an escape from the rigid, orthogonal forms typically found in densely populated cities and likely fosters a sense of intrigue and exploration. This design encourages users to engage more deeply with the space, as their attention is subtly guided through the environment, enhancing their overall experience.

According to the Attention Restoration Theory (ART) proposed by Kaplan and Kaplan,[79] environments that offer a sense of being away, fascination, extent, and compatibility are particularly restorative and preferred by individuals. Scene 16, with its incorporation of tunnel vision, might embody these qualities more profoundly by offering an escape from urban compression and providing a peaceful space.

The scene's layout and strategic use of tunnel vision likely enhance its accessibility and appeal, acting as a vital pause for individuals to reconnect with nature within urban density. This aligns with research suggesting that the design and accessibility of green spaces significantly impact their use and attractiveness. Such spaces offer urban dwellers a much-needed respite, enabling relaxation and social interaction, thereby heightening their appeal. By serving as a natural oasis, these areas provide a critical momentary escape from the urban hustle, emphasizing the importance of integrating natural sanctuaries into city landscapes for improved well-being.

Moreover, the under-bridge location of Scene 16 presents a unique utilization of often overlooked urban spaces. Transforming such areas into inviting green spaces, complemented by the dynamic experience of tunnel vision, can symbolize a reclaiming of urban areas for nature and community use. This potentially enhances participants' appreciation for the scene due to its innovative approach to urban design and attention management. This transformation suggests a bridge between the urban fabric and natural environments, providing a secluded haven that contrasts with the urban context above, possibly contributing to its high preference.

By adding the concept of tunnel vision to the analysis, we highlight how the directed focus and guided visual experience enhance the biophilic elements of Scene 16, enriching the user's engagement with the space. This addition strengthens the argument that thoughtful design can significantly impact our connection with and preference for urban green spaces.

EEG classification analysis

A support vector machine (SVM) classifier was used to assess the association between emotional states and EEG. First, we divided the samples of each participant into 80% training set and 20% test set, keeping the percentage of each class in the training and testing sets approximately the same as the original dataset (Figure 10). The EEG classification analysis aimed to differentiate brain activity patterns associated with viewing a designed park versus a leftover space (control condition). The results, as indicated by the confusion matrix, demonstrated an overall accuracy of 92.8% for the classification algorithm. The algorithm had an error rate of 7.4% in predicting Leftover and 7.0% in predicting Park, resulting in 92.6% and 93% correct predictions, respectively. Feature importance analysis revealed that gamma power (frontal and temporal areas), delta power (distributed across all channels or areas), theta power (frontal areas), and beta power (frontal and temporal areas) contained the most information about emotional processing. Among these features, gamma power exhibited the highest coefficient, with a value of 0.3 for the F3 channel. These findings align with previous research highlighting the significance of gamma, delta, theta, and beta power in emotional processing.[62,80-86] Gamma power has been associated with positive emotional experiences, such as joy and love, and has shown involvement in processing complex visual stimuli like natural scenes. Delta power has been linked to the processing of basic emotional stimuli, including facial expressions, while theta and beta power have been implicated in attentional processes and the regulation of emotional responses.

The second classification algorithm aimed to differentiate between 5 categories of leftover spaces. The overall accuracy achieved was 52.2%, with precision values of 60.1% for In-Between, 43.5% for Lots, 47.9% for Marginal, 51.5% for Micro Lots, and 57.8% for Under bridges. Feature importance analysis for this classification indicated that gamma power (frontal and temporal occipital and parietal areas) and beta power (frontal and occipital areas) contained the most information regarding psychological indices and physiological responses. The highest coefficient was observed for gamma and beta power in frontal channels, exceeding 0.2. These findings suggest that specific patterns of brain activity may be associated with emotional responses to different types of urban environments, particularly leftover spaces. The utilization of machine learning approaches, specifically the SVM classifier, enabled the identification of features that differentiate brain activity patterns in response to different categories of leftover spaces. These results provide novel insights and contribute to understanding the relationship between brain activity and emotional experiences.

In summary, the EEG classification analysis revealed high accuracy in differentiating brain activity patterns between a designed park and a leftover space. Furthermore, it demonstrated the potential for distinguishing emotional responses to different categories of leftover spaces. These findings contribute to the existing knowledge on the significance of urban design in promoting mental and emotional well-being.[87,88] Further research could delve into the neural mechanisms underlying emotional responses to urban parks and various urban environments, exploring how different design features may influence brain activity and emotional experiences.

Discussion

The objective of this study was to investigate the impact of green spaces on individuals' psychological responses and neural activity during emotion processing. Through a combination of subjective questionnaires and analysis of electroencephalogram (EEG) data, we aimed to explore the relationship between green spaces, subjective experiences, and neural processes. In this discussion, we will interpret and analyze the results obtained from both the questionnaires and the EEG classification, provide insights into the implications of these findings, and discuss the limitations and future directions of this study.

The analysis of the questionnaires revealed significant positive effects of green spaces on participants' psychological well-being,[89-91] and emotional experiences.[92-95] Participants reported feeling more comfortable, beautiful, attractive, relaxed, colorful, and cheerful when exposed to green spaces. These findings align with previous research that has highlighted the restorative and mood-enhancing effects of natural environments. The presence of green elements in urban environments seems to contribute to a sense of tranquility, aesthetic appreciation, and positive emotional states. It suggests that the integration of green spaces into urban design can have substantial benefits for individuals' subjective experiences and overall well-being.

The EEG classification results provided insights into the neural mechanisms underlying emotion processing in the context of green spaces. Our classification model, using the power of frequency bands as features, yielded promising results in differentiating between emotional states. The gamma band exhibited the highest classification performance, indicating its crucial role in capturing information related to emotion processing.[96] This finding is consistent with previous research that has associated gamma oscillations with visual cognition, emotion, attention, and memory.[97,98] The higher classification accuracy of the gamma band suggests its sensitivity to emotional stimuli and its potential as a neural marker of emotional states.[99-101]

Furthermore, the beta and delta bands also contributed significantly to the classification accuracy. The beta band has been implicated in emotional face processing and has shown differential responses to positive and negative emotions.[102,103] The involvement of the delta band, associated with deep sleep and cognitive processes, in emotion classification highlights its role in distinguishing between emotional states. These findings emphasize the complexity of neural dynamics during emotion processing and suggest that multiple frequency bands contribute to the discrimination of emotional states in the context of green spaces.

The integration of subjective questionnaire data and EEG classification results provides a comprehensive understanding of the emotional and neural impact of green spaces in urban settings. The positive subjective experiences reported by participants, coupled with the distinct neural signatures observed in the EEG data, suggest that green spaces have a significant influence on individuals' well-being and emotional processing. The findings support the notion that incorporating green elements into urban design can contribute to the creation of more pleasant, engaging, and emotionally fulfilling environments.

Overall, our study demonstrates the utility of machine learning approaches in analyzing complex brain activity patterns and identifying features that differentiate emotional responses to different environmental stimuli. By providing new

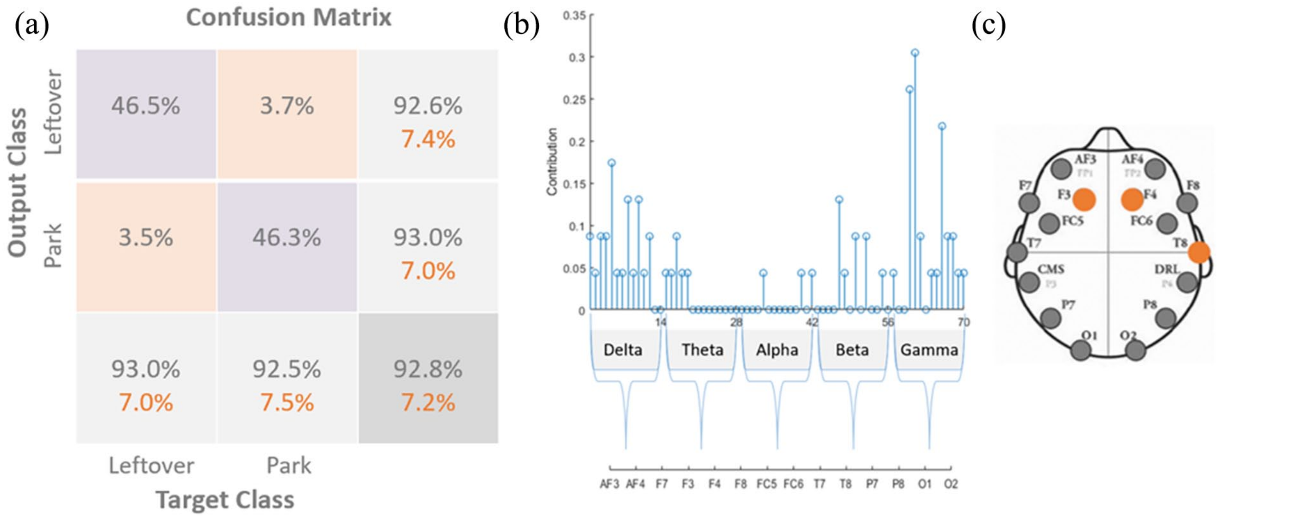


Figure 9. EEG-Based Classification of Leftover and Park Images. (a), shows a confusion matrix that visually represents the accuracy of classifying observations captured from EEG signals while participants viewed two kinds of images. This matrix allows us to observe both correct and incorrect classifications. Moving on to the second section marked as (b), we have an image illustrating the importance of different features during the classification process. This visual representation supports comprehension of the prominent features extracted from EEG data that play a crucial role in differentiating between Leftover and park images. Lastly, labeled as (c), indicate the electrode locations on the scalp during EEG recording. Notably, electrodes with distinct colors highlight their key roles in conducting accurate classification.

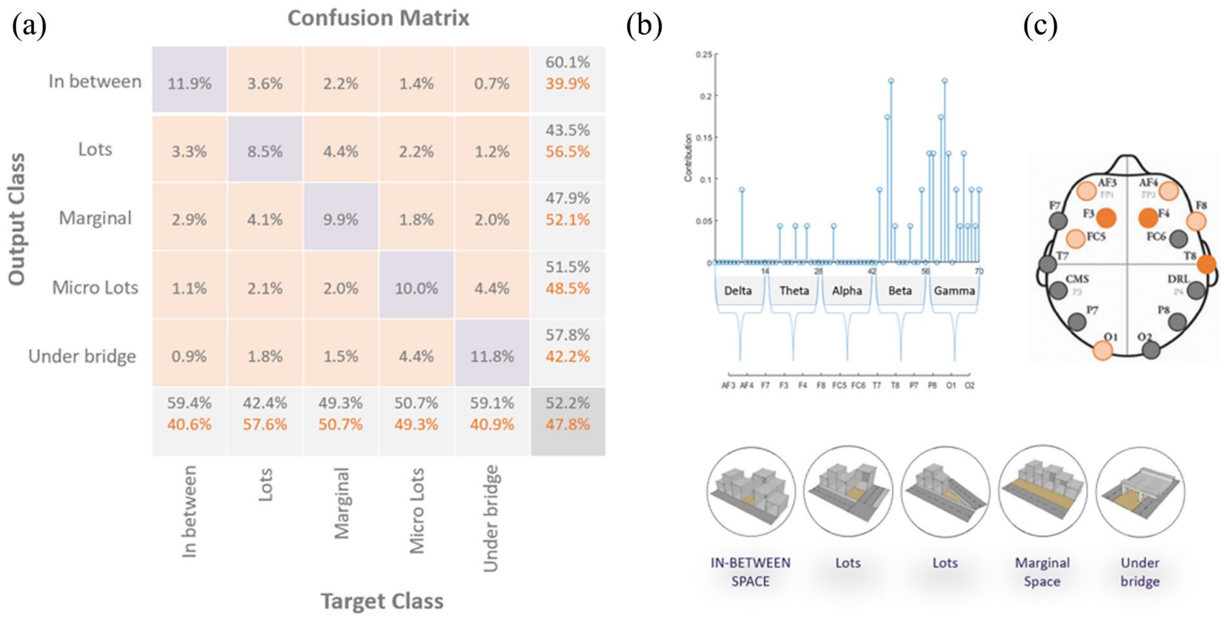


Figure 10. EEG-Based Classification of Different Types of Leftover Spaces. (a) displays a confusion matrix that visually represents the accuracy of classifying observations captured from EEG signals while participants viewed different types of leftover spaces. (b) illustrates the importance of different features during the classification process. representing the significance of various extracted features from the EEG data, helps us to realize the key factors that contribute to the differentiation between different types of leftover spaces. (c) the locations of electrodes on the scalp during EEG recording. Electrodes with distinct colors highlight their key roles in conducting accurate classification for different types of leftover spaces.

insights into the relationship between urban environments and emotional experiences, our findings have important implications for urban planning and design practices aimed at promoting well-being in cities.

The identification of the gamma band as a robust neural marker of emotion processing in green spaces opens up avenues for further investigation.[96] Future studies could explore the specific cognitive and affective processes associated with gamma oscillations during exposure to green spaces. Additionally, the role of other frequency bands, such as alpha and theta, in emotional experiences within green environments could be investigated to gain a more comprehensive understanding of the neural mechanisms at play.

Despite the valuable insights provided by this study, several limitations should be acknowledged. Firstly, the sample size was relatively small, limiting the generalizability of the findings. Future research with larger and more diverse participant groups would strengthen the robustness and validity of the results. Additionally, the study focused on a specific urban setting, and the findings may not be directly applicable to other cultural or geographical contexts. Replication studies in different environments would provide a more comprehensive understanding of the universal or context-specific nature of the observed effects.

Furthermore, while the questionnaire data provided valuable subjective insights, future studies could incorporate more objective measures, such as physiological responses and behavioral performance, to complement the self-report measures. This multi-method approach, including the integration of neuroimaging techniques like functional magnetic resonance imaging (fMRI) and other psychophysiological responses (e.g., heart rate variability, skin conductance), could provide a more comprehensive understanding of individuals' reactions to green spaces.

Conclusion

This study provides valuable insights into how design elements in urban environments influence human experiences in outdoor space. Furthermore, it sheds light on the impact of different types of SUGS on individuals' psychological responses and neural activity during emotion processing. The analysis of subjective questionnaires revealed the positive effects of green, and small recreational spaces on participants' psychological well-being and emotional experiences supporting previous research on the restorative effects of natural environments. The EEG classification results highlighted the crucial role of the gamma band in capturing emotional information, along with the contributions of the beta and delta bands. Additionally, participants reported feeling significantly more "comfortable," "beautiful," "attractive," "relaxed," "colorful," and "cheerful," along with experiencing positive mood states. These findings underscore the complexity of neural dynamics during emotion processing in green spaces. By integrating subjective questionnaire data and EEG classification results, a comprehensive understanding of the emotional and neural impact of green spaces in urban settings is achieved. This suggests that incorporating green elements into urban design can significantly enhance individuals' subjective experiences and overall well-being. Moreover, the identification of the gamma band as a robust neural marker opens up avenues for further investigation, exploring the specific cognitive and affective processes associated with gamma oscillations.

Also, this study focused on the emotional responses elicited by different categories of leftover spaces. The comparison of 5 leftover types revealed that residents held distinct preferences and perceptions for each type. In the context of transforming vacant areas into SUGS, the under-bridge space emerged as the preferred option among the various leftover spaces. Additionally, when comparing the 5 types in the current study, it was found that the beta and gamma waves exhibited greater significance.

These findings do not directly address the concept of "place" in the context of place attachment, nor do they explore traditional health outcomes. Instead, we have focused on immediate psychological responses and neural activities as proxies for the potential well-being benefits of SUGS, thereby contributing to the broader discussion on the value of integrating green spaces in urban planning for enhancing public psychological well-being.

According to Scannell and Gifford[104] the place dimension emphasizes the place characteristics of attachment, including spatial level, specificity, and the prominence of social or physical elements. This addition underlines the importance of considering place attachment in the context of urban green space development. Recognizing the multifaceted nature of place attachment—encompassing emotional bonds, memories, and identities tied to specific locations—can enrich our understanding of why certain spaces are preferred and how they contribute to individual and community well-being. Integrating this understanding into the planning and design of SUGS could further enhance their psychological benefits and ensure that these spaces meet the deeper emotional and social needs of the urban populace.

Moreover, the study's identification of specific types of SUGS preferred by participants points to opportunities for urban design with a focus on mental health. The preference for certain types of transformed spaces, like under-bridge areas, sheds light on the detailed preferences and perceptions that can inform more effective urban green space development.

This research goes beyond mere observation, revealing how SUGS positively influence individuals' well-being, emotional experiences, and neural responses. These findings highlight not only the importance but also the necessity of integrating modest community recreational areas in urban planning, due to their significant role in enhancing the quality of life. This study serves as a compelling call to action for urban designers and policymakers, urging the incorporation of green elements in urban landscape. It also opens new avenues for in-depth research into the cognitive and neural mechanisms that are activated by exposure to these green spaces. Ultimately, the integration of SUGS near residential areas emerges as a key strategy for fostering inclusive, vibrant, and health-promoting urban environments, significantly enriching human experiences, and enhancing overall societal well-being.

Limitations and future aspects

This study, while providing significant insights into the impact of small urban green spaces (SUGS) on psychological well-being, acknowledges several limitations that pave the way for future research. Firstly, the study's focus on immediate neural and psychological responses does not encompass long-term well-being effects or the concept of place attachment. Furthermore, this research was conducted in a controlled environment, which may not fully replicate the diverse and dynamic nature of urban settings.

Future research should aim to expand upon the initial findings presented here, potentially including a broader range of psychological and health outcomes to comprehensively assess the long-term impact of SUGS on well-being. Investigating the gamma band as a neural marker offers valuable insights into emotional restoration and cognitive processes in green spaces, known as SUGS environments. Furthermore, exploring additional neural markers beyond the gamma band could offer a more comprehensive understanding of how exposure to green spaces influence cognitive processes. Exploring the emotional and cognitive restoration through longitudinal studies and across diverse demographics can further enrich our understanding of SUGS's role in urban life. Studies exploring place attachment and its influence on the psychological benefits of green spaces could provide deeper insights into the emotional bonds that individuals form with urban environments. By refining the scope of the study to address the complexities of urban green space effects, subsequent research can continue to illuminate the critical interplay between urban design and public well-being.

Recommendations

Based on the findings of this study, we recommend the following for urban designers, policymakers, and future research:

1. Integrate SUGS into urban planning initiatives: Prioritize the development of SUGS, particularly in areas identified as preferred by the community, such as under-bridge spaces. This approach can significantly enhance urban livability and psychological well-being.
2. Community Engagement and Co-Creation: Smart technologies can facilitate greater community engagement in the design and development of SUGS. Digital platforms and apps can allow residents to express their preferences, suggest improvements, and participate in the co-creation of green spaces. This participatory approach ensures that the development of urban green spaces is aligned with local desires and perceptions, fostering a sense of ownership and a deeper connection to the urban environment, which is crucial for the long-term sustainability and effectiveness of these spaces in promoting public health.

3. Data-Driven Design for Healthier Environments: The use of smart technologies allows for the collection of large-scale data on how people interact with green spaces. This data can inform evidence-based design improvements that directly address public health concerns, such as enhancing features that promote physical activity or relaxation. Additionally, the integration of plant species that are known to improve air quality or reduce urban heat islands can be optimized based on the collected data, tailoring green spaces to community health needs and environmental benefits.
4. Interactive Health Monitoring Installations: By embedding environmental sensors and interactive displays in SUGS, urban spaces can become active participants in promoting public health. These installations can monitor air quality, temperature, and noise levels, providing real-time feedback to visitors. Such data-driven insights can raise awareness about environmental health, encourage healthier lifestyle choices, and foster a sense of safety and well-being. Public interaction with these displays can also be designed to reflect community health metrics, directly relating the quality of green spaces to community health outcomes.
5. Develop Virtual Reality (VR) Prototypes for Community Engagement: Use VR technology to involve communities in the design process by allowing them to experience and interact with virtual prototypes of proposed green spaces. This can help gather feedback and preferences before physical development, ensuring the final designs resonate deeply with community needs and desires.
6. Implement Gamification for Conservation and Education: Introduce gamified elements into SUGS, such as QR code scavenger hunts or mobile apps that reward users for learning about local flora and fauna or for participating in conservation efforts. This approach can foster a stronger connection between the community and urban green spaces, promoting education and environmental stewardship.
7. Personalized Wellness Experiences: Smart technologies enable the personalization of green space experiences, catering to individual health needs and preferences. For example, wearable device integration with green space infrastructure can offer personalized health recommendations, such as stress-relieving walking paths or sun exposure based on vitamin D requirements. This personalization aligns with the increasing demand for health-centric urban designs and enhances the public's perception of green spaces as integral to personal health and wellness.
8. Promote inclusive and accessible green spaces: Ensure that SUGS are designed to be inclusive and accessible to all members of the community, thereby maximizing their public health benefits.
9. Further research into the cognitive and emotional impacts of green spaces: Encourage interdisciplinary studies that explore the complex interplay between urban green spaces, cognitive processes, and emotional well-being. This includes investigating the role of various neural markers in emotional restoration.

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Author Contributions

Maryam Naghibi: Conceptualization, Methodology, Software, Investigation, Resources, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. Mohsen Faizi: Conceptualization, Validation, Writing, Supervision. Ashkan Farookhi: Methodology, Software, Validation, Writing – original draft, Visualization, Writing – review & editing.

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