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Interpreting regenerated post-industrial lands as green spaces: Comparing public perceptions of post-industrial landscapes using human factor design framework

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A B S T R A C T

Urban green spaces shaped by the post-industrial landscape possess distinctive characteristics and aesthetic features due to the exceptional properties of industrial remains. Previous studies have indicated that various types of urban green spaces without industrial remains, such as urban parks, waterfronts, and streets, have a positive impact on the public's physiological and psychological well-being. However, the extent and mechanisms of the public's response to post-industrial landscapes remain unclear. To investigate mechanisms of public perceptions of and preferences for post-industrial landscape types and elements, we conducted quantitative analysis by coupling multimodal data and comparative or difference analyses among urban green spaces. We conducted a randomized controlled experiment with 48 participants who viewed images of different combinations of post-industrial landscapes in a distraction-free environment. After a pause, Positive-Negative perception and Preference questionnaires were completed. Eye tracking data were recorded during the experiment. Changes in electrodermal activity and heart rate variability were used to measure physiological stress. This study employed Pearson's correlation model to examine the relationships between objective data and subjective data. The ANOVA test was utilized to investigate the variability of objective and subjective data across different groups. Additionally, a multiple-stepwise regression model was employed to analyze the specific influencing factors and their respective degrees of influence. We found that (1) artificial landscape elements in post-industrial landscapes were more appealing to participants and heightened their sense of stress; natural landscape elements can alleviate stress and promote restoration. (2) The percentage of flowering shrub and tree elements was significantly positively correlated with preference, while the percentage of ground-covering plant elements was significantly negatively correlated with preference. (3) Industrial construction was significantly positively correlated with the sense of historical value while industrial construction and pavement elements negatively correlated with preference. However, pavement elements significantly mitigated the sense of insecurity, poor accessibility, and pollution risk. (4) Industrial construction and pavement distinguished the post-industrial landscape from other green spaces without industrial remains while maximizing historical value and curiosity helped increase positive effects. Although impact mechanisms of natural elements in other green spaces without industrial remains showed homogeneous similarities, the scene composed of industrial mixed with natural elements may lead to different perceptions. Our findings indicate that multimodal data coupled with comparative analysis of multiple green space types can help to fully identify mechanisms by which landscape types and elements influence public perceptions and preferences. This understanding can help increase public satisfaction with post-industrial landscapes and enable researchers to determine the sustainability of post-industrial sites using interrogative design.

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1. Introduction

1.1. Urban green space effects on well-being

Exposure to nature or green space has been shown to have numerous psychological and physiological restorative benefits. It is well-documented, for instance, that nature reduces depression, anxiety, and aggression (Kuo and Sullivan, 2001a,b; McEachan et al., 2016), provides better sleep (Grigsby-Toussaint et al., 2015; Shin et al., 2020), greater happiness, well-being, life satisfaction (Ambrey, 2016), as well as lower blood pressure (Shanahan et al., 2016), improved eyesight (He et al., 2015), enhanced immune function (Li et al., 2010), and lower obesity (Stark et al., 2014). Adopting concepts of sustainable development, brownfield conversion, and redevelopment can resolve the inconsistency between the need for extensive green space and intensive land use (Loures and Panagopoulos, 2010; Loures, 2015). The Budapest Declaration regarded heritage protection, including industrial landscape, as an "instrument for the sustainable development of all societies through dialogue and mutual understanding." The sustainable post-industrial environment demonstrates the persistent presence of two fundamental principles: the implementation of a comprehensive and enduring planning process, and the active involvement and empowerment of various stakeholders (Landorf, 2009). Post-industrial lands have been used in various ways as redeveloped inner-city open spaces to provide sustainable opportunities for active engagement with the natural environment (Keil, 2005). The sustainable utilization of post-industrial land, without abandonment, would be driven by human usage and preference. The objective of this study is to investigate the comprehension of sustainability by examining the public's perceptions and preferences towards post-industrial landscapes. The aim is to establish a theoretical foundation for the sustainable utilization of post-industrial areas.

In general, urban green space can be characterized as publicly accessible land that is open and located within urban areas. Green space encompasses a variety of locations that are accessible to the public. These areas include parks, reserves, woodlands, riparian areas (such as stream and river banks), greenways and paths, community gardens, street landscapes, and so on (Roy et al., 2012; Wolch et al., 2014). Post-industrial landscapes could be classified within the wider scope of urban green space. However, the research findings don't incorporate industrial remains features in the context of urban green spaces, such as urban parks (Wang et al., 2016) and waterfront landscapes (Li et al., 2021). Compared to other types of urban green spaces without industrial remains, the post-industrial landscape not only contains industrial remains but may also have a unique spiritual significance, including local identity (Miles, 2005) as well as historical and cultural perception (Ruelle et al., 2013; Loures et al., 2016; Kim and Miller, 2017). Historical and cultural perception has recently grown in importance as an academic subfield of ecosystem services. Recent research has confirmed that the public values preserving industrial heritage as interest in heritage issues significantly increases (Swensen, 2012; Loures et al., 2016). However, due to their previous use, abandoned industrial sites may have real or perceived contamination and security issues (De Sousa, 2003; Mathey et al., 2018). The greater the authenticity of industrial areas, the greater the level of protection, and the more likely abandoned industrial sites are susceptible to negative perceptions of site contamination and safety hazards (Loures and Vaz, 2018). This can cause the public to feel uncomfortable when they visit such lands. Previous research has indicated that perceived danger may elicit positive emotions in some people (Herzog and Miller, 1998); a landscape that appears dangerous and stimulates a feeling of dread may be intriguing and therefore liked (Lis et al., 2019). Public perceptions and preferences are complex in relation to the specificity and complexity of the post-industrial site. Several studies have discovered significant negative perceptions of brownfields (De Sousa, 2003; Mathey et al., 2018). Some studies also found people with mixed feelings. Despite the prevalence of negative attitudes, some regard brownfields positively (Rupprecht et al., 2015; Mathey et al., 2018). It is crucial to investigate the public's perception and preference of landscape elements to sustainably transform post-industrial landscapes, an essential component of evidence-based design.

1.2. Dual artificial-natural aesthetic dimensions and human factors in sustainable design

Natural spaces, as opposed to artificially constructed features (Ulrich et al., 1991; Wherrett, 2000; White et al., 2010; Li et al., 2021), are frequently perceived as places that are beneficial to physical and mental health (Twohig-Bennett and Jones, 2018). They have been shown to enhance positive perceptions and well-being while reducing psychological stress and negative perceptions through natural encounters or experiences (Ulrich et al., 1991; Capaldi et al., 2014; Ambrey, 2016).

Previous research has suggested that our preference for natural environments with vegetation and water might be an evolutionary response to human experience (Kaplan and Kaplan, 1989). However numerous studies have categorized scenes into either natural or artificial (for discussion), where natural scenes were presented with a more positive visual aesthetic than artificial scenes, to induce greater preference, greater positive perception, and greater concentration (Purcell et al., 1994; Laumann et al., 2003; Tyrväinen et al., 2014). This has been demonstrated in studies of part of urban green spaces such as urban parks (Wang et al., 2016; Jahani and Saffariha, 2020), urban waterfronts (Li et al., 2021), urban green spaces (Wang et al., 2019), and other scenes. Additionally, the post-industrial landscape has a strong dimension of this artificial-natural dual aesthetic, distinguishing it from other green spaces where artificial elements can be a significant quality. Industrial resources include histories, transmit historical values, and shape the site's characteristics. Their fragility and scarcity allow them to retain the capacity to interpret and corroborate historical information (Jonsen-Verbeke, 1999; Muehlebach, 2017). Few studies have compared and analyzed post-industrial landscapes with other green space types, such as urban parks, waterfronts, and urban open green spaces to identify differences.

Numerous experiments have shown that industrial structures tend to make participants feel threatened, eliciting negative assessments. Interestingly, particular patterns and combinations of vegetation have been found to increase positive perceptions (Lafortezza et al., 2008; Rink and Arndt, 2016; Kim and Miller, 2017), which has focused a related discussion on participants' perceptions of artificial and natural elements in post-industrial landscapes. Few studies have focused on the problem of how to adjust the proportion of artificial and natural elements to modify the types or functions of artificial and natural elements to reduce participants' negative perceptions of artificial elements in post-industrial landscapes. However, these two aspects are crucial for the sustainable development of post-industrial land reuse and urban ecology.

Using concepts of evidence-based design and sustainability, we attempted to develop a descriptive model of the post-industrial landscape using human physiological and psychological characteristics. We added eye-tracking activities based on contemporary human factors techniques and quantitative empirical measurement data. The significance of visual landscapes extends beyond aesthetics to include their influence on emotional experience (Ulrich, 1979). This allowed us to compare and analyze it with other types of green space, drawing on more compelling solutions with similar content, and proposing solutions with different content to drive the design of post-industrial landscapes. The post-industrial landscape encompasses a combination of industrial and natural elements. The concept of industry traditionally encompasses the production logic, encompassing machine, manufacturing, efficiency, and transportation. It holds significant historical value, however, for most of the public, it remains a far-body cognitive category. Converting a derelict industrial site into a publicly accessible area with the near-body cognitive category poses significant challenges. The objective of this study is to explore the potential of human factors design in repurposing industrial remains for public activities. By incorporating recreational functions and ecological values, we aim to form a life logic that includes emotion, health, recreation, and equity. Ultimately, our goal is to establish a meaningful connection between industrial remains and the public, thereby creating a harmonious and balanced environment. We suggest new options to transform current urban industrial wastelands and enhance the design quality of post-industrial landscapes based on protecting and developing their "artificial-natural" dual attributes and aesthetic dimensions (Fig. 1).

1.3. Subjective and objective approaches to perception investigation and multimodal data coupling

Questionnaires have been used extensively to quantify the psychological perception of participants to determine landscape preference (Yuan et al., 2023), investigate stress recovery and mechanisms of health-promotion (Grahn and Stigsdotter, 2010; Deng et al., 2020b), and determine emotional correlations (Li et al., 2018). Even though the affective scales have been verified for reliability and validity, it remains challenging to eliminate the effect of an individual's subjective views. It has been shown that the emotional changes caused by viewing landscape scenes are related to physiological changes (Ulrich, 1979). As well, autonomous physiological responses such as electrodermal activity (EDA) and heart rate variability (HRV) induced by images can accurately reflect an individual's affective valence and stimuli arousal (Lang et al., 1993; Bradley et al., 2001).

By analyzing physiological indicators such as HRV, EDA, and salivary cortisol (sCort), researchers have examined the impact of stress recovery in various trials involving participants (Ulrich et al., 1991; Laumann et al., 2003; Jiang et al., 2014). Although independent physiological measurements could provide sufficient objective data support, subjective evaluations without participants are frequently understood to diverge from actual perception. Due to the constraints inherent in either independent psychological tests or physiological measurements, some researchers have included both in their studies. The respondents' EEG, EMG, and blood oxygen saturation have been monitored to examine physiological and psychological responses to different types of landscapes and stress recovery (Chiang et al., 2017; Lin et al., 2019). Using physiological data such as EDA, HRV, sCort, body temperature, and blood pressure, the effects of diverse landscape types and landscape features on human psychological and physiological activities have been examined (Tyrväinen et al., 2014; Li and Sullivan, 2016; Wang et al., 2016; Deng et al., 2020a).

When viewing a scene, eye-tracks are not merely a random collection of fixed locations but rather the outcome of selective attention (Dupont et al., 2016). People always concentrate on the objects they like (Firestone and Scholl, 2016). Eye tracking has been used extensively in psychology, geography, and other fields of study (Müller et al., 2012; Sun et al., 2018). In landscape architecture, eye tracking combined with factor analysis has the potential to identify characteristic patterns of participants in landscape observation trials (De Lucio et al., 1996). Several studies have explored the difference in attention and visual evaluation of participants in diverse landscapes using eye tracking and questionnaires (Amati et al., 2018; Liu et al., 2019; Chen et al., 2022). Numerous studies supported the potential connection between eye tracking, landscape preference, and perception. (Dupont et al., 2015, 2016; Amati et al., 2018). The elements and forms of post-industrial landscapes are unique, making it worthwhile to investigate eye-tracking responses.

Psychological tests investigate psychological perception and preference, and physiological measurements reflect the degree of affective valence and stimuli arousal via physiological autonomy. Eye-tracking techniques characterize visual preferences by identifying selective attention. These three methods have been used to characterize the subjects' preferences with distinct emphases, however, few studies have simultaneously tracked them. We used all 3 of these methods simultaneously, combining objective and subjective approaches to realistically measure public perceptions and preferences in a comprehensive, which can help determine mechanisms of landscape restoration and transformation in post-industrial areas, to encourage the sustainable growth of post-industrial abandoned areas to turn brown into the green.

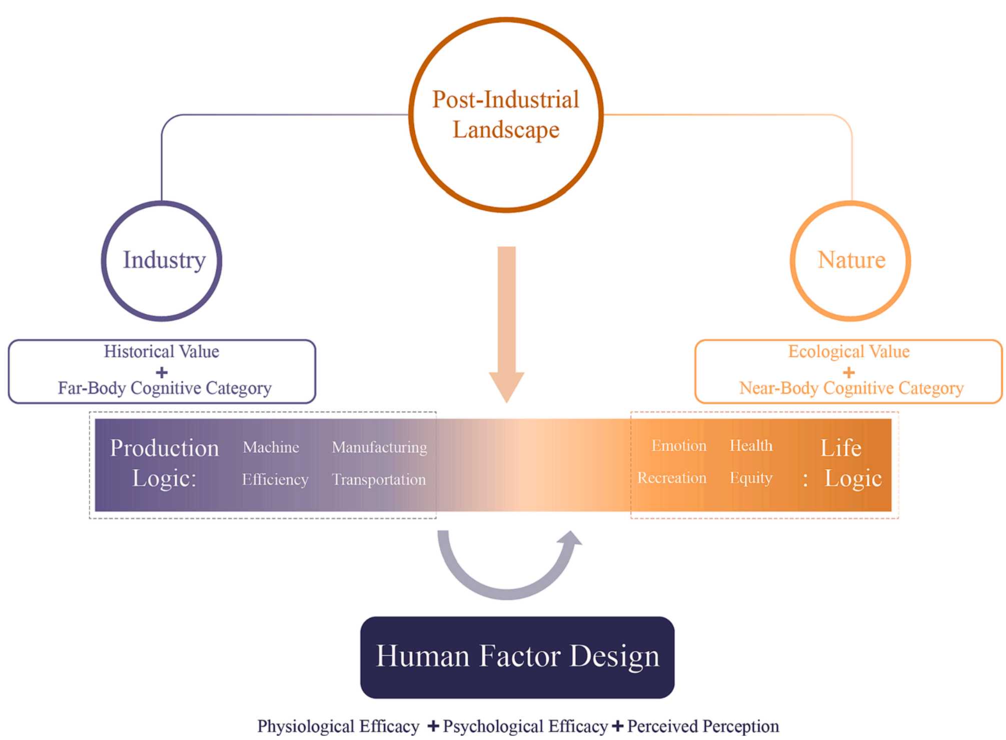

Fig. 1. Framework of the post-industrial landscape and human factors evidence-based design.

2. Materials and methods

2.1. Visual stimuli design

With visual stimuli as a substitute for the actual landscape, image manipulation has been widely used in research due to the advantage of controlling the experimental environment from extraneous factors such as on-site people and weather, as well as being simple to operate and feasible (Cañas et al., 2009; Deng et al., 2020b). We selected Shougang Park in Beijing, China as the location for a visual landscape for experimental samples. The Shougang Park, formerly a substantial steel manufacturing factory, served as a prominent hub of industrial activity in northern China during the modern era, contributing significantly to the region's economic achievements. As one of the first pilot projects to move and modify an old urban industrial zone, the park has been converted into a modern industrial integrated service area that combines sports, technology, business, and entertainment with the concept of green and ecologically sustainable development. Currently, this location holds significant prominence as one of Beijing's foremost cultural icons, owing to its rich blend of industrial culture and Winter Olympics culture. It enjoys widespread popularity among visitors and locals alike. The transformation and upgrading of the city's industrial districts exhibit characteristics of representativeness and typicality. Abandoned iron and steel factories are frequently encountered in post-industrial landscapes, and the Shougang Park exemplifies the transformation and upgrading of urban industrial areas. Its research on transformation and upgrading holds the potential for broader applicability to old industrial zones in numerous cities.

We photographed all building groups at the industrial site in Shougang Park. Following evaluation by landscape experts, the building group that best depicts the post-industrial site chosen by experts was the original in every image as the visual center. To assess the physiological responses, emotional perceptions, and aesthetic preferences of the visual stimuli generated among landscape types, we manipulated the original photographs to create 20 images with various combinations of five landscape element variables (plant height, percent industrial construction, percent pavement, intensity of human intervention, and vegetation type and density) (Fig. 2).

The plant height group includes image A,B,C,D, where the industrial remains remain unchanged and the plant heights show a gradual incremental gradient. The industrial construction group includes image E, F,G,H, where the natural environment remains unchanged and the industrial constructions show a gradual incremental gradient. The pavement group includes image I,J,K,L, where the industrial remains and natural elements remain unchanged and the pavements show a gradual incremental gradient. The intensity of the human intervention group includes image M,N,O,P, where the industrial remains remain unchanged and the level of human intervention in roads leading to industrial sites is diminishing, while the incorporation of natural elements is increasing gradually. The vegetation type and density group includes Q,R,S,T, where the industrial remains remain unchanged and the vegetation situated on either side of the road leading to the industrial site exhibits an increasing diversity and color in its appearance.

2.2. Measurements

In this study, both objective and subjective data were collected (Table 1).

2.2.1. Physiological measurements

Using baseline measurements and physiological signal markers, physiological measurements can objectively, precisely, and

Fig. 2. Twenty images for visual stimuli design.

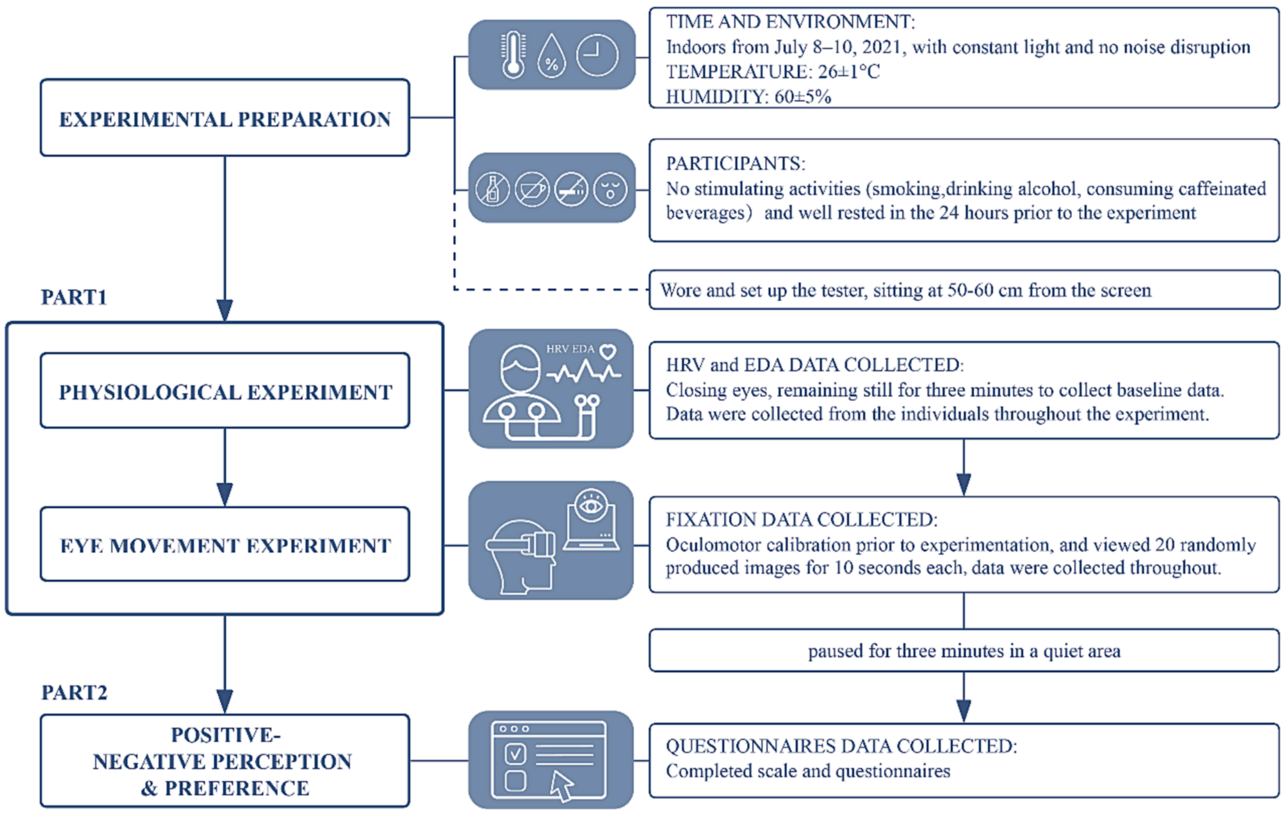

Fig. 3. Flowchart of procedure.

Table 1
Indicators of objective and subjective data.

Objective Indicator (Machine Learning)	Abbr	Objective Indicator (Physiological and eye tracking measurement)	Abbr	Subjective Indicator	Abbr
Percentage of artificial elements	PAE	Time to First Fixation	TTFF	Positive perception	PP
				Negative perception	NP
Percentage of natural elements	PNE			Sense of comfort and relaxation	SCR
Percentage of industrial constructions	PIC	First Fixation Duration	FFD	Sense of natural wilderness	SNW
Percentage of pavements	PPV			Sense of curiosity	SCI
				Sense of visual aesthetic	SVA
Percentage of ground-covering plants	PGP	Value of TTFF and FFD	TTFF-FFD	Sense of historical value	SHV
				Sense of ecological value	SEV
Percentage of flowering shrubs	PFS			Sense of insecurity	SIS
		Total Visit Duration	TVD	Sense of poor accessibility	SPA
Percentage of trees	PH			Sense of pollution risk	SPR
		Total Fixation Duration	TFD	Sense of disturbing visual effects	SVE

continuously record a participant's physiological state without interfering with the testing procedure while accurately predicting behaviour (Papinutto et al., 2020). In this study, we chose to measure the physiological indicators of EDA and HRV, which are the more widely used methods for quantifying physiological stress and objective emotional representation among participants (Jiang et al., 2014; Li and Sullivan, 2016; Wang et al., 2016).

We used the electrodermal skin conductance level (SCL) index in the study to assess the degree of emotional arousal. The SCL response is determined by measuring the electrical flow on the skin's surface, which varies with sweat efficiency. When a person is aroused, the sweat glands on their skin secrete more water, and the SCL value rises (Reinhardt et al., 2012). A high density of sweat glands occurs in the palms of the hands or feet (Setz et al., 2010). The electrodermal response is related to the psychological state and is directly related to the degree of arousal (Boucsein, 2012). Numerous physiological measures have demonstrated that the electrical skin response elicited by an image is positively correlated with the degree to which the image arouses the observer and can objectively reflect the emotional change (Lang et al., 1993; Bradley et al., 2001).

The LF/HF index has been used to evaluate emotional stress conditions. It was determined using neurobiology that HRV is altered by stress and can be used to objectively assess the degree of psychological stress (Kim et al., 2018). HRV is also an essential characteristic of physiological signals in individuals under stress, with a rapid and significant increase in stressed participants (Sánchez-Navarro et al., 2008). In the HRV frequency domain, the LF band is regulated by both sympathetic and parasympathetic activity, whereas the HF band corresponds to parasympathetic activity. The LF/HF ratio is considered the most prominent feature of HRV, with a significant increase in LF/HF when participants are stressed (Castaldo et al., 2015; Giannakakis et al., 2022).

All participants were supplied with wrist, finger, and earlobe receivers to measure EDA and HRV signals recorded by feedback equipment (manufactured by KINGFAR International Inc, China) throughout the experiment.

2.2.2. Eye-tracking experiments

In this experiment, eye movement was tracked using a non-contact, high-precision, desktop eye-tracking device (Tobii Fusion 250 Hz) with a high sampling rate, high stability, and little interference from light and motion. Using semantic segmentation determined by deep learning algorithms based on a training model, we established two areas of interest (AOI) prior to experiments: artificial and natural. The Ergo LAB human–machine environment synchronization cloud platform (KINGFAR International Inc) continuously records and visualizes the participant's fixation using the measured HRV and EDA data. Data on eye tracking included time to first fixation (TTFF), first fixation duration (FFD), total visit duration (TVD), and total fixation duration (TFD).

A lower TTFF implies a shorter duration, suggesting that the topic was the initial entity to address it. The FFD refers to the length of time that a subject initially directs their attention towards a certain AOI. This metric can be used to assess and describe the subject's tendency to prioritize attention towards certain stimuli. The utilization of the FFD in conjunction with the TTFF can serve as an indicator of initial scene detection and sustained attention. If the TTFF is brief and the FFD is extended, the region in question probably possesses a high degree of fascination or appeal. The variables TVD and TFD denote the cumulative durations of visits and gazes on AOIs, respectively. Higher values of these variables indicate a stronger level of interest (Nordh et al., 2009; Behe et al., 2013; Zhang, 2022).

2.2.3. Positive and negative perception scales

Twenty images in the questionnaire were used to measure "positive perception" (PP) and "negative perception" (NP). Following this study, the PANAS scale (Positive and Negative Affect Schedule) (Watson et al., 1988), PRS (Perceived Restorative Scale) (Hartig et al., 1997), and PSD scale (Perceived Sensory Dimensions) (Grahn and Stigsdotter, 2010) were integrated to establish positive and negative perception scales for post-industrial landscape elements. The positive perception scale contains six questions on the sense of comfort and relaxation (SCR), sense of natural wilderness (SNW), sense of curiosity (SCI), sense of visual aesthetic (SVA), sense of historical value (SHV), and sense of ecological value (SEV). In comparison, the negative perception scale contains four questions on the sense of insecurity (SIS), sense of poor accessibility (SPA), sense of pollution risk (SPR), and sense of disturbing visual effects (SVE). Participants answered whether they had a positive or negative perception based on their perceptions of the landscape in the 20 images, where 0 means "no such perception" and 1 means "perception".

2.2.4. Landscape aesthetic preference investigation

We also gathered data on participants' preferences for 20 images. Preferences were measured on a five-point Likert scale "How much do you like this image? " with zero representing "don't like it at all," one representing "don't like it," two representing "don't like it but don't hate it," three representing "like it," and four representing "like it very much."

2.2.5. Objective indicator by machine learning

A training model based on the ADE20K dataset and a null convolutional neural network (Deeplab v3+) combined with the Xception65 model was used to semantically separate the 20 images by deep learning methods to estimate the elemental perception of visual stimuli. The ADE20K dataset, as described comprises 150 distinct semantic tag categories (Zhou et al., 2017). It enables the classification and identification of various natural elements, including water, trees, flowers, shrubs, and under-grounding features. Additionally, it encompasses artificial elements such as buildings and pavements. Consequently, this dataset adequately caters to the requirements of semantic segmentation in post-industrial landscape parks, offering a comprehensive solution (Wei et al., 2023). Therefore, we classified the objective content depicted in the images into two categories: artificial element and natural element based on the results obtained from semantic segmentation using machine learning techniques. Artificial element (PAE) indicators could be composed of industrial constructions (PIC) and pavement (PPV). Natural element (PNE) indicators could be composed of ground-covering plants (PGP), flowering shrubs (PFS), and trees (PH).

2.3. Participants

Forty-eight participants were selected to engage in the experiment. Participants' ages ranged from 18 to 39, and all had at least a bachelor's degree in urban planning, landscape design, or a plant design-related major. They could accurately interpret the landscape element-related entries on the affective association scale of this study. The participants had corrected or uncorrected visual acuity greater than or equal to 0.8, no color blindness, color weakness, strabismus, or evident eyelid ptosis, and exhibited regular blink frequency, normal eye size, no history of psychiatric-related disorders, and were in good health. All experimental techniques were disclosed before the trial and all participants were informed and consented to participate. Data collection process adhered to all ethical criteria.

2.4. Procedure

The field experiment was conducted indoors from July 8–10, 2021, with constant light and no noise disruption. The room temperature and humidity were adjusted to 26 ± 1 °C and 60 ± 5 % during the experiment. The experiment consisted of a visual stimulation trial of 20 images and a questionnaire-completion experiment. Before beginning the experiment, we ensured that the participants had not engaged in stimulating activities, such as smoking, drinking alcohol, or consuming caffeinated beverages and that they were well rested in the 24 h prior to the experiment.

In the first part of the experiment, 48 participants wore and set up the HRV and EDA tester in turn, sitting at 50–60 cm from the screen, calibrating the eye-tracking device, then closing their eyes, and remaining still for three minutes to collect baseline data. Next, the participants viewed 20 randomly produced images for 10 s each on a computer monitor. EDA, HRV, and fixation data were collected from the individuals throughout the experiment. After completing the first part of the experiment, the participants paused for three minutes in a quiet area to complete the Positive-Negative Perception Scale and Preference Questionnaires. The duration of the experiment was regulated to ensure that participants were able to finish it comfortably within a period of 35 min.

2.5. Data processing

2.5.1. Physiological data processing

R-point extraction includes R-peak extraction, ectopic detection, and ectopic correction using the Ergo Lab human–machine environment synchronization cloud platform (Designed by KINGFAR) for HRV and EDA data filtering and denoising. We obtained 43 complete physiological signals all of which were normalized for subsequent analysis.

Electrodermal activity (EDA): In our study, the change in EDA in response to visual stimulation for each image was measured as the difference between the maximum SCL value in each image and the baseline SCL value for that image. A positive result indicates that the participant is aroused by the image, with a more significant value indicating greater arousal. A negative value indicates that the participant is not aroused by the image.

Heart rate variability (HRV): In this study, the LF/HF ratio in each image was chosen to indicate the amount of change in the participant's HRV in response to the visual stimuli, with larger values representing more intense duress and smaller values representing less extreme duress in the participant's response to each image.

2.5.2. Eye-tracking data processing

We completed quantifying and processing the eye tracking data using the Ergo Lab human–machine environment synchronization cloud platform with 43 sets of complete eye tracking signals. All measurements were chosen and normalized for further analysis. The platform was also used to build eye-tracking maps that directly reflected the image's visually appealing sections and the participants' visual movement trajectories.

2.5.3. Subjective perception data processing

The data of Positive-Negative perception and preference scales were coded and standardized, and outliers were identified and replaced with pluralities using an interquartile range (IQR) outliers identification model. The data were analyzed using a Shapiro-Wilk test, which revealed absolute kurtosis and total skewness values both less than two, indicating a normal distribution with good reliability.

2.6. Data analysis

The Pearson's correlation model was used to test relationships between objective data (image element percentage data from deep learning semantic segmentation, physiological data including HRV and EDA, and eye tracking data), subjective data (positive–negative perception scale data, and preference scale data), and their interactions. We used ANOVA to explore the variability of objective and subjective data in industrial heritage and pavement groupings, followed by a multiple stepwise regression model to investigate the specific influencing factors and their degree of influence, as well as constructing a post-industrial landscape perceived preference evaluation model based on coupled multiple data.

3. Results

3.1. Eye-tracking experiments

We analyzed 860 validated post-standardized eye tracking data points. The average time to first fixation (TTFF) spent in the artificial AOI was significantly shorter than TTFF in the natural AOI, which was only 45 % of its duration. The average first fixation duration (FFD) in the artificial AOI was longer than that in the natural AOI, which was 187 % of its duration. TTFF is used in combination with the FFD measure. When TTFF is shorter and FFD is longer, the region is likely to be particularly captivating, meaning the artificial AOI immediately captures, and continues to hold the participant's attention. TVD is positively associated with landscape visual appeal. The average total visit duration (TVD) of participants in the artificial AOI was slightly longer than those in the natural AOI, indicating that the artificial AOI was more appealing to the participants throughout the experiment, as supported by the eye-tracking track map which was achieved by superimposing the eye-tracking track data of all participants to build generate group eye-tracking track supported by the Ergo LAB human–machine environment synchronization cloud platform (Fig. 4).

The semantic segmentation results were clustered, with the artificial group containing elements of industrial construction and pavement and the natural group containing elements of ground-covering plants, flowering shrubs, and trees. Artificial TVD increased as the percentage of artificial elements increased from 6.39 % to 26.94 %. Natural TVD increased significantly as the percentage of artificial elements increased from 30.5 % to 35.86 %. Presumably, the critical interest value for the manual percentage fell between 26.94 % and 30.55 %. As the natural percentage rose, artificial FFD was always longer than natural FFD. The artificial and natural TVD increased alternately, and the duration of the

Fig. 4. Eye-tracking track map.

natural TVD decreased, then increased, and then decreased again as the natural percentage increased. When the natural percentage reached 86.58 %, the natural TVD was longer than the artificial TVD.

The artificial TVD increased as the percentage of industrial construction element rose from 6.39 % to 26.94 %. In contrast, the natural TVD increased significantly when the industrial construction percentage decreased significantly, with an increase of 32.77 % to 35.86 %. We assume that the critical value of the interest in the percentage of industrial construction was between 26.94 % and 32.77 %. When the percentage of pavement elements is 0, the artificial group contains only industrial construction elements. In this case, the participants' TVD for industrial construction was longer than the natural AOI, and TTFF was less, indicating that industrial construction elements were more likely to attract and hold the participants' attention. As the percentage of flowering shrub elements increased, artificial FFD was always longer than natural FFD, but when it exceeded 20.49 %, natural TVD was longer than artificial TVD in the range of 20.49 % to 34.42 %. It was important to note that the natural TVD was over two times higher than the artificial TVD when the percentage of flowering shrubs was 34.44 %. When tree elements were included, the natural TVD gradually rose as their percentage rose; when the percentage of trees exceeded 55.42 %, the natural TVD was longer than the artificial TVD.

In brief, it was shown that artificial AOI first captured the attention of participants and consistently maintained a higher level of attraction compared to natural AOI. However, further analysis indicated that the degree of mutual interest between artificial and natural AOI might vary, with some instances showing a higher level of interest and others showing a lower level.

3.2. Physiological effect activities

We found significant negative correlations between EDA and the percentage of industrial construction, HRV and the percentage of natural elements, and significant positive correlations with the percentage of artificial elements (Table 2). This indicated that participants felt less stress with an increasingly higher percentage of natural elements, but greater stress as the percentage of artificial elements increased. The percentage of industrial construction in artificial elements decreased the individuals' arousal.

We found significant negative correlations between EDA and natural TVD, and significant positive correlations with artificial TVD (Table 3). The relationship between HRV and eye-tracking data was not significant. This indicated that the longer a participant was fixed on the artificial AOI, the greater the EDA arousal. When a participant observed a natural AOI for a more extended period, the level of EDA arousal decreased.

3.3. The influence of the percentage of natural and artificial elements

We found that preferences were significantly positively correlated to all six positive perceptions and negatively correlated with all four negative perceptions. Further stepwise regression analysis of perceptional indicators was performed to identify the dominant factors influencing preferences and constructed stepwise regression models with p-values less than 0.001. After automatic model elimination and combination, a stepwise regression model was built using eight indicators of sensation (comfort and relaxation (SCR), natural wilderness (SNW), curiosity (SCI), visual aesthetic (SVA), ecological value (SEV), insecurity (SIS), pollution risk (SPR), and disturbing visual effects (SVE)). These explain 53 % of preferences, excluding the sense of historical value (SHV) in the positive perception and the sense of poor accessibility (SPA) in the negative perception.

Table 2
Correlation between physiological data and semantic image percentage.

Indicator	HRV(LF/HF)	EDA(ΔSCL)
Percentage of natural elements	−0.061(0.074*)	0.042(0.214)
Percentage of artificial elements	0.061(0.074*)	−0.042(0.214)
Percentage of industrial constructions	0.044(0.194)	−0.068(0.045**)
Percentage of pavements	0.043(0.212)	0.013(0.707)
Percentage of ground-covering plants	0.013(0.693)	−0.045(0.191)
Percentage of flowering shrubs	−0.054(0.112)	0.018(0.608)
Percentage of trees	−0.019(0.570)	0.052(0.130)

Table 3
Correlation between physiological data and eye tracking data.

Indicator	HRV(LF/HF)	EDA(ΔSCL)
TTFF of artificial AOI	0.030(0.374)	−0.023(0.498)
TTFF of natural AOI	−0.014(0.673)	0.050(0.143)
FFD of artificial l AOI	−0.001(0.981)	−0.017(0.626)
FFD of natural AOI	0.001(0.971)	−0.020(0.561)
TTFF-FFD of artificial AOI	0.018(0.607)	0.000(0.998)
TTFF-FFD of natural AOI	−0.012(0.718)	0.050(0.139)
TVD of artificial l AOI	−0.038(0.264)	0.064(0.062*)
TVD of natural AOI	0.014(0.679)	−0.089(0.009***)

Significant positive correlations were observed between the percentage of natural elements and preference, but significant negative correlations between artificial elements and preference (Fig. 5). In particular, the percentage of flowering shrubs and trees was significantly positively correlated with preference, whereas the percentage of ground-covering plants was significantly negatively correlated with preference. The percentage of industrial construction was significantly negatively correlated with preference, whereas the percentage of pavement was not significantly associated with preference; but its correlation coefficient was still negative. The introductory presentation of natural elements was significantly positively correlated with a positive perception and negatively correlated with a negative perception. However, the opposite occurred for artificial elements. Neither the percentage of natural nor artificial elements was significantly associated with SHV, SIS, or SPA.

We found that the percentage of flowering shrubs and trees was significantly positively associated with SCR and SEV and significantly negatively associated with the four negative perceptions. One exception was the percentage of trees, which only showed a negative relationship with SIS. In contrast, the percentage of ground-covering plants was significantly negatively related to SCR and SEV, positively associated with SVE, and significantly positively related to the other three negative perceptions. It was apparent that an increasing percentage of flowering shrubs and trees among the natural elements most likely resulted in an increase in positive perception and a decrease in negative perception. Ground-covering plants resulted in the opposite effect. In particular, the percentage of trees had a significant negative correlation with SHV, while the percentage of ground-covering plants had a significant positive correlation. For specific artificial element percentages, we found that industrial construction and pavement elements had opposing significant relationships with SHV—the greater the percentage of industrial construction, the stronger the SHV but the greater the percentage of pavement, the weaker the SHV. Both showed negative relationships with the other five positive perception categories. The percentage of industrial construction was significantly and positively correlated with the four negative perceptions, whereas the percentage of pavement was significantly and negatively associated with SIS, SPA, and SPR. This suggests that an increase in industrial construction and pavement most likely led to a significant decrease in the participants' positive perceptions. In contrast, an increase in the percentage of industrial construction led to a significant increase in the participants' negative perceptions. An increase in the percentage of pavement decreased the perceptions of SIS, SPA, and SPR.

In brief, a significant positive association exists between the percentage of natural elements and preferences, while the opposite for artificial elements, but the correlation between positive and negative perception might vary. Furthermore, participants disliked very high

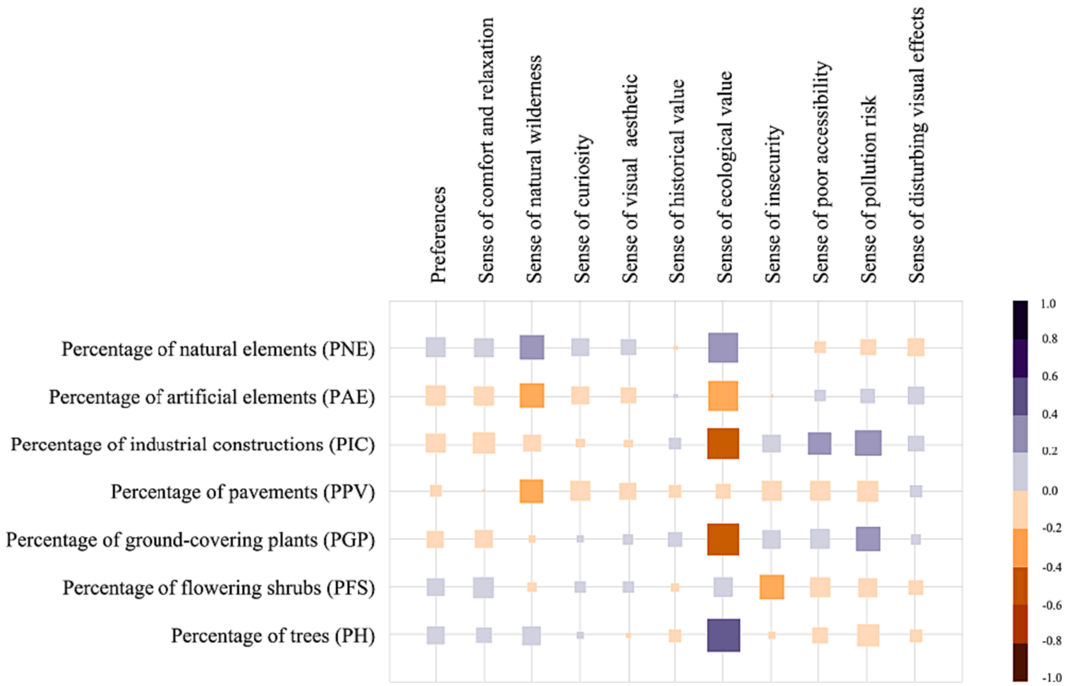

Fig. 5. Correlation among preference, positive–negative perception and image semantic percentage.

percentages of pavement and industrial construction.

3.4. Coupled multivariate data between natural and artificial groups

Four data indicators were included in a stepwise regression analysis: eye tracking, physiology, perception, and preference. After automatic elimination and combination, the dominant factors affecting perception and preference were excluded, and multiple regression models were determined (Fig. 6).

Positive perceptions: In images where artificial AOI was less noticeable, participants felt more comfortable and relaxed (SCR). Sense of natural wilderness (SNW) was affected by changes in physiological electrodermal signals and was lower when the EDA value was higher; participants were emotionally aroused. The longer the TTFF of the participant at the natural AOI, the lower the participant's perception of SNW. The stronger the SNW, the greater the sense of insecurity (SIS) and poor accessibility (SPA). In terms of sense of curiosity (SCI), the shorter the TTFF of artificial AOI, the more significant was SCI when participants quickly viewed an artificial AOI. A greater sense of pollution risk (SPR) significantly positively affected SCI. When the EDA value was greater, and emotions more aroused, SHV was significantly enhanced. But when HRV was greater, with higher stress, SHV was also significantly improved.

The shorter the TTFF of artificial AOI, the greater is SHV. For the sense of ecological value (SEV), the longer the TTFF of artificial AOI, the greater SEV and the stronger the sense of disturbing visual effects (SVE), the greater is SEV. We found no significant effect of SHV on preference, while all other positive perceptions were significantly positive.

Negative perceptions: For the participants' sense of insecurity (SIS), the higher the HRV value, the greater the stress, and the stronger the SIS. However, the stronger the SPA and SPR, the greater the SIS. The sense of pollution risk (SPR) was stronger when the HRV value was smaller, with lower stress. When the TTFF of artificial AOI was shorter, with stronger attraction, the stronger the SPR was. Higher SIS and SPA also positively and significantly affected the sense of disturbing visual effects (SVE). We found no significant effects of SPA on preference, while all other negative perceptions had significant negative effects.

We performed a one-way ANOVA on two sets of experimental image data, with the percentage of industrial construction (Image E, F, G, H in Figs. 2 and 3) and the percentage of pavement (Image I, J, K, L in Figs. 2 and 3) serving as independent variables. In images E, F, G, and H, only the percentage of industrial construction increased (in alphabetical order). In images I, J, K and L, the percentage of pavement cover increased, again in alphabetical order.

In our examination of percentage of the industrial construction, we found significant differences in TTFF-FFD of artificial AOI, TVD of artificial AOI, and preference for all four images. Image E elicited the smallest artificial TTFF-FFD values after multiple comparison (LSD) analyses— significantly different from Images F, G, and H. Image E, with the lowest percentage of industrial construction, was the most preferred and was significantly distinct from Images F, G, and H. This indicated that participants were immediately attracted to industrial construction and had the greatest preference for a lower percentage of industrial construction. Image H showed the highest percentage of industrial construction, but the artificial AOI had the shortest TVD and was significantly different from Images E, F, and G. This indicated that participants had a lower preference for images where the percentage of industrial construction was very high and spent substantially more time observing the natural AOI.

In our analysis of the percentage of the pavement cover group, we found significant differences in TTFF-FFD of artificial AOI, TVD of natural AOI, and preference for all four images. Image J had the smallest values of artificial TTFF-FFD after multiple comparison (LSD) analyses— significantly different from Images I, K, and L. This indicated that Image J might be exceptionally compelling. With an increasing percentage of pavement cover, the TVD of the natural AOI in Images I, J, and K gradually decreased. However, we observed a shift with Image L; it displayed the highest percentage of pavement, but the TVD of the participants' natural AOI increased significantly. Image L had the lowest preference values and was clearly distinct from Images I, J, and K. This suggested that when the percentage of pavement cover in images was very high, participants had the lowest preference and spent significantly more time observing the natural AOI.

In brief, the shorter the TTFF of artificial AOI, the greater is the sense of historical value or curiosity. Participants had a lower preference for images where the percentage of industrial construction or pavement

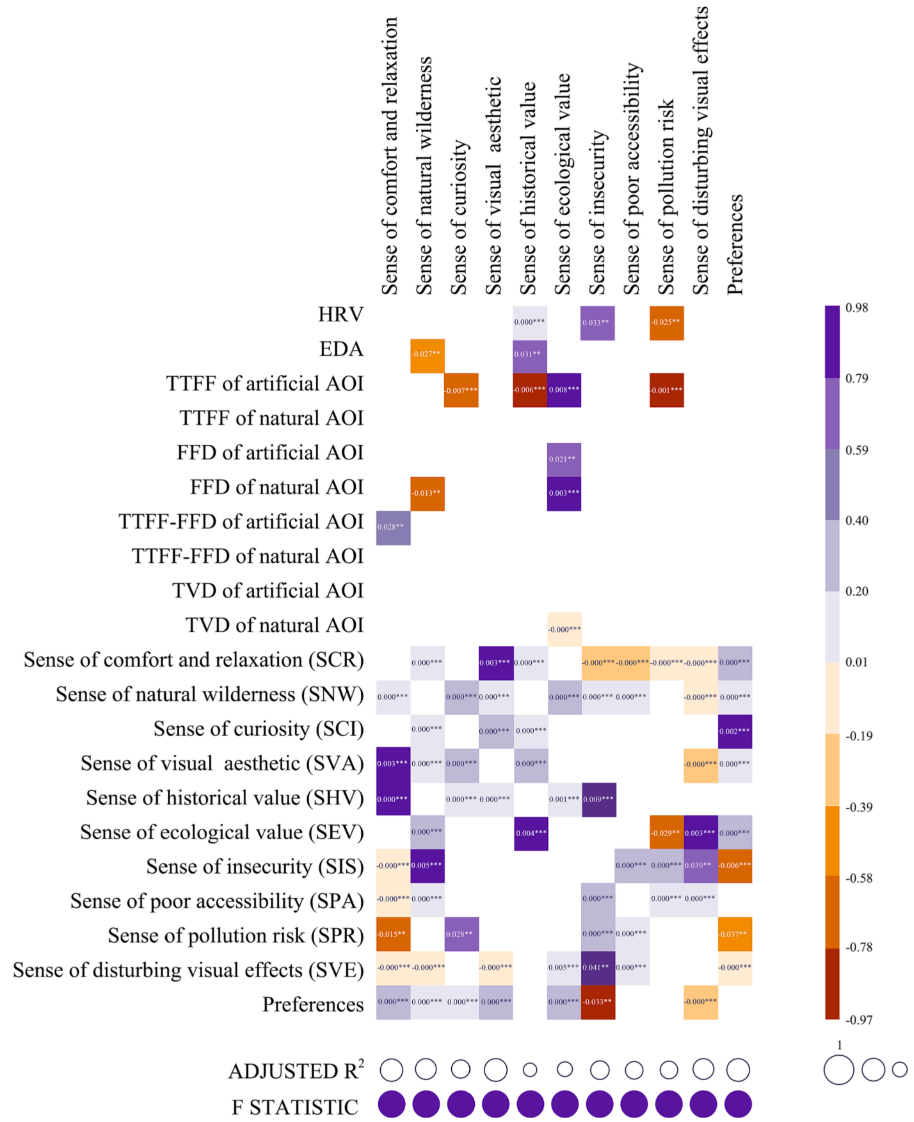

Fig. 6. Results of a stepwise regression model with multiple data coupled.

cover was very high and spent substantially more time observing the natural AOI.

4. Discussion

4.1. *Eye-tracking analysis based on natural and artificial AOI*

Overall, the artificial AOI was more visually appealing to the participants than natural AOI, as determined by eye-tracking data. In previous studies, although buildings (Noland et al., 2017) or artificial elements (Dupont et al., 2016) may tend to quickly attract participants' attention, comparative studies of parks have indicated that participants spent more time with their attention focused on natural AOI, such as bushes or trees, and less time looking at artificial AOI (Amati et al., 2018). In urban canalized waterfront park experiments, it was found that participants paid less attention to artificial elements and more attention to natural elements like plants and water bodies (Li et al., 2022b). In an experiment designed to explore attention in urban streetscapes, vegetation received the greatest percentage of attention (Yin et al., 2020). Among the various types of urban green spaces, the natural AOI areas tend to be more visually appealing to participants than artificial AOI. Interestingly, artificial AOI was more visually appealing to the participants in our study. This observation may be attributed to the absence of industrial remains in the majority of urban green spaces examined in the study, in contrast to our study which specifically included areas with industrial remains. Previous research has consistently demonstrated the positive public perception and recurring recognition of the historical and cultural significance of preserved industrial sites that are strategically planned for utilization (Kowarik et al., 2005; Vileniske, 2008). The concept of visual attractiveness is intricately connected to various factors such as human training, cultural influences, historical context, and other related elements (Grahn and Stigsdotter, 2010). In sustainability research and renovation design of post-industrial landscapes, it is necessary to emphasize how to fully use, and benefit from, the enhanced aesthetic appeal of the artificial AOI in post-industrial parks.

Our study also determined that the TVD of natural AOI was higher than the artificial AOI when tree cover exceeded 55.42 % or that of flowering shrubs exceeded 20.42 %. This may be related to the low exposure and occupancy of post-industrial characteristics when the percentage of artificial AOI was short. Alternatively, vegetation has been shown to influence human physiological responses, psychological perception, and preference through color and morphological characteristics (Elsadek et al., 2013). Several studies have demonstrated that flowering shrubs enhance both restoration potential and aesthetic preferences (Van den Berg et al., 2014; Deng et al., 2020a), and the presence of flowers and trees could increase the restorative potential (Lindal and Hartig, 2015). When a threshold percentage of trees or flowering shrubs was reached in the post-industrial landscape, the visual attractiveness of the scenes was consistent with the results of spatial types such as urban parks. This means that natural AOIs are more visually appealing to the participants under such conditions.

Several studies have found that a built environment with artificial elements elicits stronger physiological stress than the natural environment (Wang et al., 2016; Huang et al., 2020). Physiological measurements synchronized with the eye tracking experiment in our study confirmed that HRV was significantly and negatively correlated with the percentage of natural AOI and significantly positively correlated with the percentage of artificial AOI. This also suggests that the greater the percentage of natural elements, the less stress experienced by participants. The greater the percentage of artificial elements, the stronger the stress the participants experienced. Our results were consistent with a large number of studies demonstrating that natural environments mitigated the effects of physiological stress and restored physiological health more effectively than artificial environments (Ulrich et al., 1991; Jiang et al., 2014; Van den Berg et al., 2014; Li and Sullivan, 2016).

Nevertheless, in this study, electrodermal data revealed that EDA was significantly positively correlated with TVD in the artificial AOI but significantly negatively correlated with TVD in the natural AOI. This suggests that the longer a participant looked at the artificial AOI, the greater the degree of arousal and, most likely, the more appealing the artificial element was to the participant. This finding differed from previous research in which natural elements were more attractive than artificial elements (Amati et al., 2018; Li et al., 2022b). We hypothesized that this finding remains relevant to the post-industrial characteristics of the artificial elements we presented, which is supported by previous studies' in which buildings can be both positive and negative regarding visual appeal attributes (Noland et al., 2017). Indeed, the degree of arousal decreased the longer a participant observed natural AOI, most likely due to the physiologically restorative effect of natural elements, where an increase in positive perception was associated with a decrease in autonomous physiological responses (Ulrich et al., 1991).

4.2. Relationship between spatial attribute and positive-negative perceptions

In our examination of specific positive and negative perceptions, we discovered that almost always the natural landscape was significantly positively correlated with positive perceptions and negatively associated with negative perceptions. The artificial landscape was the opposite. All positive perceptions, except for the sense of historical value (SHV), were significantly positively correlated with natural landscape elements. SHV was significantly negatively correlated with the natural landscape. This may be attributable to the historical character of the industrial heritage, as studies have indicated that the post-industrial landscape evoking SHV was highly rated (Kim and Miller, 2017). The SHV more easily elicits satisfaction (Loures, 2015).

Our study also confirmed that industrial construction elements were significantly and positively correlated with SHV, while the flowering shrub and tree elements in natural images were negatively correlated with SHV and reduced the percentage of industrial construction exposure. We also found that the greater the percentage of industrial construction, the greater the participants' negative perceptions of sense of insecurity (SIS), sense of poor accessibility (SPA), sense of pollution risk (SPR), and sense of disturbing visual effects (SVE). Several studies have demonstrated that designs that retain industrial residues may raise concerns about residual contamination and possible adverse health effects (Erdem and Nassauer, 2013; Kim and Miller, 2017; Kim and Kang, 2019), and post-industrial sites were commonly perceived as messy or dangerous (Lafortezza et al., 2008; Kim and Kang, 2019). It has also been argued that most hardscapes have a negative impact on visual perception (Gungor and Polat, 2018; Deng et al., 2020b; Li et al., 2022a). Using pavement in the artificial landscape type can improve these negative perceptions. Studies have shown that participants feel significantly less SIS, SPA, and SPR as the percentage of pavement increases, which may be due to perceptions of increased accessibility in paved landscapes. According to the access-exposure model (Archea, 1985; Andrews and Gatersleben, 2010), the more opportunities offered to escape potential exposure, the easier the environment was to enter and the safer the person felt.

We also confirmed that images with more natural landscape elements could significantly reduce the two negative perceptions of SPR and SVE. This was consistent with conclusions from earlier studies that vegetation can improve visual effects (Li et al., 2021). Vegetation could help reduce SPR at post-industrial sites (Lafortezza et al., 2008; Kim and Miller, 2017). We specifically analyzed landscape elements and discovered that flowering shrubs and trees played a significant role. In contrast, an increase in the ground-covering plants led to a substantial increase in the perception of SPR and a positive correlation with SVE. It could be that flowering shrubs and trees were visually obstructive (Asgarzadeh et al., 2014); vegetation pattern complexity is positively correlated with perception (Lafortezza et al., 2008). Therefore, to reduce the negative perception caused by industrial construction in the post-industrial landscape, the percentage of pavement could be increased appropriately, the percentage of flowering shrubs and trees increased to a degree, and the percentage of ground-covering plants could be controlled.

4.3. Multiple data coupling on participants' perceptions and comparison with other types of green spaces

Human Factors Design is the scientific study of the quality of the human spatial experience. It uses objective data to assist and enhance the subjective judgment of the design method to fully consider human-centered needs (Zhang et al., 2022). Coupling multiple data provides the possibility of exploring human physiological resilience and mental health. For example, several studies have reported a positive correlation between fixation duration and visual preference (Noland et al., 2017) and a close relationship between eye-tracking indicators and restorative benefits (Franěk et al., 2018). By investigating public perception, the design and renovation of the post-industrial landscape's sustainable development provide a more scientific and advanced approach.

In this study, we developed a multivariate coupled model revealing that natural AOIs made participants feel comfortable and relaxed, whereas artificial AOIs induced intense curiosity. The positive effects of natural elements are somewhat consistent with urban parks (Wang et al., 2016; Kothencz and Blaschke, 2017), urban open green spaces (Grahn and Stigsdotter, 2010; Hadavi et al., 2015; Hoyle et al., 2017), urban waterfront spaces (Steinwender et al., 2008; Li et al., 2021), urban streets (Sheets and Manzer, 1991; Li et al., 2015), forests (Liu et al., 2019), among other spaces. A small negative effect we found was that the natural AOI was less visually appealing to participants than the artificial AOI. Other post-industrial landscape studies (Lafortezza et al., 2008; Rink and Arndt, 2016; Kim and Miller, 2017) have reported that this could result from the disorder and disarray caused by unmanaged natural scenes. Moreover, the sense of natural wilderness was weaker when the value of EDA changes was greater, which meant that participants' emotions were aroused when the duration of the first fixation at the natural AOI was longer. However, perceptions of greater insecurity and poor accessibility significantly increased with the sense of natural wilderness. This may be due to the complexity of people's attitudes toward the wilderness. Although people had a positive perception of wilderness landscapes (Kaltenborn and Bjerke, 2002), it may also be perceived as cluttered (Hands and Brown, 2002); people's preference for nature may also be associated with neatness (Nassauer, 1995).

Regarding specific natural elements, we also confirmed that the flowering shrub and tree elements were significantly and positively correlated with participants' preferences. These two elements are found in other post-industrial parks (Lafortezza et al., 2008; Zhang, 2022), urban street spaces (Akbar et al., 2003; Todorova et al., 2004; Harvey et al., 2015; Lindal and Hartig, 2015), urban parks (Nordh et al., 2011; Amati et al., 2018; Jahani and Saffariha, 2020; Deng et al., 2020a), urban open green spaces (Wang et al., 2017, 2019; Liu et al., 2022), and waterfront green spaces (Sun et al., 2021; Li et al., 2022b), all of which have also been verified to have positive effects on people and enhance both recovery potential and aesthetic preferences. Different from findings of ground-covering plant elements being positively correlated with preference (Rink and Arndt, 2016; Huang et al., 2020), we discovered that ground-covering plant elements showed both positive and negative effects in this study. Although the percentage of it was significantly negatively correlated with preference, with the sense of comfort and relaxation, ecological value, and significantly positively associated with the sense of pollution risk and historical value. These findings may be attributable to the characteristics of post-industrial landscapes. The public's concerns regarding pollution in post-industrial landscapes may contribute to their preference for rich and clustered vegetation, as it is often associated with a stronger perception of ecological restoration (Schroeder and Orland, 1994; Nassauer, 1995). Previous research has demonstrated that complex patterns of vegetation, such as clusters of trees, tend to increase public preferences for post-industrial landscapes (Lafortezza et al., 2008). In contrast, the ground-covering used in this experiment consisted of a single layer of ground-covering plants with a simple structure. This simplicity may hinder the decontamination of post-industrial landscapes by individuals, as evidenced by the significant and positive correlation between the percentage of ground-covering plants and the sense of pollution risk observed in the study results. Consequently, flowering shrubs and trees are essential and effective natural landscape elements in the post-industrial landscape for human restorative and perceptual preferences. Nevertheless, attention should be paid to their proportional and screening relationships with post-industrial construction to minimize their impact on the sense of historical value. Excessive growth should be avoided, and proportional relationships between ground-covering plant elements should be established. In addition, ground-covering plant can reduce the amount of shade on post-industrial elements while increasing the amount of greenery in the view-scape, which may be a crucial factor in the transformation of post-industrial sites.

The majority of artificial elements in urban parks (Deng et al., 2020b), urban built environments (Acar et al., 2006), and urban waterfront spaces (Li et al., 2022a), are thought to elicit negative perceptions that were not entirely consistent with our findings in a post-industrial landscape. In urban parks (Wang et al., 2016; Gungor and Polat, 2018; Jahani and Saffariha, 2020), urban open green spaces (Wang et al., 2019; Huang et al., 2020; Liu et al., 2022), and waterfront green spaces (Chen and Lin, 2007; Li et al., 2021, 2022b) both the overall artificial elements and specific building elements negatively affect people. Pavement elements can also negatively affect people in urban open green spaces (Liu et al., 2022) and waterfront green spaces (Chen and Lin, 2007; Li et al., 2022a). In urban parks, however, studies have shown that parks with paved trails were more likely to be used for physical activity than parks without paved trails (Kaczynski et al., 2008); older adults prefer soft paved surfaces in urban parks (Zhai and Baran, 2017).

In urban street spaces, building and pavement elements had both positive and negative effects on people. Studies have found that enclosed buildings have a positive effect on the visual quality of street spaces (Harvey et al., 2015) and that the maintenance structure provided by intact and continuous building facades creates an orderly and dynamic streetscape (Ewing and Handy, 2009), and that different types of street pavement materials with different visual styles added aesthetic value (Kawther, 2018). Nevertheless, other studies have found that the visual qualities of street buildings in older cities require improvement (Tang and Long, 2019). In this study, although the percentage of industrial construction elements was significantly negatively associated with preference, it was significantly positively associated with the sense of disturbing visual effects, insecurity, poor accessibility, and pollution risk. This was similar to the negative effects of green space types we discussed earlier. The greater the percentage of industrial construction, the stronger the sense of historical value.

This finding is supported by other post-industrial landscape studies (Keil, 2005; Kim and Miller, 2017), where industrial remnants were aesthetically valuable if they could be accessed and reused, and where industrial remnants were increasingly becoming cultural relics (Keil, 2005). We also found that pavement in artificial landscapes can significantly reduce the sense of insecurity, poor accessibility, and pollution risk, and enhance the positive effects of artificial landscapes. This has rarely been addressed in previous post-industrial landscape studies. In traditional agricultural landscapes, it has been shown that people have positive perceptions of old traditional farmhouses (Kaltenborn and Bjerke, 2002) and old buildings with stone walls (Strumse, 1994). In military heritage landscapes, the higher the readability of defensive installations, the higher the participants scored their positive perceptions (Pardela et al., 2022). Cultural heritage sites and art venues tend to inspire a sense of curiosity in visitors with high-quality restoration (Packer and Bond, 2010). Based on the above landscape types, it is evident that construction sites with historical or cultural connotations have the potential to be positively perceived and favored by individuals, assuming rational and appropriate use. According to the theory of place attachment, individuals always favor locations that "connect them to the past or evoke their memories" (Scannell and Gifford, 2017). The inclusion of culture and history can increase interest in the environment (Karmanov and Hamel, 2008), while construction heritage was considered to contribute to the sustainability of a heritage landscape by preserving and enhancing the local sense of place (Vileniske, 2008). For industrial sites, most participants agreed that preserving industrial heritage was important (Loures et al., 2016), and regeneration programs that preserve industrial heritage can play a significant role in reflecting a sense of local identity (Miles, 2005). By increasing the percentage of flowering shrubs, trees, and pavements and controlling the percentage of ground-covering plants, the sense of curiosity and historical value of industrial site can be enhanced and promoted with low negative perception. This is a potential development path for environmentally responsible redesign and transformation of post-industrial landscapes (Fig. 7).

4.4. Limitation and future study

The participants in this experiment were planning and landscape architecture majors and their professional training may have affected the results. To obtain more generalized results and contributions to post-industrial landscape perceptions and preferences, subsequent studies with participants with varying levels of education should be considered. Furthermore, the participants in this experiment provided feedback on their perception of experiencing the real environment by viewing images. Their responses may have been limited by individual imagination. It may be worthwhile to conduct quantitative research on post-industrial landscape perceptions and preferences in the actual outdoor space. Furthermore, the experimental design employed in this study neglected to adequately account for the impact of variations in angular distance on participants' visual evaluation and psychological reactions. This oversight is particularly relevant as the study aimed to examine participants' perceptions and preferences for industrial remains scenes across different environments, with the central scene serving as the image. Finally, only the post-industrial park transformation of the steel mill relic type has been examined, with a limited number of study objects and case sites. This study has not yet included other typical post-industrial park transformation types, such as mine restoration and manufacturing factory sites. Thus, the diversity of post-industrial landscape studies can be expanded.

	Our studies	Other post-industrial landscape studies	Urban green street space studies	Urban park studies	Urban green open space	Urban waterfront space
Artificial element	Both Positive and Negative effect	/	/	Negative effect	Negative effect	Negative effect
	• negatively correlated with preference • appealing and heightening the stress	/	/	• lowered landscape aesthetics(Jahani, 2020) • negative impact on visual perception (Gungor,2018; Deng, 2020)	• negatively correlated with preference (Wang,2019) • weaker physiological restorative impacts(Huang,2020)	• reduce the visual quality(Li,2021) • a negative impact on visual quality(Sun, 2021)
Construction element	Both Positive and Negative effect	Both Positive and Negative effect	Both Positive and Negative effect	Negative effect	Negative effect	Negative effect
	• negatively correlated with preference • significantly positively correlated with the sense of historical value(SHV)	• threatened and negative assessments (Rink,2016; Kim,2017) • the stronger the sense of historical value (Keil 2005; Kim,2017)	• positive effect on the visual quality(Harvey, 2015) • the visual quality in older cities needed to be improved(Tang,2019)	• negatively correlated with landscape score(Jahani,2020) • degrade the landscape aesthetics(Jahani,2020)	• negative effect on the restoration benefits(Liu,2022) • affect the public's perception of green(Yang,2009)	• negatively correlated with the landscape aesthetic(Li,2022) • negative effects on artificial bank modification(Steinwender, 2008)
Pavement element	Both Positive and Negative effect	/	Both Positive and Negative effect	Positive effect	Negative effect	Negative effect
	• negatively associated with preference • weaken the SHV, insecurity(SIS), poor accessibility(SPR), and pollution risk(SPR)	/	• different types of materials can add aesthetic value(Kawther,2018)	• more likely to be used for physical activity (Kaczynski,2008) • older adults prefer soft pavement (Zhai,2017)	• negative effect on the restoration benefits (Liu,2022) • negatively affect people in it(Yang,2009)	• negatively correlated with the landscape aesthetic (Li,2022) • questioned by experts as negative elements(Chen,2007)
Natural element	Both Positive and Negative effect	Both Positive and Negative effect	Positive effect	Positive effect	Positive effect	Positive effect
	• negatively correlated with preference • less appealing and shortening the stress • the degree of arousal decreased the longer a participant observed natural AOI	• ambivalent and negatively dominated • negative comments with spontaneous vegetation unmanaged(Mathey, 2018) • increasing positive perception with particular vegetation combinations(Lafortezza,2008; Rink,2016; Kim,2017)	• contribute to the visual quality(Tang, 2019) • a positive element that can enhance comfort(Sheets,1991) • the greatest concentration(Yin,2020)	• the more attractive to visitors(Kothencz,2017) • positive effect on the visual quality of the park(Gungor, 2018) • increasing restoration potential and aesthetic preference(Deng,2020)	• provided maximum restorative effects(Hoyle,2017) • associated with better-perceived health and mental health(Su,2019) • the most favored scene(Hadavi,2015)	• improved public perception(Li,2021) • stronger positive effects on perception(Steinwende,2008) • important factor in attracting visual attention(Li,2022)
Ground-covering plant element	Both Positive and Negative effect	Negative effect	Positive effect	Both Positive and Negative effect	Positive effect	Positive effect
	• significantly negatively correlated with preference, comfort and relaxation(SCR), ecological value(SEV) • significantly positively correlated with SHV and positively with disturbing visual effects(SVE)	• always had a negative effect(Lafortezza, 2008) • disliking dense environments(Rupprecht, 2015; Kim,2019)	• a combination of grasses and flowering be the most popular type(Akbar,2003) • streets with grass be more popular (Todorova,2004)	• a predictor of the likelihood of recovery (Nordh,2011) • well-manicured lawn lacked the quiet atmosphere necessary for attention recovery and mental relaxation(Deng,2020)	• positively correlated with preference • highly restorative environments (Huang,2020)	• be attractive with adjusted proportions of trees, shrubs and ground-covering(Sun,2021)
Flower shrubs element	Both Positive and Negative effect	Positive effect	Positive effect	Positive effect	Positive effect	Positive effect
	• significantly positively correlated with preference • negatively correlated with SHV • theTVD for natural AOI was much larger than artificial AOI with flower shrubs high enough	• Artificial floral received a shorter TVD and weaker emotional interaction than the wild plants(Zhang, 2022)	• increase the restoration potential(Lindal, 2015) • be the most favored(Todorova, 2004) • a combination of grasses and flowering be the most popular type(Akbar,2003)	• positively correlated to landscape scores (Jahani, 2020). • enhance both restoration potential and aesthetic preferences(Deng,2020) • wood edge treatment with flowers was most preferred(Jorgensen ,2002)	• increasing aesthetic preference and restorative potential(Wang,2017; Wang,2019) • positive effect on the restoration benefits(Liu, 2022) • enhance restoration potential and aesthetic preferences(Kuper,2020)	• concern of the riverwalk features : aquatic plants > shrubs > water bodies(Li,2022)
Tree element	Both Positive and Negative effect	Positive effect	Positive effect	Positive effect	Positive effect	Positive effect
	• significantly positively correlated with preference • negatively correlated with SHV • theTVD for natural AOI was much larger than artificial AOI with tree high enough	• a particular pattern of vegetation combinations could increase positive perceptions(Lafortezza,2008; Rink,2016)	• increase the restoration potential(Lindal, 2015) • positive effect on visual quality(Harvey, 2015) • the preference model revealed trees to be the factor with the greatest influence(Todorova,2004)	• a predictor of the recovery(Nordh,2011) • positively correlated to landscape score(-Jahani, 2020) • vegetation AOIs in the tree be dwelt on the most(Amati, 2018)	• increasing aesthetic preference and restorative potential(Wang,2019) • positive effect on the restoration benefits(Liu, 2022) • health benefit(Nasution,2014)	• be attractive with adjusted proportions of trees, shrubs and ground-covering (Sun,2021)

Fig. 7. Comparative and differential analysis of perceptions and preferences of our study and other green space types in terms of landscape types and elements. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5. Conclusions

The public's perceptions and preferences are crucial to landscape use and the transformation of post-industrial sites. Independently, subjective data (perceptions and preferences questionnaires) and objective data (physiological data or eye-tracking data) have limited accuracy in quantifying participants' real perceptions and preferences. In this study, we proposed a multi-data quantification method that combined subjective questionnaires, objective physiological data, and objective eye-tracking data measures to scientifically demonstrate human perceptions and preferences from as many aspects and perspectives as possible. We thereby provide a unique perspective for comprehending the correlation between objective elements and subjective perceptions. The correlation between post-industrial landscapes in two major landscape types, artificial and natural, the landscape elements they contained, and multivariate data are discussed in depth. Through comparative analysis, we also investigated the similarities and differences between post-industrial landscapes and other types of green space. Based on these correlations, we clarified what can be learned and applied to the conservation and transformation of post-industrial landscapes.

We uncovered the relationship between quantified post-industrial landscape types, landscape elements and participants' physiological responses, eye-tracking activity, and psychological perceptions via semantic segmentation of images using deep learning and cluster analysis techniques. We demonstrated both the different roles of indicators to elicit positive–negative perceptions and preferences, as well as the differences in physiological responses and eye tracking between natural and artificial landscapes in post-industrial landscapes, where industrial construction and pavements played a significant role.

Our work focused on identifying heterogeneity and homogeneity in post-industrial landscapes through multivariate data and comparative analysis of perceptions and preferences in various types of green space. Industrial construction and pavement were crucial indicators in the transformation of post-industrial landscapes. The sense of historical value and curiosity contributed to the positive effect of participants on artificial types of landscapes in post-industrial landscapes. With full consideration of the effects of shading and proportionality between plants and industrial construction, an extensive knowledge of plant types, colors, heights, and effective combinations in park and green street spaces can be applied to post-industrial landscapes. The percentage and combination of landscape elements can have a pronounced impact on perceived results, necessitating greater care in landscape design. These findings are essential for enhancing people's preference and satisfaction with post-industrial landscape transformation via proportional control of natural and artificial landscape types and the configuration of specific landscape elements.

CRediT authorship contribution statement

Chuli Huang: Conceptualization, Methodology, Investigation, Data curation, Software, Formal analysis, Visualization, Writing – original draft. **Fang Wei:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition, Supervision, Project administration. **Sijia Qiu:** Investigation, Data curation, Visualization, Formal analysis. **Xuqing Cao:** Investigation, Data curation, Visualization. **Lu Chen:** Investigation, Data curation. **Jing Xu:** Investigation, Data curation. **Jiayang Gao:** Investigation, Data curation. **Qing Lin:** Investigation, Data curation.

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.

Data availability

Data will be made available on request.

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