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Perception of urban parks: the influence of topography, vegetation density and park attributes on perceived safety, mystery and preference

Abstract

In this study we analysed how topography, vegetation density and selected park attributes influence features such as coherence, complexity, legibility, mystery, sense of safety and preference in the context of natural-looking urban parks. We also examined relationships with other landscape features that may affect preference. We employed a within-subjects design where participants evaluated a set of 108 eye-level computer generated photorealistic visualisations of park environments. Our sample comprised 200 participants (118 females and 82 males). Our findings suggest that flat terrain is perceived as safer. Dense vegetation increases the sense of mystery, while sparse vegetation was conducted for safety and legibility. The presence of plants in bloom and park architecture, and furniture were most preferred features of the park landscapes we studied. Park landscapes with plenty of light and visible sky were perceived as safer, while landscapes with less light and sky were thought to be more mysterious. The strongest predictors of Kaplan preference model preference were legibility, complexity and coherence. The greater the coherence and readability, the more the landscape was preferred. Landscape complexity positively influenced preference. Our findings indicate the complexity of the relationship between topography, vegetation and landscape preference, emphasising their relevance when designing attractive and safe parks with a natural feel.

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1 Introduction

1.1 Motivation and goals of the study

Parks and other green spaces are one of the basic components of urban landscapes, a form of mediated contact point between the social and the 'natural' (Fu et al., 2024; Lee et al., 2024; Naghibi et al., 2024; Rastkhadiv et al., 2024; Zachariasz, 2024). In a social context, spending time in green areas creates opportunities to experience a sense of 'removal from civilisation'. Parks can be safe and at the same time appealing (Lis & Iwankowski, 2021b). People in parks may experience strong emotional bonds with natural elements such as vegetation (Bjerke et al., 2006; Talal & Santelmann, 2020; Rahnema et al., 2019; Maurice et al., 2025). Being surrounded by plants has a calming and relaxing effect (Chiesura, 2004; (Relf et al., 1992). Varied topography is also considered one of the most appreciated values of urban parks, because it stimulates the curiosity of their visitors and enhances their desire to explore the area (Lis et al., 2014). The occurrence of landforms such as hills can also be appealing in terms of the location of observation points offering an overview of space conducive for recreation (Mercadé-Aloy & Cervera-Alonso-de-Medina, 2024). However, landform is less frequently studied as a factor that influences sense of safety in parks, in contrast to ground cover, for example (Borysiak & Stępniewska, 2022; Polko & Kimic, 2022; van Vliet et al., 2021; Lis, et al., 2024). For this reason, the study of social preference for parks of various shapes, supported by computer techniques that help precisely model landform and landcover (e.g., water, vegetation, etc.), as used in our study, is now a 'hot' direction for research. A thorough understanding of human perception may assist designers in creating park environments that people want to be in (Khaledi et al., 2022).

Numerous studies have been conducted on preference for various green spaces using computer-generated urban and rural green areas (Liu & Nijhuis, 2020). Different types of stimuli were used, including photomontages, photorealistic images, non-photorealistic images, 2D and 3D models, virtual reality (VR) environments and mixed-methods of comparative studies between 3D visualisations and photos taken in the natural environment (Al Shawabkeh & Arar, 2024; Luo et al., 2021; Mostajeran et al., 2023; Naghibi et al., 2024; Nassauer et al., 2021; Reese et al., 2022; Schroeder & Orland, 1994; van Vliet et al., 2021). Very often, when creating specific types of landscapes, software for designing ready-made 3D landscape models (e.g. Visual Nature Studio or Lumion) were used alongside popular game engines (such as Unity), game editors or computer games (Lis et al., 2024; Reese et al., 2021; Roncken, 2019). The transition to more comprehensive 3D modeling and environment visualisation technologies enables superior representation of various landscapes and rapid manipulation of park landscape features. Nowadays, such visualisations are extremely similar to photos taken in a natural environment, taking into account different plant communities, and – most importantly – may also affect the respondents' preference (Daniel, 2001; Shr et al., 2019).

The concept of preference in the context of landscape studies involves measuring the extent to which people like or dislike the appearance of a given landscape (Scherer, 2005). In other words, it reflects how much the respondents appreciate the studied environment. Preference is therefore a subjective feeling that reflects individual taste and aesthetics (Pardela et al., 2022b). There are two main theories regarding preference for landscape: evolutionary and cultural (Arnberger & Eder, 2011; Tveit et al., 2006). Evolutionary theory, rooted in biology, suggests that our preferences are genetically determined and result from the need to adapt and survive in the natural environment (Appleton, 1975; Zube et al., 1982; Kaplan & Kaplan, 1989). In turn, cultural theory emphasises the influence of cultural factors on aesthetic preference and how landscapes are perceived (Zube et al., 1982). One of the most commonly used models when studying preference for a specific type of environment is the Kaplan model (1989), which we used here. This model distinguishes four preference predictors referring to various types of environments, including coherence and complexity (two-dimensional variables) as well as legibility and mystery (three-dimensional variables). The first – 'coherence' – encapsulates 'a sense of order' (Kaplan et al., 1989), related to 'immediate understanding' (Stamps, 2004). The second – 'complexity' – concerns the variety of visual elements in a scene (Kaplan et al., 1989), colours and organisation (Stamps, 2004) (Shayestefar et al., 2022). The Kaplan model (1989) defines the third variable – 'legibility' (Lynch, 1960) – as the expressiveness of the elements that constitute the scenery, or 'inferred understanding' (Herzog, 1989; Herzog, 1992; Strumse, 1994; Herzog & Leverich, 2003; Herzog & Kropscott, 2004; Herzog & Bryce, 2007). It is often associated with attributes such as 'visual access' and 'physical access' (Shayestefar et al., 2022). In connection with the above, our questionnaire defined 'legibility' as distinctive elements in the landscape that assist orientation. The final variable in the Kaplan model – 'mystery' – refers to features of the environment that 'promise more if one ventures further' (Herzog & Smith, 1988) and is identified as 'interfered exploration' (Stamps, 2004).

As the results of previous studies have shown, the amount and type of vegetation in city parks influences visitor preferences (Bjerke et al., 2006), although the reasons for this phenomenon are not fully understood. Studies show that the relationship between greenery and preference may boil down to sense of safety (Lis, Zalewska, & Grabowski, 2024; Lis & Zalewska, 2024; Pardela et al., 2022a; Lis et al., 2021). We defined environmental safety here according to Haans and de Kort (Haans & Kort, 2012), as a 'person's immediate sense of safety, free from anxiety of being victimised when walking through a particular environment'. Odufuwa et al.'s research (Bashir et al., 2019) indicates that subjective, rather than objective, sense of safety is a deciding factor in whether or not to visit a particular place. This means that people are more likely to visit parks that they perceive as safe, even if they are not objectively safer than others. Other factors that may play a role in greenery preference include, for example, a sense of mystery offered by lush vegetation (Herzog & Kropscott, 2004; Pardela et al., 2022b) and legibility that enhances the scenic value (Pardela et al., 2023).

In this study we investigated the influence of terrain and vegetation density on preference. Additionally, we studied their impact on all components of the Kaplan model as well as on sense of safety in the case of computer-generated park landscapes, and additionally examined how other features of the studied landscapes affect preference.

1.2 Topography in the context of preference and perceived safety

Terrain forms can have a twofold impact on safety, especially in parks. Diverse terrain can naturally divide the park area into different functional sectors, which in turn can attract a variety of visitors, thereby enhancing sense of safety through social surveillance. Diverse terrain, although it boosts the aesthetic and scenic value of a park, may also hinder a quick escape (Lis et al., 2014; Lis, et al. 2024). The values of topographic forms and their aesthetic role are described by three classic theories (Lis et al., 2014; Han, 2007). The most popular research perspective here is the Nasar/Fisher model based on Appleton's 'prospect and refuge theory' (Appleton, 1996; Fisher & Nasar, 1992). This theory has been confirmed by numerous studies (El-Metwally et al., 2021; Hagerhall, 2000; Lis, Zalewska, et al., 2019; Lis & Iwankowski, 2021a; van Rijswijk & Haans, 2018), though not all (Klopp & Mealey, 1998). Appleton argued that people prefer landscapes similar to the African savannah, conducive to observing the surroundings ('prospect') as well as seeking safety ('refuge') – both key attributes of the environment of our ancient ancestors (Błaszczyk et al., 2017). In the park context, an example of a popular space would be one with open viewing areas with sheltered spots, offering the chance to 'see without being seen' (Han, 2007). Furthermore, the Berlyne (Berlyne, 1974) model states that people prefer environments that provide a moderate level of stimulation and uncertainty (the extent to which the particular components of the environment are divers). The final theory explaining aesthetic preference for the environment is the Kaplan model (Kaplan & Kaplan, 1989), which combines nativist and constructivist elements, suggesting that we prefer landscapes that stimulate our cognitive abilities, but that are also legible and comprehensible. As Lis and colleagues noticed (Lis, et al., 2024) when analysing sense of safety and privacy in parks relative to topography, elevations can offer a sense of control over the environment thanks to the possibility they give to observe a larger area, and this translates into an enhanced sense of safety. Schroeder (Schroeder, 1987) observed that long view distances create a perception of high safety. In turn, depressions in the terrain, although they may offer a sense of privacy due to limited visibility from the outside, at the same time expose visitors to observation from above, which in turn can lead to a sense of danger. Appleton's theory and the Kaplan model, although distinct, do show some similarities in how the impact of landscape on people is perceived. Key elements of both theories, such as Appleton's 'secondary view' and the Kaplans' 'mystery' model, along with the need for 'shelter', 'coherence' and 'legibility', indicate that being able to gradually discover the area and feeling safe important aspects in shaping positive experience (Lis et al., 2014). In addition to the terrain, the presence, formation and extent of vegetation upkeep can also influence sense of safety. Therefore, maintaining openings and visual connections plays an important role in landscape preference (Hwang et al., 2019; Lis et al., 2014; Nassauer, 1995; Pardela et al., 2023).

1.3 Vegetation density in the context of preference and perceived safety

Previous studies have demonstrated that a sense of safety has a substantial effect on people's attitudes about greenery (Fisher & Nasar, 1992; Lis, Pardela, et al., 2019; Nassauer et al., 2021). The relationships between plant content and preference have been studied, inter alia, in terms of 'wild' appearance, individual psychological benefits or restorative values. There are discrepancies in study findings on how people evaluate dense vegetation. Some researchers have noted that the 'wild' appearance of dense vegetation is often associated with neglect, which consequently lowers the aesthetic appeal of a park (Hands & Brown, 2002; Jorgensen et al., 2002). Therefore, they suggest that green areas with dense vegetation should be 'cared for' (Nassauer, 1995). Other researchers mention the benefits of dense, 'wild' vegetation (Mc Morran et al., 2008). The pro-ecological approach emphasises the value of such arrangements because people can experience greater psychological benefits from being in an environment with the rich diversity of species that dense vegetation provides (Bjerke et al., 2006; Kurz & Baudains, 2012; Fuller et al., 2007; Lindemann-Matthies et al., 2010; Luck et al., 2011; Suppakittpaisarn et al., 2020). Studies show varied reactions to green areas with a high density of vegetation, ranging from enthusiasm to reluctance (Harris et al., 2018; Schroeder, 1987), which is also related to the cultural context (Bjerke et al., 2006). When analysing the impact of vegetation content in an urban environment on landscape preference, theories such as Attention Restoration Theory (Kaplan & Kaplan, 1989), the Biophilia Hypothesis (Wilson, 1984) or Stress Reduction Theory (Ulrich, 1981) are of significance. Studies show that the presence of plants, especially in areas bereft of greenery, has a positive effect on psychological restoration and aesthetics (Jiang et al., 2014; Suppakittpaisarn et al., 2019). However, in the context of forest areas, more open, transparently structured forests are preferred, since these have more recreational value. Nevertheless, the removal of dense undergrowth, although beneficial for recreation, may undermine the aesthetic appeal of a forest (Tahvanainen et al., 2001). In the context of our research, dense plantings of trees and shrubs, often occurring in areas with diversified relief, may limit visibility, impede navigation and create hiding places for potential attackers (Lis et al., 2014).

Vegetation density can also have a twofold effect on sense of safety (Altman, 1975; Fisher & Nasar, 1992). On the one hand, dense plants can provide a sense of privacy, which is desirable and may enhance psychological well-being (Newell, 1997). They create physical and visual barriers that offer isolation from the surroundings and obscure the view from outside. On the other hand, dense vegetation can also evoke a sense of danger, because it creates potential hiding spots for dangerous people (Maruthaveeran & van den Bosch, 2014; Park et al., 2012; Yang et al., 2013; van den Berg et al., 2014). Dense vegetation limits visibility and creates the impression that someone may be watching us, while we do not see the threat. This means that the greater the sense of danger, the lower the preference for a given place. In the context of vegetation distribution, this means that places with dense vegetation that create potential hiding places may be less popular precisely because of the sense of danger they arouse (Lis & Iwankowski, 2021a; Pardela et al., 2023). The effect of plant content on sense of safety may depend on the context and someone's individual characteristics. Lis and colleagues (Lis & Iwankowski, 2021b) have isolated three indicators used to study vegetation in the context of safety in parks: (a) (‘cover’), which refers to plant forms that can provide shelter or a viewing screen; (b) (‘sky’) – the amount of open space and visible sky above the line of sight; (c) (‘light’), focusing on the proportion of horizontal, illuminated surfaces, such as lawns, paths or forest floor, characterised by variable light intensity. The latter two relate to the density of tree crowns observed when looking up (‘sky’) or down (‘light’).

1.4 Mystery and vegetation density

According to Stamps (Stamps, 2007), ‘mystery’ is one of the most frequently researched topics in environmental psychology (e.g., Gimblett et al., 1985; Herzog & Miller, 1998) and is a variable that influences preference for park or forest landscapes (Herzog et al., 1982; Herzog & Kirk, 2005; Herzog & Kropscott, 2004; Stamps, 2004; Suthasupa, 2012), large-scale resident streets (Nasar & Cubukcu, 2011), urban streams (Asadpour, 2017) or urban alleys (Herzog & Flynn-Smith, 2001). Mystery depends on the context and type of environment, including visually closed and open environments, as well as diverse and more monotonic ones (Herzog & Miller, 1998; Subiza-Pérez et al., 2019). As previous studies have shown, ‘mystery’ is a feature of fortifications and forest landscapes that is popular among visitors (Herzog & Bryce, 2007; Pardela et al., 2022b). However, some studies have shown that no such effect occurs or that mystery is even detrimental to preference (e.g. Asadpour, 2017; Herzog & Kropscott, 2004; Stamps, 2004). Mystery also relates to landscape form and cover. Gimblett and colleagues (Gimblett et al., 1985) noticed in the case of wooden screens that with increasing physical accessibility, mystery also increases. They mentioned the important role of screening, distance of view and spatial definition in the perception of mystery.

1.5 Preference and selected park attributes

In the case of parks, visitor preferences are influenced by aspects such as size and distance from the park, park furnishing, amenities, presence of other people, noise or maintenance (Ling et al., 2023; Lis, et al., 2024; van Vliet et al., 2021). The main preference factors to consider when designing plant arrangements include high canopy cover and flowers Rahnema et al., 2019; Talal et al., 2021; Tomitaka et al., 2021). Plants in bloom also enhance preference for green areas, although respondents note that after the flowering period some shrubs are no longer as attractive. In the case of multi-use parks, people desired more flowers, colour, grass, medium-sized trees, and fruiting plants, as well as improved placement (Talal et al., 2021). Also a water-wise design is more preferred, for example, in the summer season (Nazemi Rafi et al., 2020). The presence of water is a strong predictor of preference for landscapes in general (Franěk, 2023; Naghibi et al., 2024; Völker & Kistemann, 2011). Aquatic environments are associated with stronger preference and more positive subjective reactions in both natural and built settings without water. Water connected with naturalness boosts its visual rating (M. White et al., 2010. Although water elements are preferred, they are less important for people’s satisfaction than the presence of grass and trees (van Vliet et al., 2021). Similarly, the presence of park furnishing and path materials are associated with individual visitor preference (Ozer & Bariş, 2013), while the presence of frequently visited and used paths indicates that an area is accessible (Lis, et al., 2019).

Taking into account the above considerations, we asked the following detailed research questions in relation to the park space:

R1. How do different types of terrain differentiate the components of the Kaplan model and sense of safety?

R2. How does dense or sparse vegetation differentiate the components of the Kaplan model and sense of safety?

R3. What is the nature of the relationships between features measuring vegetation density and park landscape components, on the one hand, and sense of safety and mystery, on the other?

R4. What are the strongest predictors of preference for the studied environment?

2 Methods

2.1 Questionnaire design and survey context

We opted for a within-subjects design where participants evaluated a set of 108 eye-level computer generated photorealistic visualisations of park environments. The visualisations of the green areas were selected from a larger set (from a pool of 360 generated images) by a group of 6 experts in landscape architecture from universities for landscape architects in Poland. The procedure adopted in our study involved the manipulation of computer visualisations (e.g. Häfner et al., 2018; Hägerhäll et al., 2018; Lis, et al., 2024), allowing control over the research scenario, thereby eliminating the influence of variables not included in the study. Methods based on sets of computer-generated visualisations have long been used in studies related to preference for different types of landscapes (e.g. Bergen et al., 1995; Bishop & Leahy, 1989; Häfner et al., 2018; Kuper, 2017; Nassauer et al., 2021; Reese et al., 2022; Sezavar et al., 2023; Stamps, 2007).

The participants were presented with stimuli created by computer visualisation software Lumion Pro 12.5. We used eye-level (160 cm above ground) rendered images (3840 x 2160 pixels, 16:9) of daylight exteriors presenting photorealistic parks with the horizon line located centre-frame. The visualisations were based on three extensive 3D models of green areas with different terrain features (Table S1). We diversified the studied landscapes according to three levels of topography (flat, elevated and varied) and two levels of vegetation (dense and sparse). The images also contained a varied amount of illuminated surfaces (‘light’), the amount of visible sky (‘sky’), cover towards the horizon line (‘cover’), ponds, park architecture and furniture, and flowering plants. All of the pictures were designed to simulate conditions in a sunny environment (the background sky was free from cloud cover) between 11 am and 2 pm during the growing season (late spring and summer). The generated images avoided scenes containing rain or fog and depicting evidence of vandalism, antisocial behaviour, people, and wild or domestic animals. The hardware used to create the visualisations as well as other technicalities are described in the Supplementary A.

2.2 Research variables

Our research included eleven variables – five independent variables relating to different aspects of park landscapes and vegetation density: ‘light’, ‘sky’, ‘cover’, plants in bloom, ponds, and park architecture/furniture, as well as six dependent variables: coherence, complexity, legibility, mystery, preference and safety. The examples of urban park settings (108) were divided into three ambiguous categories regarding the current state of the terrain configuration and vegetation density: (1) ‘flat terrain with sparse (18) or dense vegetation (18)’ (36 visualisations); (2) ‘elevated terrain with sparse (18) or dense vegetation (18)’ (36 visualisations) and (3) ‘varied terrain with sparse (18) or dense vegetation (18)’ (36 visualisations). Figures 1 and 2 show examples of computer visualisations ranked the highest and lowest by the participants for each of these categories.

Our research used two methods of measurement. The first involved the independent variables, measured from the computer generated visualisations. This gave us the relative cover, determined by the total proportion of the photo pixels covered by independent variables. The calculations were made via ImageJ (Image processing and Analysis in Java, v. 1.54f; Java 1.8.0_322) (Rueden et al., 2017). This mainly involved selecting and subtracting elements from the total number of pixels in the frame (see also (Pardela et al., 2023). The second method was based on the study participants’ perception. Therefore we used anonymous surveys which are ideal for documenting perceptions and collecting quantitative data. The respondents were presented with computer generated visualisations representing 108 different park scenes. These variables were evaluated on a single-item 5-point Likert scale (1 = the lowest, 5 = highest). The following questions were drafted using operational definitions from environmental psychology (Herzog & Bryce, 2007; Nassauer et al., 2021) and read as follows:

- Preference: ‘How much do you like the setting? (I like it, I quite like it, I neither like it nor dislike it, I don’t like it very much, I don’t like it at all)

Flat terrain, sparse vegetation

Flat terrain, dense vegetation

Elevated terrain, sparse vegetation

Elevated terrain, dense vegetation

Varied terrain, sparse vegetation

Varied terrain, dense vegetation

Figure 1. The most preferred terrain configuration types with dense and sparse vegetation.

- Safety: 'Would you say this place looks dangerous, quite dangerous, neither dangerous nor safe, quite safe, safe'?
- Coherence: 'How well does the scene hang together? How easy is it to organise and structure the scene?' (not coherent, a little coherent, averagely coherent, quite coherent, very coherent)
- Complexity: 'How much is going on in the scene? If the scene contains a lot of elements of different kinds, rate it high in complexity' (nothing happening, a little happening, average, quite a lot happening, a lot happening)
- Legibility: 'How easy would it be to find your way in the setting? How easy it would be to figure out where you are at any given moment or to find your way back to any given point in the setting' (not legible, a little legible, averagely legible, quite legible, very legible)
- Mystery 'How much does the setting promise that more could be seen if you just walked further inside? Does the setting seem to invite you to go further inside and discover more?'(not mysterious at all, not very mysterious extent, averagely mysterious, quite mysterious, very mysterious).

Flat terrain, sparse vegetation

Flat terrain, dense vegetation

Elevated terrain, sparse vegetation

Elevated terrain, dense vegetation

Varied terrain, sparse vegetation

Varied terrain, dense vegetation

Figure 2. The most legible terrain types with dense and sparse vegetation.

2.3 Sampling size and data collection procedure

The study participants were recruited from among the staff and students of Wrocław University of Environmental and Life Sciences taking courses including design and IT in landscape architecture and spatial planning. They were informed of the survey date in advance. There was no remuneration for participating in the study. The respondents were informed beforehand that participation in the survey was voluntary and that they could withdraw from the study at any time. The study participants were only adults (18 years of age or older), not legally incapacitated, of Polish nationality. They were men and women of different ages (age range = 19–65 years; Mage = 22.82; SDage = 8.74). Our sample comprised 200 participants (118 females and 82 males). A total of 207 questionnaires were collected, of which 7 were incomplete and were discarded. The answers were marked by the respondent in the presence of an interviewer. The study participants were randomly divided into 16 groups ranging from 12–14 people in size. Before starting the actual study, the participants watched a trial slide show containing 8 visualisations that varied in terms of the variables being measured. This was to familiarise them with the procedure and create a scale in their mind on which they would evaluate the photos, adapted to the range of features of the presented landscapes (Lis & Iwankowski, 2021b; Lis et al., 2021). The participants handed in their completed questionnaire forms to the person in charge before leaving the laboratory. As a result, the participants rated the landscapes presented in 108 slides in terms of one dimension only (by answering a question on one of the six dependent variables). The participants evaluated computer generated visualisations of urban parks for preference (n = 33), safety (n = 33), mystery (n = 35), legality (n= 33), coherence (n = 31) or complexity (n = 35)). Such a procedure is often used in studies where landscape assessments are analysed (van Rijswijk & Haans, 2018; Lis et al., 2022; Pardela et al., 2023). The study lasted approximately 30 minutes along with the introduction and trial demonstration, and was held in a computer laboratory. The study was conducted in Polish from September to October 2023.

2.4 Data analysis

We chose settings as the unit of analysis and the setting scores were the raw scores (cf. Herzog & Kirk, 2005; Lis, et al., 2019; Lis & Iwankowski, 2021a; van Rijswijk & Haans, 2018). All the pictures were assigned to one of the three terrain groups (flat, elevated and varied) and to one of the two vegetation groups (dense and sparse). In order to minimise the possible impact of uncontrolled factors on our dependent variables (coherence, complexity, danger, legibility, mystery and preference), the images used in the research sample also met specific criteria. For the first set of variables (independent variables: light, sky, cover – measured as percentage of pixels filling the image, while plants in bloom, water and park architecture, and furniture were measured as quantitative variables (absence/occurrence)), the setting score was the percentage of pixels measurement based on a given photo. For the second set of variables (dependent variables: preference, safety, mystery, coherence, complexity and legibility), the setting score was the mean score for each setting based on all participants who completed one of the evaluation tasks. Therefore, for each rated variable, each of the 108 pictures displayed on the slides had a setting score. Internal consistency reliability coefficients (Cronbach's alpha), based on settings as cases and participants as items, ranged from .81 to .97 (αsafety = .97, αpreference = .87, αmystery = .93, αcoherence = .93, αlegibility = .81, αcomplexity = .95). To answer the research questions, we conducted statistical analyses using the JAMOVI 2.3.26 package (The Jamovi Project, 2022). We performed several Pearson correlations analyses as well as ANOVA analysis of variance, t-Student tests for independent groups and regression analysis. We adopted $\alpha = .05$ as the level of significance in the hypothesis testing process.

3 Results

3.1 Terrain analysis

Initially, we checked whether the photos assigned to one of the three groups differed in terms of the second set of variables: preference, safety, mystery, legality, coherence, and complexity. To so we conducted an ANOVA analysis. The findings revealed that groups differed according to safety and preference (Table 1 and Table S1). Post-hoc analysis showed that pictures from group 1 (flat) differed from pictures from group 2 (elevated) in terms of safety. Group 1 was considered to be safer than pictures from group 2, so we observed the same pattern of preference (psafety = .05, ppreference = .03). The average level of preference divided by terrain is presented in Figure 3. In summary, photos depicting flat terrain were perceived as safer than ones featuring elevated terrain. This difference in perceived safety also affected preference, with flat terrain proving to be prefera-

Table 1. Statistics for the second set of variables for terrain analysis.

	F	p
Safety_mean	3.00	.054
Preference_mean	3.76	.027
Mystery_mean	2.47	.090
Coherence_mean	1.85	.162
Legibility_mean	1.34	.267
Complexity	0.66	.517

ble. Other variables such as mystery, coherence, legibility, and complexity did not significantly influence the differences between the photo groups.

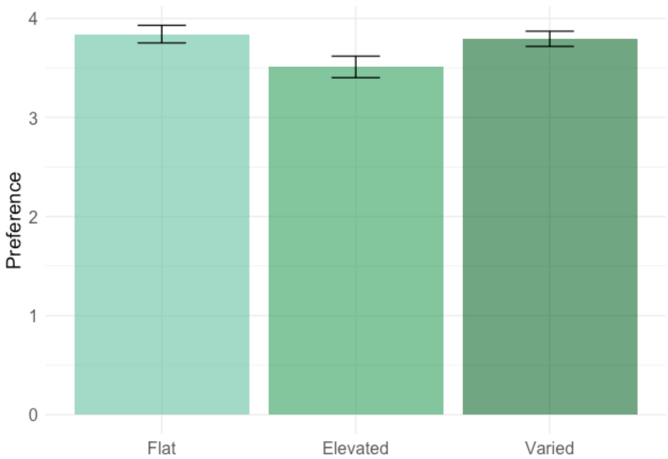

Figure 3. Average level of preference according to terrain configuration.

3.2 Vegetation analysis

We checked whether the pictures assigned to one of the two groups differed for the second set of variables: preference, perceived safety, mystery, legibility, complexity and coherence. To do so, we conducted t-Student tests. Results showed that groups differ according to safety, mystery, legibility and coherence (Table 2). Photos with dense vegetation were considered as more mysterious and complex while photos with sparse vegetation were seen as safer and more legible. Figure 4 presents the average for the second set of variables according to vegetation.

That means that the photos depicting dense vegetation were perceived as more mysterious and complex, while those featuring sparse vegetation were thought to be safer and more legible. Dense vegetation can obstruct one's view and evoke a feeling of uncertainty, which explains the perception of mystery. In contrast, sparse vegetation facilitates visibility, which promotes a sense of safety and legibility. It is worth noting that preference did not differ significantly between photos depicting dense or sparse vegetation. So, despite the variations in perceptions of safety, mystery, and legibility, both types of photos were similarly appealing to observers. The group descriptiveness was presented in Table S2 in the Supplementary A.

Table 2. Statistics for the second set of variables for terrain analysis.

	Statistic	p	Mean difference	Effect Size
Safety_mean	14.05	**< .001**	1.56	2.70
Preference_mean	-0.30	.764	-0.03	-0.06
Mystery_mean	-7.84	**< .001**	-0.77	-1.51
Coherence_mean	-0.82	.413	-0.05	-0.16
Legibility_mean	3.22	**.002**	0.38	0.62
Complexity	-5.91	**< 0.001**	-0.66	-1.14

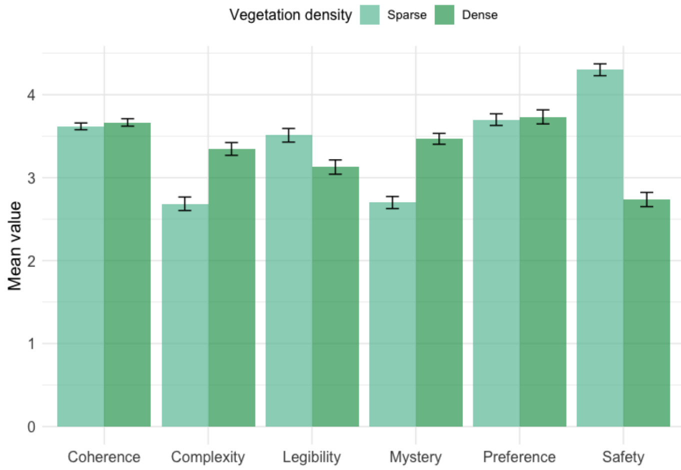

Figure 4. The average for the second set of variables according to vegetation

3.3. Relationships between the features depicted by the photos and the respondents' evaluations

Next, we checked which of the first set of variables (measured on a quantitative scale – 'sky', 'light' and 'cover' – photo features) correlated with the second set (respondents' evaluations). To do so, we conducted Pearson correlations (Table 3). Our findings revealed that 'sky' and 'light' correlated with mystery and perceived safety (Figure 5 and 6). All correlations with mystery were moderately negative, while those with perceived safety were positive: low for 'sky' and moderate for 'light.' 'Cover' also demonstrated a moderately strong positive correlation with mystery and coherence, but a weak negative correlation with legibility. Only 'sky' showed a weak negative correlation with preference. This means that the amount of light in a photo affects how it is perceived in terms of safety and mystery. Brighter photos with plenty of light are thought to be safer, while darker photos with less light are seen as more mysterious. In turn, the amount of visible sky shown in a pho-

Table 3. Correlations coefficients for the photo features x respondents' evaluations.

		Complexity	Coherence	Safety	Preference	Mystery	Legibility
Cover	Pearson's r	**0.557*** **	0.121	-0.679	0.020	**0.577*** **	**-0.250** **
	p-value	**< .001**	0.211	< .001	0.840	**< .001**	**0.009**
Light	Pearson's r	-0.269	-0.119	**0.536*** **	-0.095	**-0.429*** **	0.081
	p-value	0.005	0.219	**< .001**	0.327	**< .001**	0.402
Sky	Pearson's r	-0.157	-0.007	**0.301** **	**-0.206* **	**-0.373*** **	0.153
	p-value	0.105	0.943	**0.002**	**0.033**	**< .001**	0.113

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

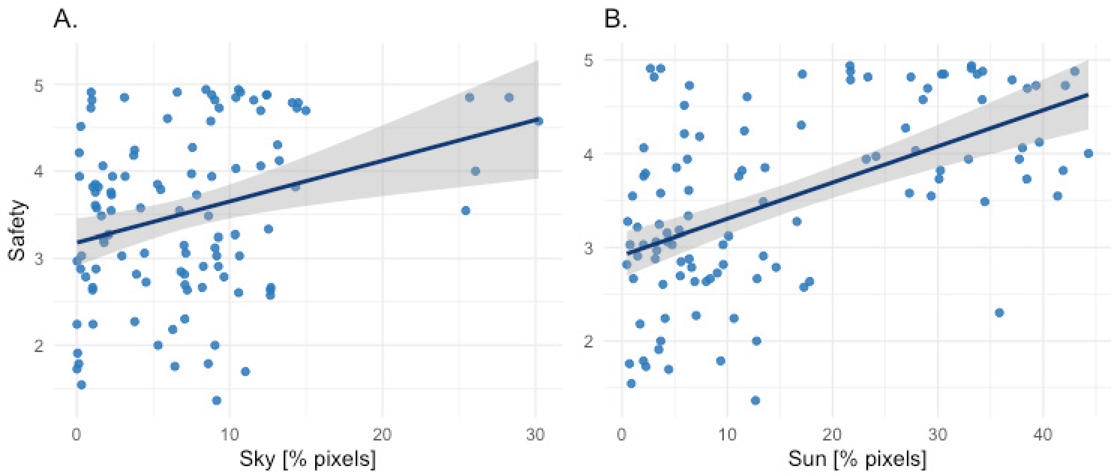

Figure 5. Scatter plots for perceived safety and sky (A) and sun (B).

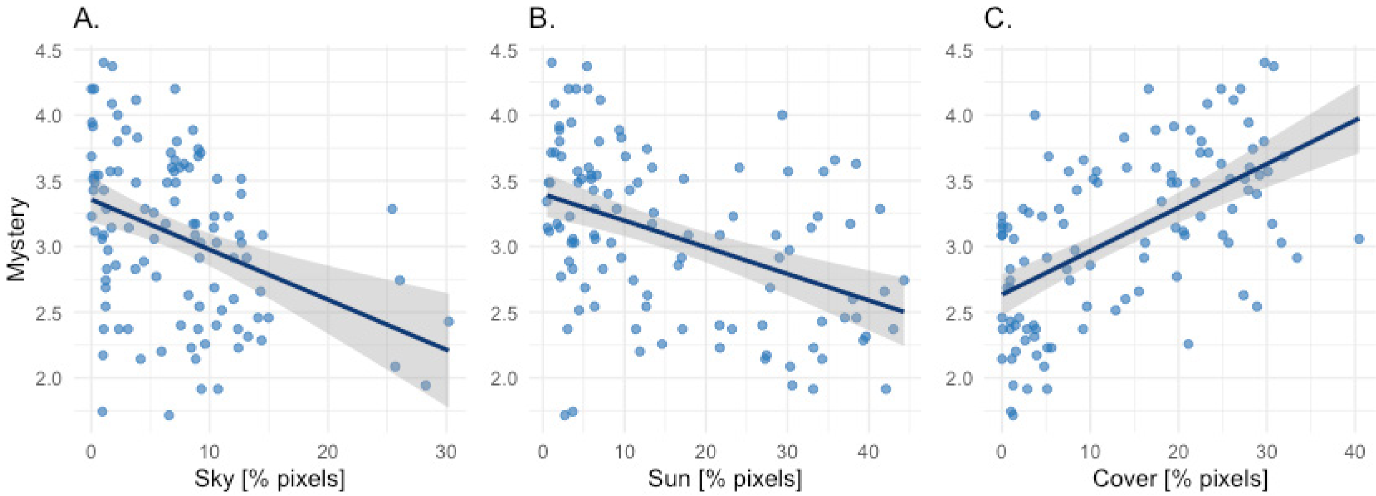

Figure 6. Scatter plots for mystery and sky (A), sun (B) and cover (C).

to also affects the perception of safety and mystery. The more sky, the safer, while the less sky, the more mysterious it is perceived to be.

Next, we checked whether preference differed depending on the presence or absence of the first set of variables measured on a nominal scale (water, park architecture and the presence of flowers in bloom). For this purpose, a series of t-Student tests were performed. Analyses showed that landscapes containing flowers in bloom (t(106) = 3.12, p = 0.002) and park furniture (t(106) = 1.81, p = 0.073 (on the border of statistical significance)) scored higher in terms of preference (Figure 7). To summarise, the respondents prefered park photos featuring flowers as well as park furniture.

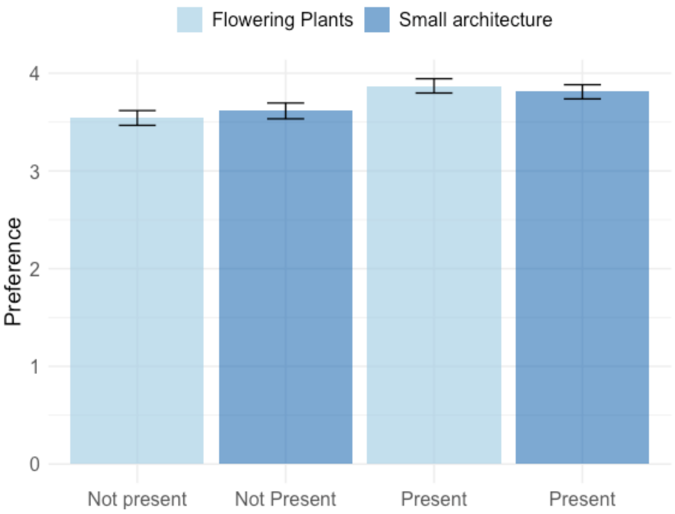

Figure 7. Mean preference for pictures with and without plants in bloom and park furniture.

Table 4. Results of linear regression analysis for perceived preference.

Predictor	Estimate	SE	t	p
Intercept	2.6901	0.68556	3.924	< .001
Complexity	0.3961	0.09924	3.991	< .001
Terrain configuration:				
Elevated – Flat	-0.1178	0.12771	-0.923	0.358
Varied – Flat	0.0204	0.12002	0.170	0.865
Coherence	0.0522	0.16321	0.320	0.750
Safety	0.0301	0.06440	0.467	0.641
Mystery	-0.3068	0.13196	-2.325	0.022
Legibility	0.2160	0.07996	2.702	0.008
Sky	-0.0283	0.00848	-3.342	0.001

3.4 Regression analysis

To check how the above-mentioned significant results could predict preference, we ran a regression analysis. The results showed that the model fits the data well, $F(8,99) = 5.67$, $p < .001$ and explained 31% of the variance. The higher the level of coherence and legibility, the higher the preference. The less sky and the lower the level of mystery, the higher the preference (Table 4). This means that strongly coherent and legible photos are preferred, especially if they are easy to understand and interpret. The less visible sky there is, the more attractive they appear, probably because they offer an optimal level of mystery. Regression analysis showed that more complex photos were well received, suggesting that more engaging photographs are rated higher. In contrast, terrain configuration and sense of safety did not significantly affect preference.

4 Discussion

Our study analysed how terrain and vegetation density may influence preference and sense of safety in the context of computer-generated park landscapes. Our findings indicate that terrain does have an impact on preference and safety, while the relationship with the components of the Kaplan model turned out to be statistically insignificant. In turn, vegetation density has an impact not only on preference, but also on mystery and safety, in line with previous research. The strongest predictors of preference for the park landscapes we created turned out to be legibility, complexity and coherence.

4.1 Impact of terrain on preference and safety

The first group of analyses were performed with the aim of furthering our understanding of how park terrain impacts the preference and safety components of the Kaplan model. Variance analysis showed that diverse terrain, although it enhances a park's aesthetic and scenic values, undermines sense of safety. This confirms earlier observations made by Lis and colleagues (Lis et al., 2014; Lis, et al, 2024). In turn, because it is easy to move freely around flat terrain, sense of control over the environment may be strengthened, which translates into a higher level of perceived safety. This is consistent with Appleton's theory and other observations (e.g. Schroeder, 1990; Han, 2007). Flat terrain also elicits a higher level of preference compared to elevated terrain. This may be due to the fact that flat areas are more legible, which facilitates navigation. Easier orientation may in turn translate into a sense of control over the environment, and therefore a stronger sense of safety (Lis, Zalewska, & Grabowski, 2024).

4.2 Impact of vegetation density on mystery, safety and legibility

Correlation analysis further revealed a relationship between vegetation content and sense of mystery, safety and legibility in the context of evaluating park landscapes. Dense vegetation was considered to enhance sense of mystery compared to sparse vegetation. This finding suggests that people prefer denser vegetation in urban environments, as confirmed by theories such as the Attention Restoration Theory and the Biophilia Hypothesis. This can be explained by the fact that dense shrubs limit visibility, which stimulates the imagination and creates the impression of hidden spaces (Newell, 1997). This is confirmed by the Kaplans' theory of landscape preference, according to which mystery is one of the key aesthetic elements of green areas. At the same time, dense vegetation impairs sense of safety, while sparse vegetation promotes a sense of safety and legibility because dense vegetation can offer potential hiding places for dangerous people, which reduces sense of control over the environment (Lis & Iwankowski, 2021a; Lis, Zalewska, & Grabowski, 2024; Sezavar et al., 2023). In turn, a transparent vegetation layout offers good visibility, which facilitates orientation and enhances one's sense of control over the situation. This is confirmed by the findings of other authors, where respondents assessed visualisations of parks with different vegetation densities. It turned out that the more transparent the layout of greenery, the higher the sense of safety and legibility (Suppakittpaisarn et al., 2020).

4.3 The correlation between vegetation density metrics and other elements of park landscapes, contrasted with perceptions of safety and mystery

While our findings concur with previous research in several ways, especially in terms of preference for vegetation density, some of the findings differ from previous studies. All three features ('cover', 'sky' and 'light') demonstrated correlation with mystery. However, this correlation was positive for 'cover' and negative for 'sky' and 'light'. This means that the more plant forms can offer a place of concealment or a viewing screen ('cover'), the greater the mystery of the landscape, while the sparser the tree crowns observed when looking up or down ('light' and 'sky'), the lower the mystery. Correlation analyses also showed that both 'sky' and 'light' are moderately associated with perceived safety. Only the 'sky' variable correlated with preference, which differs from the finding obtained by Lis and Iwankowski (Lis & Iwankowski, 2021b) and requires further research.

The landscape feature that increased respondents' preference for the studied landscapes was vegetation in bloom, despite the fact that the landscapes we generated were primarily natural and dominated by greenery. Park architecture and furniture, although bordering statistical significance, also affected the respondents' preference for the landscapes. This may be related to the landscapes, the presence of natural surfaces, the paucity of park furniture such as benches or rubbish bins, and the lack of hardscapes.

The results indicate that the presence of water in the landscapes did not affect the respondents' preference, an observation that differed from the findings obtained by White et al. (White et al., 2010) . However, we did notice that water in its natural form was present among the highest rated visualisations for diverse and elevated terrain, thus confirming White's et al. observation that naturalness enhances visual rating (White et al., 2010).

4.4 Limitations

The study featured several limitations. We decided to use computer-generated images based on 3D models and stationary surveys because it allowed us to manipulate the terrain and vegetation density with the same viewpoints. However, as Bishop and Rohrmann report (Bishop & Rohrmann, 2003), even the most detailed computer simulations do not necessarily generate the same responses as a corresponding real environment. Therefore, we suggest that future research should focus on determining preference for terrain for non-computer-generated and more diverse topography in various environments. Simulated nature in the form of image slideshows elicits improvements in emotional state as well, although the effects are somewhat smaller than those of actual nature exposure (Meidenbauer et al., 2020). We are therefore aware that assessments made in situ could differ due to factors that our study did not take into account. Therefore, the respondent neither saw any other people in the park (Lis & Iwankowski, 2021a), nor heard any sounds from the surrounding area (Chrobak et al., 2024), nor felt changes in weather conditions (Półrolniczak & Kolendowicz, 2021), including air temperature and humidity (Yu et al., 2020, p. 20). It would also be worth checking if cultural differences affect how park landscapes are perceived. Another limitation is the sample selection, including the type of park landscape, terrain, vegetation cover and season (simulated late spring and summer). Landscapes of a natural character, physically accessible, with low or moderate level of design intensity and maintenance were studied. These were visualisations that did not take into account specific forms of nature protection and were made during the day in the Central European environment (vegetation cover). In our opinion, a subsequent study could include varying degrees of landscape naturalness, including hardscapes and various composition of plant species for specific scenarios (e.g. including climate change).

5 Conclusion

In this study we aimed to determine how different features of the park landscape – primarily terrain and vegetation density – affect preference for natural-looking park landscapes. For this purpose, we used computer-generated images of parks with different terrain configuration, vegetation density, illuminated surfaces, sky presence, presence of water features, flowering plants and park furniture, and furniture. The respondents rated these images according to various aspects, including coherence, complexity, legibility, mystery, preference, and perceived safety.

Main findings from the study:

1. Flat terrain is perceived as safer than elevated terrain, which in turn affects preference (photos of flat terrain received better ratings). Flat terrain enhances one's feeling of control over the environment, which then translates into stronger perceived safety.
2. Dense vegetation is perceived as more mysterious and complex, while sparse vegetation is seen as safer and more legible. Dense vegetation can limit visibility and so may also stimulate the imagination, which promotes a sense of mystery. However, sparse vegetation is more conducive to visibility, which enhances sense of security as well as legibility.
3. The amount of light and visible sky affects perceptions of safety and mystery. Park landscapes with plenty of light and visible sky are seen as safer, while landscapes with less light and sky are thought to be more mysterious.
4. Flowering plants and park furnishing enhance preference for park landscapes.
5. Coherence, legibility and natural complexity of the natural are strong predictors of park landscape preference. The greater the coherence and legibility, the stronger the preference. Landscape complexity positively affects preference.

In summary, the findings of our research provide some insight into the relationship between selected landscape features and their reception, which is particularly relevant when it comes to designing park areas. Terrain configuration ought to be considered when designing natural-looking parks. In the case of flat terrain, designers should strive to create open spaces with good visibility and that facilitate orientation. In turn, diversified terrain can enhance the aesthetic appeal of landscape. Therefore, designers should attempt to find a balance between safety and visual appeal. Creating open viewing spaces that also offer sheltered spots – for instance, by planting trees or shrubs – may be helpful in this respect. At the same time, a balance should be sought between the desired degree of mystery and the aesthetic appeal of the landscape (complexity and legibility) by creating open spaces with a visible sky, which are also accessible (via a network of paths). These spaces should encourage people to visit and offer psychological well-being (a small number of viewing screens and hiding places, a large amount of sunlight). Flowering plants and park architecture, and furniture make a park more appealing for visitors. For this reason, designers should include a variety of plant species with different flowering periods to ensure the visual aesthetics of plant cover throughout the year. Additionally, park furniture such as benches or rubbish bins, which users tend to prefer, should be included.

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Declaration of Competing Interest

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

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Supplementary A

Table S1. Results of the manipulation of independent variables.

Terrain configuration	No. of visualisations	Plants in bloom	park architecture/ furniture	Water
Flat	Dense 18	8	7	10
	Sparse 18	9	9	9
Elevated	Dense 18	8	8	10
	Sparse 18	9	9	10
Varied	Dense 18	8	10	10
	Sparse 18	9	9	9

Table S2. Group descriptives for dependent variables.

	Group	N	Mean	*SD*	*SE*
Safety_mean	1 Flat	36	3.83	0.956	0.1593
	2 Elevated	36	3.29	0.935	0.1559
	3 Varied	36	3.43	0.978	0.1630
Preference_mean	1 Flat	36	3.84	0.534	0.0890
	2 Elevated	36	3.51	0.651	0.1085
	3 Varied	36	3.79	0.460	0.0766
Mystery_mean	1 Flat	36	2.90	0.719	0.1198
	2 Elevated	36	3.21	0.579	0.0965
	3 Varied	36	3.14	0.577	0.0961
Coherence_mean	1 Flat	36	3.71	0.306	0.0510
	2 Elevated	36	3.57	0.273	0.0455
	3 Varied	36	3.64	0.351	0.0585
Legibility_mean	1 Flat	36	3.39	0.689	0.1148
	2 Elevated	36	3.18	0.628	0.1047
	3 Varied	36	3.39	0.606	0.1011
Complexity	1 Flat	36	3.00	0.740	0.123
	2 Elevated	36	2.94	0.634	0.106
		36	3.11	0.624	0.104

Technical information regarding the preparation of the visualisations in Lumion Pro 12.5*

For each visualisation, three render passes were made to store additional information regarding the background information (‘SkyAlpha’, ‘Lighting’, and ‘MatID’). In order to make the shots more photorealistic for the study, high-quality seamless ground cover textures, customisable 3D terrain grass and high-quality animated plant models from the built-in Library (Evermotion 3D plant models available in Lumion Pro version) were used.

The hardware used to create the visualisations was a PC with a Gigabyte RTX 3080 Ti Aorus Master graphics card (12 GB RAM) and an Intel Core i9-12900K main processor (3.2 GHz) on a MSI MAG Z690 Tomahawk main board with 64 GB RAM.

The computer lab was equipped with Lenovo AIO ThinkCentre E92z computers with 21.5-inch screens and an Epson EH-TW6250 4K UHD projector (3840 x 2160, 16:9) to display the slides. Each slide was displayed for 15 seconds for evaluation.

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