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Original Research Article

The Role of Trees in Evaluating the Visual Aesthetics and Morphological Complexity of Urban Landscapes*

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Abstract | Despite the vital role that trees play in enhancing the visual quality of urban spaces, there is no clear scientific consensus regarding the extent and manner of their influence on the aesthetics and complexity of urban landscapes. Most previous studies have focused primarily on subjective evaluations, with limited analysis of how the removal or addition of trees precisely affects the morphological complexity and visual aesthetics of such environments. This gap underscores the need for a rigorous and comprehensive investigation. This study aims to examine the impact of adding or relocating trees on the visual aesthetics and morphological complexity of urban landscapes. The central research question is whether such interventions consistently enhance visual quality, or whether, in certain cases, they may produce counterproductive effects. The study adopted a mixed-methods approach. By employing augmented reality (AR) visual simulation techniques and image analysis through ImageJ software, 11 images of diverse urban landscapes from around the world were selected. Subsequently, visual questionnaires were used to collect responses from 51 urban design experts. Data analysis was carried out using chi-square and independent t-tests, alongside fractal dimension analysis of the selected images. In 9 out of 11 cases, the addition of trees significantly enhanced both visual beauty and perceptual complexity (p-value < 0.05; Cramér's V = 0.977). Fractal analysis and independent t-tests further confirmed the higher complexity of tree-lined landscapes. However, in certain instances, trees diminished visual appeal by obscuring architectural details. The findings indicate that the spatial placement of trees relative to the built structure plays a critical role. In other words, the relationship between complexity and beauty is non-linear, suggesting the existence of a "visual threshold" beyond which the addition of natural elements may produce adverse effects. These insights can assist designers in enhancing urban visual experience and quality of life through strategic and context-sensitive tree placement.

Keywords | *Visual complexity, Morphological complexity, Fractal dimensions, Trees, Landscape aesthetics.*

Introduction| Landscape is the result of the interaction between humans and the environment, playing a central role in shaping identity, culture, and quality of life. It serves as a vital foundation for social and economic development as well as the preservation of cultural heritage (Mansouri & Habibi, 2011, 64). "The most usual approximation to the aesthetic quality of the landscape tends to be through its visual dimension" (Serrano Giné et al., 2021, unpaginated). The aesthetic values of a landscape stem from a spectrum of visual attributes and characteristics, or a combination of both. A landscape that captivates the viewer through a legible and memorable structure—or unusual features such as its appearance, smell, or the sound of its natural or artificial elements—is typically assessed as having high aesthetic value (Othman et al., 2015, 331). Aesthetics plays a crucial role in the landscape, serving as a driving force for its transformation grounded in cultural values, social justice, and environmental rights. This approach supports the creation of sustainable, beautiful, and meaningful landscape spaces through the generation of innovative formal expressions (Habibi, 2017, 65). Moreover, visual appeal and aesthetic qualities play a decisive role in

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shaping user preferences and encouraging public presence within urban open spaces (Haghani, 2015).

Recognizing trees as key components of green infrastructure—with their roles in reducing temperatures, conserving energy, and mitigating the urban heat island effect—can offer an effective strategy for addressing the growing challenges faced by contemporary cities (Habibi & Kahe, 2024; Arsiya & Mehrabani Golzar, 2018). Urban green space, as a fundamental element of the urban environment, not only contributes to improved quality of life and enhanced ecological health, but also plays a significant role in shaping the visual identity and aesthetic experience of urban residents (Chiesura, 2004; Tzoulas et al., 2007; Nowak & Dwyer, 2007). Moreover, trees and vegetation—primary indicators of such spaces—substantially enhance visual appeal and increase environmental complexity (Liu et al., 2021). However, the extent and manner of their influence on urban landscapes remain subjects of ongoing debate.

Many previous studies have addressed the importance of natural elements in enhancing the visual quality of urban spaces. However, these investigations have largely focused on general assessments of aesthetic impacts, with limited exploration of the precise relationship between the addition or removal of trees and resulting changes in the morphological complexity of built structures. Furthermore, most of these studies emphasize individuals' subjective perceptions of the beauty of green spaces, whereas quantitative and analytical methods capable of accurately evaluating visual changes resulting from the interaction between natural and built elements have been used far less frequently.

Given that cities are composed of both natural and artificial physical structures, achieving a balance between these two elements is essential. On the one hand, the addition of trees and vegetation can enhance the visual appeal and attractiveness of urban spaces; on the other hand, it may reduce visual legibility or lead to excessive complexity, thereby affecting the overall environmental experience. Accordingly, this study seeks to investigate this issue through a combination of visual analysis methods, expert evaluations, and image processing techniques. The aim of the study is to provide a deeper understanding of how natural elements influence the visual and perceptual structure of the urban environment.

The central focus and primary objective of this study is to examine the impact of adding or relocating trees in urban landscapes on visual aesthetics and morphological complexity. The key research question is whether the addition or relocation of trees consistently leads to enhanced beauty and visual complexity in urban scenes—and how an optimal balance between these two criteria can be achieved. In this context, the research hypothesis can be formulated as follows: the addition of trees consistently results in a simultaneous increase in both visual beauty and morphological complexity of urban landscapes.

Research Background

The investigation of the interrelationship between complexity, aesthetic quality, and functional use of green spaces has emerged as a pivotal theme in recent scholarly discourse. Such inquiry contributes to a more comprehensive understanding of how urban design strategies can enhance the quality of residential environments. To establish a cohesive framework for interpreting the scope of existing research, these studies may be systematically categorized into four principal domains.

• Studies on parks and public green spaces

A substantial body of research has concentrated on examining the relationship between vegetation and aesthetic quality within parks and public green spaces. Mendes et al. (2024), through an empirical study of natural remnants, urban parks, and vacant lots in Canada, demonstrated that in green spaces, visual complexity, and botanical diversity are positively associated with aesthetic evaluations. Conversely, the presence of artificial structures within vacant lots tends to diminish perceived aesthetic value. Jahani et al. (2021) similarly applied artificial neural network modeling to assess factors influencing visual complexity in park landscapes, identifying elements such as hard surface coverage, average tree diameter, and building presence as the most significant predictors. Their model has been proposed as a predictive tool for estimating spatial complexity and fostering urban tourism development. Furthermore, the study by Hami et al. (2014), focusing on urban green environments, revealed that lower complexity of natural elements correlates with increased social interaction, whereas higher complexity levels may result in reduced visual appeal and perceived safety. These findings underscore the necessity of maintaining a balanced interplay between visual aesthetics and functional performance in the design of green urban spaces.

• Studies on residential environments and urban fabric (suburbs and streetscapes)

A segment of scholarly investigations has centered on residential environments, encompassing both suburban landscapes and intra-urban streetscapes. Vukomanovic & Orr (2014), in their study on suburban scenery, found that residences featuring greater vegetation coverage, more intricate land patterns, and expansive visual corridors were associated with enhanced visual appeal. Their findings reinforce the role of visual complexity and view scale as significant parameters in environmental aesthetic perception. In a complementary vein, Weber et al. (2008), through an analysis of urban street elements, identified symmetry, uniformity, vegetative presence, stylistic lightness, and scale homogeneity as key determinants of aesthetic judgment. Both studies underscore the significance of physical configurations and vegetative diversity in shaping aesthetic experience within the everyday urban context.

• Studies with historical and longitudinal perspectives

A number of studies have adopted a historical and longitudinal lens to examine the transformation of urban landscape aesthetics over time. Sarafraz Asbagh et al. (2022), through a diachronic analysis of urban visual quality in Tabriz between 1984 and 2020, revealed that urbanization has contributed to the fragmentation and diminished coherence of cityscapes. However, their findings also highlight a growing significance attributed to visual complexity and naturalistic characteristics over time. These insights underscore the imperative of continuous monitoring of landscape complexity and integrating such dynamics into urban design frameworks. Similarly, Orzechowska-Szajda (2014) identified complexity as a fundamental indicator of aesthetic quality, demonstrating that diversity and richness in natural elements are pivotal in shaping visual perception and enhancing users' psychological well-being. She cautioned that homogenization and reduced diversity within landscapes may undermine their perceived aesthetic value.

• Conceptual studies based on vegetative diversity

Studies such as those by Zhang et al. (2022), Harris et al. (2017), and Bergerot et al. (2020) have explored the role of plant diversity in shaping the aesthetic perception of urban landscapes. These investigations have primarily focused on parks, private gardens, or spatially confined intra-urban environments. Within these studies, the concept of "complexity" is predominantly equated with "vegetative diversity" and is consistently associated with positive aesthetic preferences. However, scholarly resources that offer a comparative and integrative analysis of complexity within both the constructed physical environment and natural systems[1] in urban settings remain limited. The present study approaches the notion of complexity from a differentiated perspective, examining its impact on the aesthetic quality of urban streetscapes by incorporating both morphological and compositional parameters.

In contrast to numerous preceding studies that primarily focused on general evaluations of how visual complexity and natural element diversity influence the aesthetics of urban landscapes, the present research undertakes an empirical investigation into the effects of adding or removing natural elements—such as trees—on both perceived complexity and, subsequently, on the aesthetic appraisal of urban scenery. Distinctively, this study transcends subjective assessments by employing rigorous statistical methodologies, including the chi-square test and independent samples t-test, to evaluate the significance of visual variation. Furthermore, whereas earlier research has largely emphasized overarching correlations between landscape complexity and aesthetic perception, this paper offers an alternative analytical framework that centers on the interplay between natural and physical components of the urban fabric. In doing so, it proposes a more integrative approach to urban space design and management—one that simultaneously addresses the psychological, aesthetic, and ecological needs of urban inhabitants.

Theoretical Framework

Urban green spaces, as one of the most pivotal components of the urban environment, play a vital role in enhancing the quality of life for city dwellers and elevating the aesthetic dimension of urban settings. These spaces not only serve as platforms for social interaction and psychological well-being but also act as key agents in fostering visual diversity and aesthetic richness within urban landscapes. Complexity, as a fundamental attribute of landscape composition, exerts a decisive influence on individuals' aesthetic experience. A more nuanced understanding of this relationship can serve as an effective tool for the sustainable planning and management of urban spaces. This study seeks to explore each of these dimensions in depth and ultimately proposes a differentiated conceptual framework—distinct from prior research—to better elucidate the dynamic relationship between constructed urban forms and natural elements.

• The significance of morphological and visual complexity in the definition and perception of urban landscape

Cities are inherently complex systems that exhibit nonlinear and often chaotic behaviors across their various subsystems (Haghani & Larkham, 2010). According to Reid Ewing & Handy (2009, 81), "morphological complexity refers to the visual richness of a place. The complexity of a setting depends on the diversity of the physical environment—specifically, the number and variety of buildings, architectural diversity and ornamentation, natural elements, street furniture, signage, and human activities." Based on this definition, it becomes evident that complexity permeates all components of the urban fabric. It is manifested not only in physical and natural dimensions—such as trees, green spaces, landscapes, and urban furnishings—but also in the subjective experiences shaped within individuals. Even the presence of people and the nature of their activities contribute directly to the perceived environmental complexity.

Key indicators of the urban landscape include population density, development dispersion, population concentration, urban complexity, and cultural and environmental values, among others (Delclòs-Alió et al., 2023, 194; Habibi, 2017). Ode & Miller (2011, 24 & 25) argue that complexity refers to the diversity and richness of landscape elements and features, as well as the interplay of patterns within the landscape. According to their view, landscape complexity—recognized as a critical concept for articulating visual character—is defined through a wide array of landscape metrics that describe visual intricacy. Accordingly, urban landscape complexity reflects the inherently multifaceted nature of spatial configurations, built structures, and constituent elements within an urban area. These include the heterogeneity of physical characteristics, land uses, socio-cultural functions, spatial-morphological arrangements, ecological-environmental systems, and symbolic-identity dimensions, all of which contribute collectively to the overall complexity of the urban environment (Habibi, 2017; Cadenasso & Pickett, 2008).

Findings by Bautista-Hernández (2020) suggest that the relationship between the spatial structure of an urban area and individual behavioral patterns represents a distinct dimension of morphological complexity. Empirical evidence demonstrates how the physical arrangement of urban spaces significantly influences travel behavior and trip-chain dynamics. Furthermore, the spatial distribution of built structures, socio-economic activities, cultural diversity, green infrastructure, and the intricately woven networks of transportation systems are among the multifaceted determinants contributing to urban landscape complexity. These elements interact in dynamic and interdependent ways, collectively shaping the overall complexity of the urban environment (Alberti et al., 2007). Morphological complexity in urban areas encompasses the diverse and intricate elements of the built environment that shape the urban landscape, including spatial configurations, design attributes, and the physical characteristics of the city. The morphological complexity of urban regions is influenced by a range of factors, including the heterogeneity of the urban fabric and the degree of socio-spatial homogenization within its communities. These factors significantly affect the inherently complex nature of urban development and governance processes (Baynes, 2009). Moreover, street frontage plays a vital role in structuring daily movement patterns within cities, serving as the transitional threshold between public and private domains. Visual complexity in streetscapes arises from the varied configurations of elements embedded within urban territories (Kawshalya et al., 2022).

Complexity science portrays a dynamic and evolving world characterized by pervasive uncertainty (Sengupta et al., 2016). Urban landscape complexity, as a multidimensional construct, plays a critical role in shaping both the visual identity and the functional performance of cities. This complexity emerges not only from the diversity and richness of physical elements—such as buildings, green spaces, and urban furniture—but also from the intricate web of social, cultural, and economic interactions embedded within the urban fabric. A review of the literature suggests that the configuration and spatial arrangement of these elements significantly influence urban dwellers' behaviors, perceptions, and lived experiences (Haghani, 2013). Accordingly, the conscious design and strategic management of such complexity can substantially contribute to the enhancement of urban quality of life, the reinforcement of social engagement, and the improvement of visual legibility and aesthetic appreciation of urban spaces.

• The role of natural elements and complexity in landscape Aesthetics

Green space, as a representative of nature within urban environments, constitutes an essential and inseparable component of a city's morphological and ecological metabolism. Its absence may lead to severe disruptions in the vitality and sustainability of urban systems (Mohammadi Hamidi et al., 2020, 467). Among natural features, trees are widely recognized as the most prominent indicator of urban greenery (Nowak et al., 2006). Aesthetic preference is generally observed to increase with a higher density of trees and the presence of floral components and other vegetative elements (Wang et al., 2019). However, it is important to note that the perceived quality of vegetation is contingent upon factors such as species diversity, the number of vegetative patches, and variation in vegetative forms. These factors collectively establish a framework for enhancing the aesthetic quality and cultural services offered by urban landscape design and management (Zhang et al., 2022). While such dimensions of ecological diversity extend beyond the scope of the current investigation, this study focuses specifically on the presence of trees as the primary constituent of green visual elements in conjunction with built structures and other architectural components within the physical urban environment.

In the discourse surrounding quality of life and urban livability, the physical-aesthetic index is widely recognized as a critical dimension of urban dwellers' satisfaction and perceived well-being (Bandarabad & Ahmadinezhad, 2014). Concurrently, morphological complexity—often conceptualized as visual richness—is regarded as one of the experiential-aesthetic dimensions of the urban environment (Golkar, 2001). Lang (1987) frames aesthetics and complexity within the cognitive capacity to perceive and interpret spatial cues and environmental affordances. Kaplan (1987) further argues that the processes of "perception" and "exploration"—in which complexity plays an integral part—serve as key mechanisms in the understanding and aesthetic evaluation of landscape environments. In line with this, Ode et al. (2008, 92) describe visual complexity as the degree of diversity and richness in landscape elements and patterns, and as the intersection of compositional variety within the spatial fabric.

The visual and structural complexity of green spaces plays a pivotal role in shaping individuals' aesthetic perceptions and environmental preferences (Mendes et al., 2024). This complexity significantly informs design processes and establishes a direct relationship with users' visual engagement and behavioral responses (Liu et al., 2021). Moreover, landscape complexity—characterized by compositional diversity and the presence of varied natural elements—contributes substantially to the visual perception of aesthetic attributes and is associated with numerous psychological benefits for users (Orzechowska-Szajda, 2014; Nazarboland & Sadjadi, 2013). Empirical findings indicate that visual complexity at broader landscape scales exerts a more pronounced influence on aesthetic experience. These results underscore the significance of spatial complexity and scale in green environments as critical determinants in enhancing visual quality and environmental attractiveness (Vukomanovic & Orr, 2014).

Urban green spaces, beyond their foundational role in supporting ecological health, enrich the aesthetic experience of city dwellers through their inherent visual and morphological complexity. The presence of natural elements—particularly trees—and the incorporation of diverse landscape configurations exert a direct influence on individual satisfaction. The visual and structural intricacy of these spaces contributes to enhanced user–environment interaction and augments the overall attractiveness of the urban setting. Strategically designed green spaces hold the potential to elevate urban quality of life. Fig. 1 presents the conceptual model for assessing the visual aesthetics of urban trees through the lens of morphological complexity.

Research Method

This study adopted a mixed-methods approach, employing both qualitative and quantitative dimensions, with an inductive mode of data analysis. According to Bryman & Bell (2019, 25), inductive research "entails moving from specific observations to broader generalizations, from the examination of particular phenomena toward the identification of recurring patterns and the formulation of hypotheses or theories to explain them". Within this framework, the principal aim is to uncover the relationship between the complexity of natural elements and their interaction with the built environment. Accordingly, visual quality is examined through the lens of aesthetic perception, alongside the environmental–morphological complexities that emerge from this interaction. The inductive research method offers a valuable approach to generating new theories and conceptual insights grounded in empirical observations and data. It is particularly suited for exploring socially complex phenomena. Fig. 2 illustrates the methodological framework and analytical procedures of the research, which will be further elaborated in subsequent sections.

Based on the reviewed literature, the study population in this research was defined as the street and square elevations within urban environments. This decision stems from the research objective: to examine how the presence or removal of trees influences the perception of visual aesthetics and complexity from the pedestrian's viewpoint. Given that both spatial typologies—streets and urban squares—play a pivotal role in the morphological structure of cities, and that the interaction between natural and artificial elements is distinctly observable in each, both were therefore included in the analytical scope. Urban landscape constitutes a critical dimension in environmental studies and is frequently prioritized by researchers for its relevance to visual quality assessment. In this context, evaluating the influence of natural elements—such as trees—can significantly impact multiple facets of urban visual quality. For the case studies selected in this research, 30 urban landscape samples from various cities around the world were examined. Given that all participants in the study were Iranian, the selection of international urban scenes was conducted purposively to minimize the influence of participants' cultural and historical backgrounds on aesthetic judgments. The

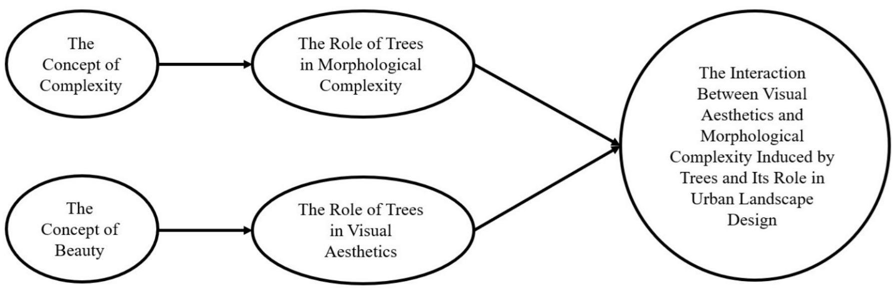

Fig. 1. A conceptual model illustrating the role of trees in enhancing urban visual aesthetics through the lens of morphological complexity. Source: Authors.

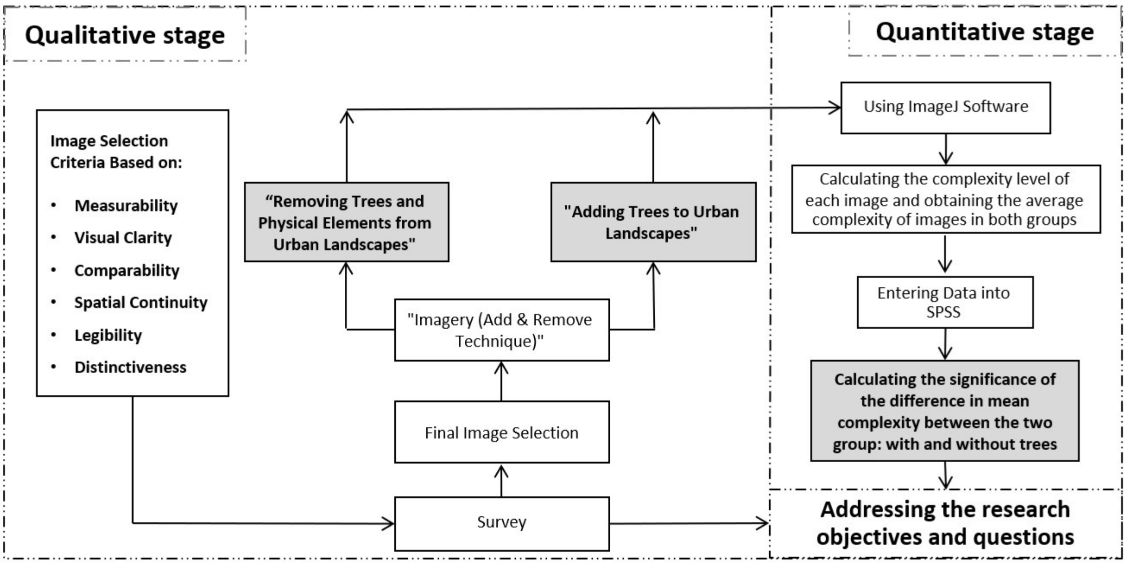

Fig. 2. Methodology. Source: Authors.

selection criteria for these scenes included: sufficient visual clarity to allow for graphic processing and the distinctiveness and legibility of the street or square as verified through a pilot evaluation conducted with a representative sample of participants. From the initial pool of 30 images, a final set of 11 images was selected based on two key conditions: first, the location depicted should be unfamiliar to the participants; and second, at least one of the two images (original or manipulated) must meet expert-defined aesthetic criteria (Fig. 3).

The sample size for this study was calculated using the proportion formula[2] (Chow et al., 2017), resulting in the selection of 51 experts— 35 urban designers and 16 architects—all possessing prior experience in urban landscape design. To gather expert insights, a visual questionnaire was developed, consisting of paired urban landscape images depicting two contrasting conditions: the presence and absence of trees. These image pairs were generated using the Add and Remove (AR) technique (Fig. 4). The questionnaire was distributed online to the selected professionals, all of whom had a proven track record in the field of urban design. Participants were asked to evaluate each image pair in a side-by-side comparison, specifically assessing the aesthetic appeal of each version. The responses were subsequently analyzed to identify perceptual patterns related to tree placement and their influence on perceived visual complexity.

The Add and Remove (AR) technique is a straightforward yet effective method used to simulate and visualize potential future changes resulting from urban policies or proposed design interventions. It assists decision-makers in understanding how spatial complexity may be altered by their choices, enabling them to select the most contextually appropriate and desirable urban scenario (Haghani, 2009). As a technique that directly influences the perceived complexity of visual representations, AR involves the strategic inclusion or removal of natural and built elements within an image. In this study, the AR technique was employed to generate manipulated urban landscape images that incorporated additions or subtractions of specific physical and natural components. Following the image manipulations, a survey was conducted among the 51 selected experts to assess how such alterations influenced their aesthetic judgments. Participants were asked to evaluate the modified images against the original ones in a pairwise comparison, indicating which version they perceived as more visually appealing.

In the visual complexity analysis phase of the urban landscapes, all selected images (in both tree-present and tree-absent conditions) were first standardized using Adobe Photoshop in terms of dimensions, resolution, brightness, contrast, and color, to establish uniform conditions for comparison. This step aimed to eliminate any technical discrepancies and to focus solely on the visual content in the aesthetic evaluation. The final images were saved in BMP format with an RGB color space and were subsequently converted to black and white to eliminate color noise and enhance the visibility of primary forms for analysis.

To measure visual complexity, ImageJ software was utilized. Within this software, the box-counting technique and the FracLac plugin were applied to calculate the fractal dimension of each image. To assess the precision and sensitivity of the analysis, each image was also evaluated at three quality levels (with varying resolutions but consistent brightness and contrast). The numerical values derived from the fractal dimension analysis, serving as quantitative indices for assessing the visual complexity of each landscape, are presented in Table 3. The data analysis process can ultimately be described as follows:

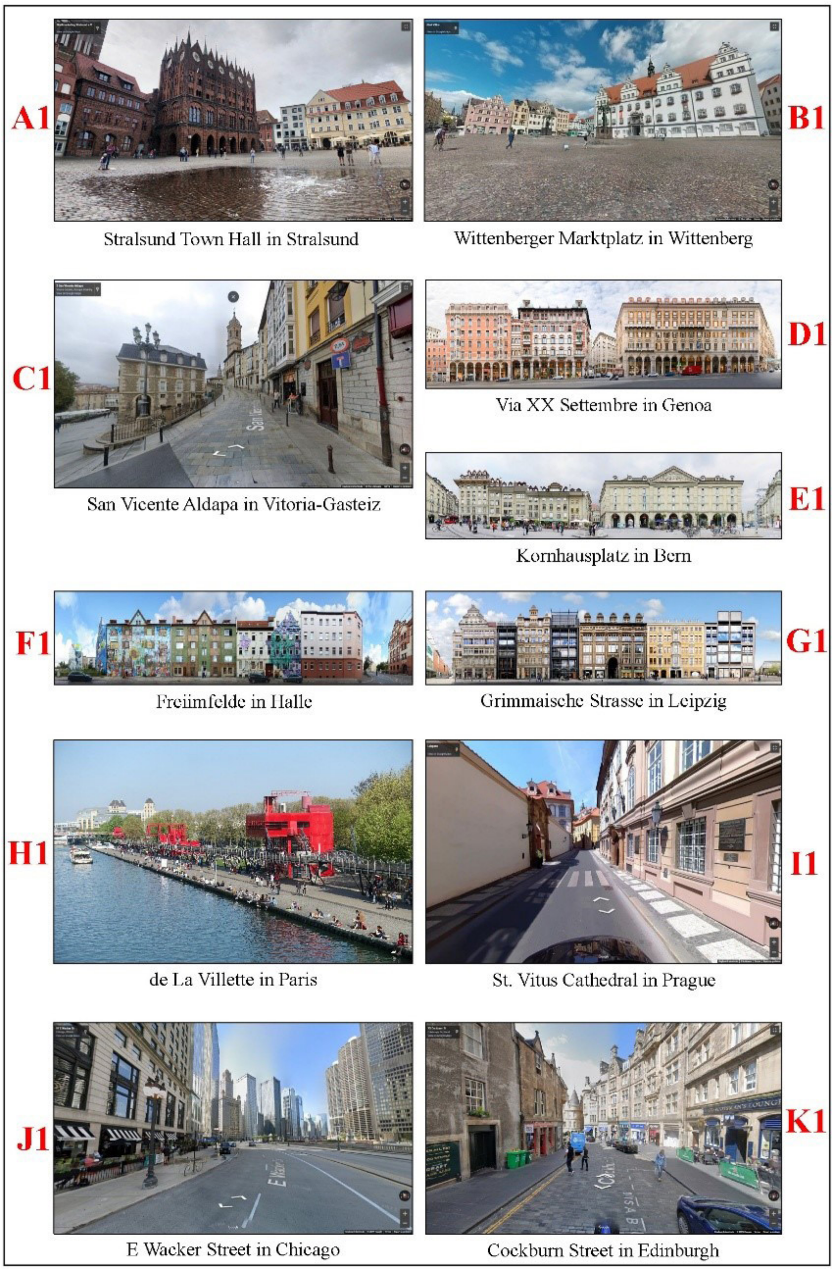

Fig. 3. Final images set. Source: A1, B1, C1, I1, J1, K1: https://www.google.com/maps/; D1, E1, F1, G1: Dietrich, 2013–2016; H1: Onniboni, 2024.

Fig. 4. Two examples of tree addition using the AR technique. Source: Authors based on https://www.google.com/maps/.

1. Qualitative analysis: Qualitative data were collected from expert opinions and examined to identify semantic patterns in aesthetic judgment based on the presence or absence of trees from the pedestrian's viewpoint.
2. Quantitative analysis: Quantitative data were extracted to evaluate changes in visual complexity in relation to aesthetic impacts across various scenarios (removal, addition, and repositioning of natural and physical elements). Finally, the mean changes for each indicator were calculated, compared, and analyzed.

The validity of the survey results was subsequently assessed using the Chi-Square test. This test determines whether the distribution of preferences (i.e., preference for tree-present, tree-absent, or neutral aesthetic judgment) differs significantly across the image pairs. The results of the Chi-Square test indicate that all alpha values for the examined cases are below 0.05 (Table 2), demonstrating a statistically significant difference in perceived aesthetic judgment across all binary images. The addition of trees (or more broadly, their presence) through the AR technique led to images being perceived as both more visually complex and aesthetically pleasing in most cases (A, B, C, D, E, F, G, J, K), in alignment with the study's hypothesis. In case study I, however, the increased number of trees—depending on their spatial orientation—resulted in a divergent aesthetic assessment by the expert respondents. In case H, responses also deviated from the initial hypothesis: although the addition of trees increased morphological complexity, it did not substantially affect aesthetic perception. The rationale behind these findings and their interpretations are discussed in the following sections.

Results and Discussion

Following the manipulation of the case study images using the AR technique, a subsequent survey was distributed among the 51 experts to evaluate which of the two urban landscapes—tree-present or tree-absent—was perceived as more aesthetically pleasing. Table 1 presents the results of this survey.

Given that statistical tests merely determine the existence or absence of a relationship or difference—without indicating the magnitude or practical significance of such differences—the use of effect size measures in statistical analyses becomes essential. Calculating the effect size enables researchers to grasp the practical relevance of the findings, not just their statistical significance. To complement the chi-square analysis and assess the strength of association between the categorical variables, Cramér's V coefficient was employed as the effect size indicator (Cohen, 1988). This coefficient quantifies the intensity and strength of the relationship between two nominal variables independently of the sample size and is particularly useful when the contingency table comprises more than two rows and columns.

The chi-square statistic obtained in the present analysis was 63. With a sample size of 33 observations and three groups (columns), this value was entered into Cramér's V[3] formula. The resulting value of 0.977, based on commonly accepted benchmarks (0.10 = small effect, 0.30 = medium

Table 1. Expert survey results. Source: Authors.

Image ID	Tree-Present Images Rated as More Beautiful (%)	Tree-Absent or Tree-Sparse Images Rated as More Beautiful (%)	No Aesthetic Difference (%)
A1	82.35	5.89	11.76
B1	80.39	13.73	5.88
C1	72.55	21.57	5.88
D1	60.78	33.34	5.88
E1	72.55	21.57	5.88
F1	78.43	17.65	3.92
G1	88.24	7.84	3.92
H1	47.06	47.06	5.88
I1	31.37	56.87	11.76
J1	70.59	25.49	3.92
K1	82.35	17.65	0

Table 2. The output of the chi-square test using SPSS software. Source: Authors.

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	63.000	40	0.012
Likelihood Ratio	69.736	40	0.002
N of Valid Cases	33	40	0.002

effect, 0.50 and above = large effect), indicates a very large effect size. This suggests that the relationship between the type of group (image) and the participants' aesthetic preferences is not only statistically significant but also demonstrates a high degree of practical relevance and impact.

The results of the complexity analysis conducted using ImageJ[4] software are presented in Table 3. The theoretical range of complexity levels spans from 1 to 2. As shown in Table 3, the difference in complexity levels between tree-included and tree-excluded images is substantial. This finding also indicates that the images containing trees exhibit higher levels of complexity, whereas the images without trees are characterized by lower visual complexity. To determine whether the differences in fractal dimensions between tree-included and tree-excluded images are statistically significant, an independent samples t-test was conducted. The independent t-test serves as a statistical tool to compare the mean values of each image group and assess whether their differences are statistically meaningful or merely due to chance. All underlying assumptions required to perform the independent t-test were met. The quantitatively assessed complexity levels function as dependent variables on a ratio scale, while the independent variable is a qualitative (categorical) factor with two groups (with trees, without trees). These groups are independent of one another, meaning that none of the values in the first group influenced those in the second. The sampling process for both groups was random, and the observations were independent. Variance equality between the two populations was tested using Levene's test (Tables 4 & 5).

In Levene's test for equality of variances, the significance value was 0.155. Since this value is not significant at the 0.05 alpha level, the variances between the two groups can be considered approximately equal, thereby validating the results of the independent samples t-test. The obtained value of 0.008 in the Sig. (2-tailed) section is below the 0.05 threshold, indicating that the difference in complexity between the two groups is statistically

Table 3. Complexity Levels. Source: Authors.

Image ID	Complexity Level – Tree-Rich Images	Complexity Level – Tree-Poor or Treeless Images	Difference
A1	1.8011	1.7860	0.0151
B1	1.7678	1.7162	0.0516
C1	1.7819	1.7359	0.0460
D1	1.8286	1.7893	0.0393
E1	1.7847	1.7538	0.0309
F1	1.7919	1.7504	0.0415
G1	1.7463	1.7162	0.0301
H1	1.7937	1.7873	0.0064
I1	1.7919	1.7803	0.0116
J1	1.8109	1.7754	0.0355
K1	1.7739	1.7361	0.0378

Table 4. Group Statistics; Result of t-test output using SPSS software. Source: Authors.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Complexity	1	11	1.78842727	0.021906898	0.006605178
	2	11	1.75699091	0.028193845	0.008500764

Table 5. Independent samples test; Result of t-test output using SPSS software. Source: Authors.

Levene's Test for Equality of Independent Samples Test Variances					t-test for Equality of Means				
		F	Sig.	t	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Complexity	Equal variances assumed	2.183	0.155	2.920	0.008	0.031436364	0.010765286	0.008980372	0.05892356
	Equal variances not assumed			2.290	0.009	0.31436364	0.010765286	0.008892161	0.053980567

significant. The significance of the t-test confirms that there is a meaningful difference in the average complexity levels between the tree-included and tree-excluded image sets.

While the independent samples t-test examines whether a statistically significant difference exists, it does not by itself convey the magnitude or practical relevance of the difference in means. Therefore, in addition to the t-test, Cohen's d was calculated as a measure of effect size (ibid.). This metric quantifies the mean difference between two groups relative to their pooled standard deviation and serves as a standardized measure for assessing effect size in two-group comparisons5. Similar to Cramér's V, Cohen's d is interpreted using conventional thresholds: a value of d = 1.24 indicates a large effect size. Accordingly, the difference in visual complexity between the two groups (tree-included vs. tree-excluded images) is not only statistically significant but also practically meaningful.

Following the confirmation of statistical significance, a closer comparison of Tables 1 & 3 reveals that—except for two cases (H1 and I1)—both aesthetic preference and visual complexity consistently align with the presence of more trees, in accordance with the study's hypothesis. In other words, there is a direct relationship between increased greenery and the enhancement of both complexity and perceived beauty in urban environments. With the exception of the noted outliers, the presence of green elements (in this study, trees) is generally preferred over their absence in urban spaces.

In the case of image I1, despite an increase in visual complexity, the presence of trees was perceived by experts as diminishing the aesthetic quality. This outcome is attributed to the partial concealment of urban façade details behind the tree canopy. Another noteworthy case is image H1, where the removal of certain physical elements made the presence of trees more prominent. Survey responses indicate that, from an aesthetic standpoint, no significant difference was perceived between the original and the manipulated versions of H1—both were rated as equally beautiful by 24 participants (47.06%). Notably, the difference in complexity between the two versions was minimal, with the tree-included version displaying a slightly higher level of complexity (Fig. 6).

To investigate the underlying reason for the reduced aesthetic quality despite increased complexity and the presence of trees in case I1, an additional test was conducted involving a comparative tree relocation scenario. Two images, both featuring the same number of trees, were examined: in one, the trees were placed in front of the more detailed side of the street façade, while in the other, they were shifted to the side with less morphological detail. Notably, a substantial difference in both visual complexity and aesthetic perception was observed between the two, despite the constant number of trees. This suggests that placing trees—or similar vegetation—on the visually less articulated side of the urban façade (I3) enhances perceived beauty. Conversely, adding trees in front of the more intricate urban façade (I2) results in diminished aesthetic appeal. In other words, it is not merely the quantity of vegetation that matters, but also its spatial positioning relative to the observer's viewpoint. This spatial configuration can create statistically significant differences in aesthetic perception (Fig. 7).

Although the fractal analysis conducted using ImageJ software demonstrated that tree-included images generally exhibit higher levels of visual complexity, this increase does not necessarily translate into enhanced aesthetic perception in all cases. The relationship between complexity and beauty, as described in the theoretical

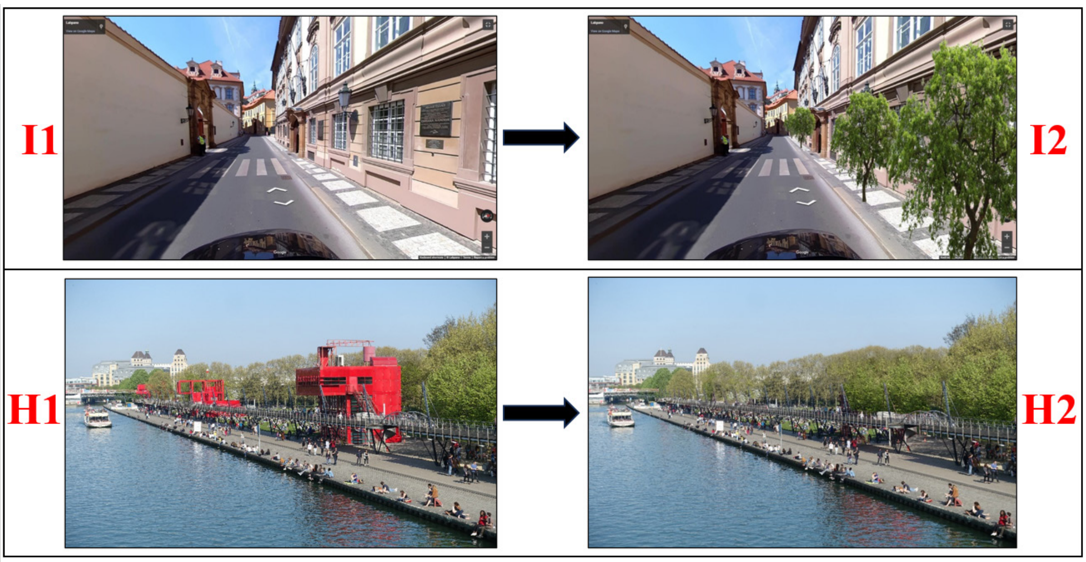

Fig. 6. Modifications applied to case studies I1 and H1. Source: I1. Authors based on https://www.google.com/maps/; H1. Onniboni, 2024.

Fig. 7. Modifications in case studies I2 and I3. Source: Authors.

literature, is nonlinear and context-dependent—excessive complexity may reduce visual legibility and overall appeal. This phenomenon was evident in cases H[1] and I1, where higher fractal dimension values did not correspond to improved aesthetic perception; in some instances, aesthetic appeal even declined. Accordingly, it can be concluded that the addition of natural complexity (e.g., trees) enhances aesthetic perception only when it does not obscure the intricately articulated façades of the built environment.

The analysis of the case studies revealed that, although an increase in tree coverage often enhances aesthetic perception, this relationship is not consistently linear or upward. Specifically, in cases H1 and I1, the addition of trees—despite raising the fractal complexity index—did not lead to improved aesthetic evaluations; in some instances, aesthetic quality actually declined. These findings suggest the possible existence of a "visual threshold" in the influence of trees—implying that beyond a certain level of tree coverage, additional natural elements may produce diminishing or even negative effects by obscuring architecturally valuable façades or contributing to visual clutter. Therefore, effective urban landscape design appears to require the identification of an optimal level of vegetation coverage that aligns with the spatial characteristics of the built environment and the observer's viewpoint.

Conclusion

This study aimed to investigate the impact of the presence or removal of trees on the perception of visual aesthetics and complexity in urban landscapes from the pedestrian's viewpoint. By combining qualitative and quantitative methods, the research provided a detailed assessment of the interaction between natural elements (trees) and physical components (buildings, façades, etc.). The use of advanced image analysis tools such as ImageJ, along with statistical tests including the independent samples t-test, chi-square test, and Cramér's V, complemented by expert evaluations, enabled the formulation of empirically grounded insights. The results offer a scientific and experiential foundation for understanding the relationship between aesthetic perception and visual complexity in the context of urban landscape design.

The research findings generally indicate that the presence of trees in urban landscapes not only elevates the level of visual complexity but, in most cases, also enhances the perceived aesthetic quality of the environment. However, this relationship is neither linear nor uniform. Certain case studies revealed that an increase in tree coverage within spaces already characterized by high morphological complexity may obscure architectural values or create visual clutter, thereby leading to a decline in aesthetic perception.

The findings also underscored that the spatial positioning of trees in relation to urban façades and the viewer's line of sight plays a crucial role in aesthetic perception. In other words, simply adding trees does not necessarily enhance the visual experience unless this addition supports visual legibility, spatial clarity, and harmony with the built environment. Moreover, the analysis of visual complexity through fractal dimension assessment revealed that, on average, tree-included images exhibited higher complexity indices. The independent samples t-test confirmed a statistically significant difference in complexity levels between tree-included and tree-excluded images, and the high effect size (Cohen's d = 1.24) substantiated the practical significance of this difference. In conclusion, it can be stated that:

- The addition of trees can enhance both aesthetic appeal and visual complexity; however, this effect is highly contingent upon contextual conditions, spatial characteristics, and the composition of built elements;
- Vegetation coverage should be designed in a way that not only contributes to spatial richness and diversity but also avoids obscuring architecturally significant façades or introducing visual clutter;
- Urban landscape design requires the establishment of a defined visual threshold for vegetation coverage to maintain a balanced relationship between aesthetic value, visual legibility, and functional clarity.

Moreover, the findings of this study may serve as a theoretical and empirical foundation for revisiting urban design guidelines—particularly in the planning of streetscapes, squares, and public spaces. Practical

recommendations derived from this research include the following:
- Strategically placing trees in areas lacking morphological richness to enhance visual legibility and appeal;
- Avoiding the planting of trees directly in front of architecturally or ornamentally significant façades to prevent interference with visual perception;
- Developing visual assessment checklists as part of the approval process for urban design projects;
- Utilizing visual simulation tools such as Augmented Reality (AR) and fractal analysis prior to physical implementation, to evaluate and anticipate the impacts of design decisions.

In conclusion, these findings offer a scientific framework for creating urban spaces that are aesthetically pleasing, visually complex, and contextually harmonious—providing valuable input for future planning efforts aimed at enhancing urban quality of life and enriching citizens' experience of the built environment. This study was limited to 11 urban street views and focused solely on the influence of trees, excluding other forms of urban greenery such as façade planters, shrubs, or in-street potted plants. While similar outcomes are anticipated in other case scenarios, confirming such hypotheses would require separate, dedicated investigations. Additionally, the study concentrated exclusively on visual aesthetics, without accounting for subjective or emotional dimensions such as collective or personal memories. These limitations point to several promising avenues for future research.

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Declaration of No Conflict of Interest

The authors declare that they have no conflict of interest in conducting this research.

Endnotes

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1. Hard and soft urban landscape

2. Proportion Formula:

$$n = \frac{Z^2_{1-\frac{\alpha}{2}} \times p(1-p)}{d^2} = \frac{(1 \cdot 96)^2 \times (0.5) \times (0.5)}{(0.15)^2} = \frac{0.96}{0.0225} = 42.6 + 15\% \approx 49$$

- $Z^2_{1-\frac{\alpha}{2}}$: Confidence level of 95%, which equals 1.96;
- p: Estimated proportion in the target population, assumed to be 0.5;
- d: Margin of error, set at 0.15.
- The values of p and d were assumed by default. Considering a 15% attrition rate in the sample size, the final required sample size was calculated to be at least 49 participants.

3. Cramér's V Formula:

$$V = \sqrt{\frac{{}^2\chi}{n(k-1)}} = \sqrt{\frac{63.000}{(1-3) \times 33}} = \sqrt{\frac{63.000}{66}} \approx 0.977$$

4. Image Analysis Method Using ImageJ: First, the image is uploaded into the ImageJ software, and then it is converted to black and white using the following command:

• Image ⟶ Type ⟶ 8-bit

The reasons for converting color images to black and white include: data uniformity, simplified processing (reducing computational load), algorithmic compatibility (preventing errors in quantitative analysis), and structural focus (eliminating irrelevant color information). Subsequently, the image was binarized sing the following command to highlight the core structural elements:

•Image ⟶ Adjust ⟶ Threshold

The reasons for binarizing images include: isolating the object from the background, enabling faster processing, facilitating shape and size analysis, and eliminating redundant information. Subsequently, to analyze the fractal dimension (complexity), the following command is applied:

• Plugins ⟶ Fractal Analysis ⟶ FracLac ⟶ BC (Box Counting)

After execution, a results window appears displaying the fractal dimension (D). The fractal dimension is a numerical value between 1 and 2, where values closer to 2 indicate higher visual complexity in the image.

5.Calculation of Pooled Standard Deviation (SD pooled):

- Formula:

$${}_{\text{pooled}}SD = \sqrt{\frac{{}^2_2SD^2_1 + (n_2-1)SD(n_1-1)}{n_1+n_2-2}}$$

- Substitution:

$${}_{\text{pooled}}SD = \sqrt{\frac{{}^2(0.0282)(1-11) + {}^2(0.0219)(1-11)}{2-11+11}} = \sqrt{\frac{(0.0007952)10 + (0.0004796)10}{20}} = \sqrt{\frac{0.007952 + 0.004796}{20}} = \sqrt{\frac{0.012748}{20}} = \sqrt{0.0006374} \approx 0.02524$$

- Calculation of Cohen's d:

$$d = \frac{{}_2M_1 - M}{{}_{\text{pooled}}SD} = \frac{1.7570 - 1.7884}{0.02524} = \frac{0.0314}{0.02524} \approx 1.244$$

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