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Web-Based Control Framework for Visual Pollution in the Urban Environment

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Abstract: Urban environments are constantly transforming to meet societal demands, but this evolution often brings challenges such as visual pollution—an overlooked factors that affect the livability and mental well-being of city inhabitants. This study explores visual pollution through the development of a conceptual web-based framework that organizes visual aspects of the urban environment into four key perceptual dimensions: Enclosure, Orderliness, Greenness, and Visual Pollution. The urban environment is reclassified into three foundational categories—Sites, Paths, and Urban Elements—to provide a simplified structure for understanding visual composition. To validate this conceptual framework, a perception-based survey was conducted using digitally altered images of a real urban node in Makkah, Saudi Arabia. A total of 490 participants engaged in a pairwise comparison of the images to reflect their visual preferences. The results show alignment between participant preferences and the conceptual framework, with greener and more organized urban scenes ranked higher, and visually polluted scenes consistently ranked lowest. These findings highlight the importance of perceptual dimensions in shaping urban visual quality and offer a foundation for more human-centered approaches in urban design and planning.

Keywords: Visual pollution; visual pollution framework; urban environment dimensions.

I. INTRODUCTION

Throughout human history, urban environments have continuously evolved to meet the needs and aspirations of modern society. However, alongside this evolution, we encounter an undesirable dimension of the urban environment that affects both the functionality and aesthetics of our urban environments. We refer to the phenomenon of visual pollution, which is evident in both undeveloped and developing countries. The term “visual pollution” was first used in 1906 in the 27th Annual Report of the New York State Department of Health, indicating its historical acknowledgment as an urban concern (“Annual Report of the State Board of Health of New York.,” 1906). Researchers and urban planners have examined its influence over time, with initial literature, such as Maclurcan's early 20th-century work, emphasizing the importance of visual aesthetics in urbanity and sanitation within the built environment (D. C. B. Maclurcan K.C.S.G., 1973).

Nawaz and Wakil 2022 have recently improved the concept of visual pollution, defining it as the "*visual clutter of numerous objects that obstruct the human eye's capacity to perceive harmony and beauty in an environment*.". This description highlights the challenges and complexities of achieving urban aesthetics in contemporary urban environments. The importance of the visual appearance of urban environments has been acknowledged in international sustainability efforts. The United Nations' Sustainable Development Goal 11 (SDG 11) advocates for making cities safe, inclusive, resilient, and livable (Nations, 2015; UN-Habitat, 2018). Studies demonstrate that urban aesthetics have a significant

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impact on human satisfaction and happiness (Florida et al., 2011; Leyden et al., 2011), underscoring the need for policies and frameworks to enhance the visual appearance of urban environments.

This study identifies four key dimensions, Enclosure, Orderliness, Greenness, and Visual Pollution, to objectively evaluate visual appearance. visual pollution denotes the presence of negative objects that disrupt the visual harmony of the environment, such as unregulated advertisements, deteriorated structures, or poorly placed objects that negatively affect visual perception.

Visual pollution is more than just an aesthetic concern; it can negatively impact mental health by raising stress levels and reducing overall quality of life (Gao et al., 2024). Despite its importance, visual pollution is insufficiently regulated and inconsistently assessed in urban development. The difficulty arises from the subjective nature of aesthetic perception, which complicates efforts to quantify and standardize it. Numerous researchers have attempted to quantify visual pollution through surveys (Bakar et al., 2019), statistical methods (Atta, 2013), and multi-criteria decision-making approaches, such as Analytic Hierarchy Process (AHP) and Strengths, Weaknesses, Opportunities, and Threats analysis (SWOT) (Allahyari et al., 2017). Various researchers have employed geospatial methodologies, such as Three-Dimensional Isovist analysis (3D Isovist), Web-based Geographic Information System (WebGIS), and machine learning-based categorization techniques (Ahmed et al., 2019; Chmielewski, 2021; Palomo et al., 2022). Wakil and others have made a systematic approach to quantify visual pollution using the Visual Pollution Assessment (VPA) tool (Wakil et al., 2019).

This study is structured into four sections, each addressing a key stage in the framework.

1. Introduction establishes the research background, problem, and objectives.
2. Literature Review examines the historical evolution, definitions, impacts, and existing assessment methods of visual pollution and urban environments, highlighting current gaps and challenges.
3. Research Methodology presents the web-based framework and the urban environment and its key dimensions, along with the validation process using a pairwise comparison survey.
4. Results and Discussion show the survey responses and discuss areas of alignment and divergence.

II. LITERATURE REVIEW

The earliest evidence of the term "visual pollution" dates to 1906, in the 27th Annual Report of the State Department of Health of New York (“Annual Report of the State Board of Health of New York.,” 1906). Furthermore, one of the earliest publications in English literature was "Visual Pollution" by Maclurcan in 1973, which highlights the importance of visual aesthetics in urbanity and sanitation within the built environment (D. C. B. Maclurcan K.C.S.G., 1973). The concept of "visual pollution" has evolved historically. Lately, Nawaz and Wakil 2022 define visual pollution as "The visual clutter of many objects that hinder the ability of the human eye to perceive harmony and beauty in an environment".

At the United Nations Sustainable Development Summit 2015 on Sustainable Development, held at the United Nations Headquarters in New York, more than 150 world leaders gathered to formally adopt an ambitious new agenda for sustainable development, known as the 2030 Agenda for Sustainable Development. The 2030 Agenda is a 15-year global framework centered on an ambitious set of 17 Sustainable Development Goals (SDGs), 169 targets, and over 230 indicators (Nations, 2015). One of the Sustainable Development Goals (SDGs) is SDG 11, "Sustainable Cities and Communities," which emphasizes the importance of making cities safe, inclusive, resilient, and livable (UN-Habitat,

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2018). This goal, however, is challenged by visual pollution, which degrades urban aesthetics and directly affects the livability of cities and communities.

Gao et al. 2024 highlights that visual pollution is not just an aesthetic issue but also negatively impacts mental health, contributing to stress and a reduced quality of life. Key visual pollution objects include unregulated advertisements, deteriorating buildings, and graffiti wall chalking, which disrupt urban environments. Weak regulations and economic priorities allow these issues to persist. Additionally, current assessment methods remain limited, underscoring the need for more objective and technology-driven approaches to address visual pollution effectively.

Kevin Lynch 1960 introduced the concept of city image in his famous book, The Image of the City, where he divided the physical city environment into five main categories: Paths, Edges, Districts, Nodes, and Landmarks. Nawaz and Wakil 2022 explained the interaction between humans and the urban environment in their book. This study simplifies the urban environment into three main categories: Site, Path, and Urban Elements. To fully understand and comprehend the meaning of visual pollution for accurate control and management it, we also need to understand the term “Environment”, where Douglas 1983 defines it in his book, The urban environment, as "*The combination of physical and natural objects, humans, and their reciprocal influence on the social interactions of its inhabitants*". Karmaoui 2019 defines urban environment as “*An ecosystem of an urban area in which the urban residents interact with biotic and abiotic factors*”. Table 1 summarizes the studies, and the methods and techniques used for visual pollution.

Table 1 Recent studies on visual pollution assessment in literature

Article	**Year**	**Method Used**
Atta	2013	Statistical methods
Wakil	2016	SDSS, AHP, open-source technologies
Chmielewski	2016	GIS-based intervisibility analysis and public surveys
Allahyari	2017	SWOT, AHP, QSPM
Kucharikova	2017	Crowdsourcing, Visual similarity clustering
Shaban	2018	Multi-disciplinary approach with visual analysis techniques
Chmielewski	2018	Geospatial techniques: 3D Isovist, Voxel Approach, Citizen science, WebGIS, Tangential View Metrics
Bakar	2019	Public surveys, Cumulative area analysis, Photo booklet survey
Ahmed	2019	Deep learning for automated identification and classification
Wakil	2019	Visual Pollution Assessment (VPA) tool
Chmielewski	2020	Geospatial techniques: 3D Isovist, Voxel Approach, Citizen science, WebGIS, Tangential View Metrics
Chmielewski	2021	Geospatial techniques: 3D Isovist, Voxel Approach, Citizen science, WebGIS, Tangential View Metrics
Palomo	2022	Deep learning for automated identification and classification
Borowiak	2024	City audit assessment and public opinion

III. RESEARCH METHODOLOGY

This section presents a redefinition of the categorization and perception of the urban environment. To achieve this, key dimensions of the urban environment will be identified and selected. This study employs a multi-method approach consisting of:

- Theoretical foundations are used to recategorize the urban environment and identify its key dimensions.

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- Validation via surveys utilizes six digitally modified images, each representing a different dimension.

The recategorization of the urban environment simplifies perception, making it more applicable to the proposed methodology. Figure 1 shows the research flow for the study. Research procedures are as follows:

- Step 1: urban environment recategorization
- Step 2: framework development
- Step 3: framework validation

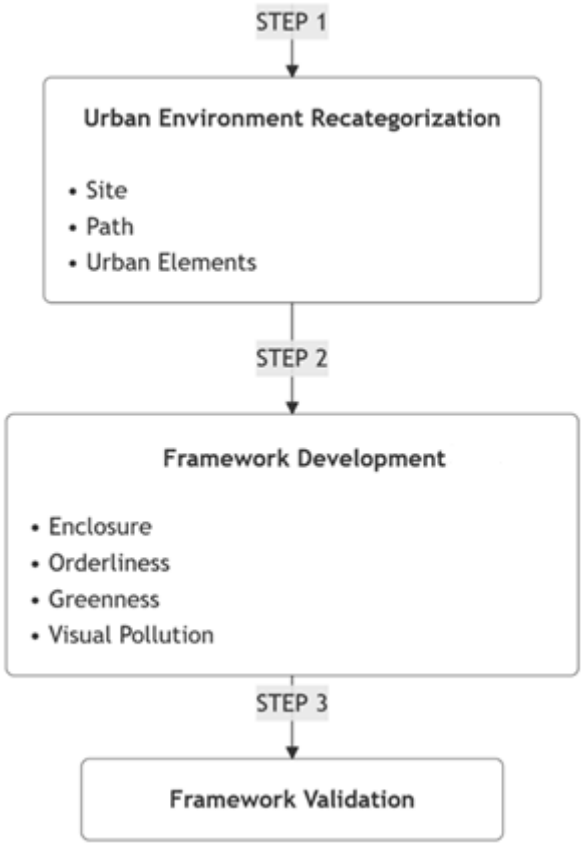

Figure 1 Research flow

Urban Environment Recategorization

Kevin Lynch 1960 Introduced the city image concept, dividing the physical city environment into five main categories: Paths, Edges, Districts, Nodes, and Landmarks. While these categorizations are foundational, they do not fully align with the specific needs of this study. Therefore, a new categorization is proposed to better serve our methodological framework. This revised structure retains the core physical elements of the urban environment while enhancing their relevance to our methodology. We categorize the urban environment into three main categories:

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- Sites: This term refers to all types of built and unbuilt areas, including buildings, vacant land, public spaces, and various site types. It also refers to any area designed to serve specific purposes or functions.
- Paths: These refer to all physical routes designed for movement and connectivity, used by pedestrians, vehicles, bicycles, and other forms of transportation, and always form and appear between sites.
- Urban elements: Refers to any object that is neither classified as a site nor a path, including street furniture and aesthetic features such as signs, streetlights, trash bins, benches, trees, statues, and iconic landmarks within the urban environment.

This refined categorization provides a more structured approach to understanding physical urban objects while preserving the foundational principles established in earlier research. Figure 2 visually represents this categorization.

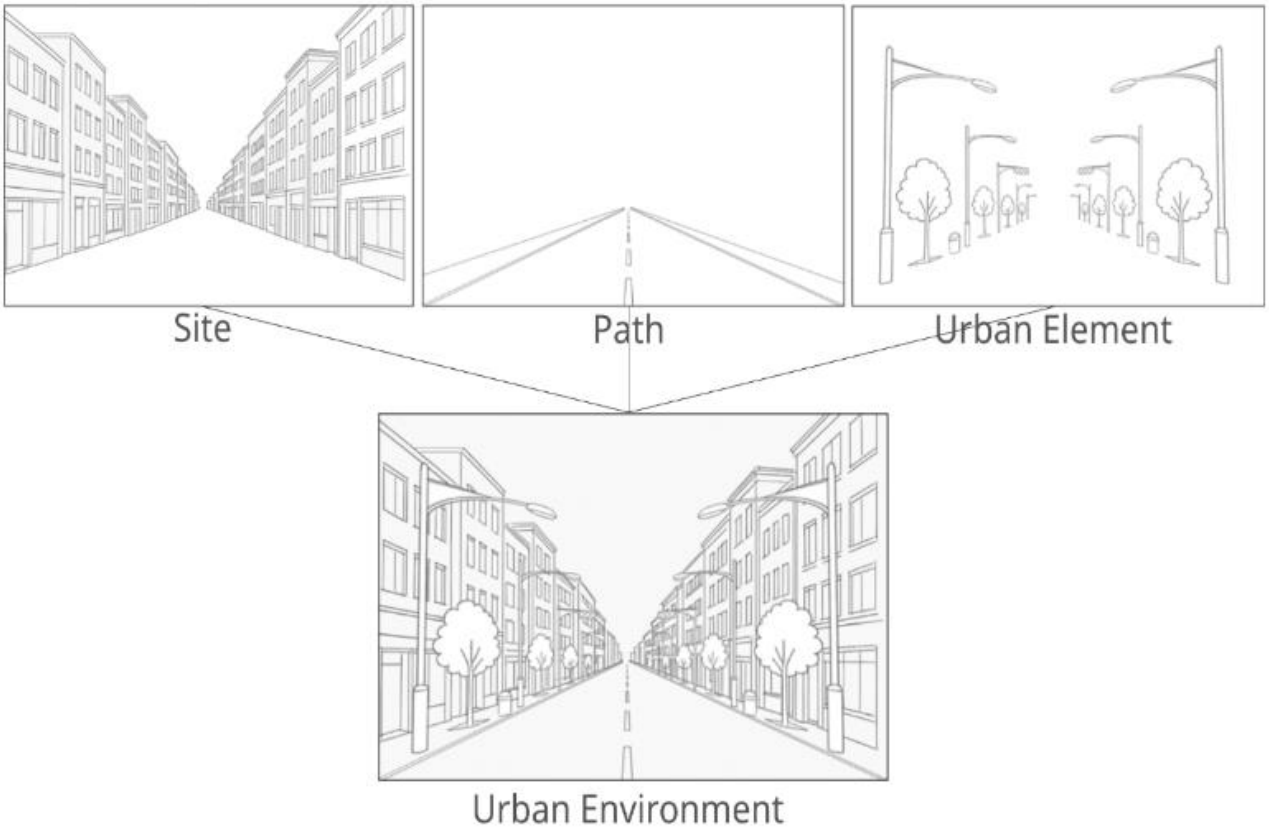

Figure 2 Urban environment categorization

Framework development:

Enclosure

Enclosure refers to the feeling of being enclosed or surrounded, creating a sense of comfort and a room-like atmosphere while avoiding undefined spaces or "no-places." Since the 1960s, researchers have explored the concepts of enclosure and the conditions under which enclosure is either fully achieved or diminished in urban environments. Enclosure have been measured in relation to the height of buildings and the distances between buildings within that node. Spreiregen and Blessing 1965

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measured the relationship between building façade height and the width of the frontal field of view, proposing that specific ratios correspond to varying degrees of spatial enclosure. Similarly, Hedman and Jaszewski 1984 measured the ratio between street wall height and street width, identifying similar levels of spatial enclosure. Table 2 summarizes the classifications of enclosure ratio levels proposed in existing literature.

Orderliness

Orderliness refers to assessing the degree of order in physical objects, reflecting coherence and organization within the urban environment, primarily aiming to evaluate the interaction of various urban systems, including building systems, transportation networks, utility infrastructures, and others. This concept encompasses the operational efficiency of these systems and, more importantly, their ability to foster a sense of safety, coherence, and organization. This is achieved through factors such as proper placement, suitable sizing, and optimal integration of urban elements, ultimately contributing to high orderliness in the urban environment.

Table 2 Enclosure ratio levels from existing literature

Spreiregen (1965)		**Hedman and Jaszewski (1984)**	
Building Façade Height: Field of View Width	**Enclosure Level**	**Street Wall Height: Street Width**	**Enclosure Level**
		3:2	Claustrophobic
1:1	Full Enclosure	1:1	Strong spatial definition
1:2	Threshold Enclosure	1:2	Sufficient spatial containment
1:3	Minimum Enclosure		
1:4	Loss of Enclosure	1:4	Weak sense of space

Greenness

Greenness refers to the presence of vegetation, including trees, grass, shrubs, and other plant life, which offers significant aesthetic, environmental, and psychological benefits, ultimately contributing to enhanced well-being and quality of life. Studies have shown that the visibility of green vegetation plays a crucial role in enhancing perceived safety within urban environments. These findings underscore the importance of incorporating green elements into urban planning to promote safer and more livable urban environments. Greenness is typically measured by calculating the percentage of urban green space within a specific area, often without accounting for the height of the vegetation.

Visual Pollution

The term Visual Pollution Object (VPO) refers to "the physical objects that are considered to be pollutants, that disrupt urban environment and contribute to visual disturbance." (Nawaz & Wakil, 2022). These objects affect the perceived quality of the environment through their placement, appearance, size, color, and functional impact. The literature review identified that most VPOs, such as outdoor advertisements, graffiti, wall chalking, and dilapidated buildings, have been categorized based on existing studies, public surveys, personal observations, and other sources.

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Framework Validation

To validate the proposed framework, this study views the framework with real-world perception data from a randomly selected node in the urban environment of Makkah, Saudi Arabia. By evaluating the alignment between human perception of the visual appearance of the urban environment and the framework. In the survey, participants evaluated six different images of the same urban node in Al-Rashidiya, a medium-sized district located east of Makkah. These images were derived from a single real photograph, which was digitally modified to create six variations, each designed to represent an urban environment dimension.

To derive images from a reference image, each image should be selected according to the specific requirements of the corresponding web-based framework. For enclosure, images should display appropriate street widths; for greenness, a higher percentage of green coverage is preferred; for orderliness, a high level of urban organization should be present; and for visual pollution, images should contain minimal VPOs. Figure 3 and Table 3 visually illustrate and summarize the reference image and its six digitally modified variations.

The survey employed a pairwise comparison approach to establish a reliable validation method, a widely recognized method in previous research (Thurstone, 1927). Participants were asked to compare the images based purely on their visual preferences. The rankings obtained from the survey were then compared with the rankings calculated by the framework for the same six images. This comparison serves as a critical validation step, assessing the frameworks to reflect human perception of the visual appearance of urban environments. By demonstrating this alignment, we can confirm that the framework aligns with the urban environments and their key dimensions: Enclosure, Orderliness, Greenness, and Visual Pollution.

Table 3 Summary of the reference image and the six modified variations

Image	**Description**
Reference Image	Original unmodified image captured from a real urban node
Image A: Enclosure	Primarily highlights the Enclosure dimension
Image B: Orderliness	Primarily highlights the Orderliness dimension
Image C: Greenness	Primarily highlights the Greenness dimension
Image D: Visual Pollution	Primarily highlights the Visual Pollution dimension
Image E: Standard	Baseline image with no exaggerated changes; used for standard comparison
Image F: All Positive	Includes all positive dimensions at high values; represents the ideal urban environment

Reference Image

Image A: Enclosure

Image B: Orderliness

Image C: Greenness

Image D: Visual Pollution

Image E: Standard

Image F: All Positive

Figure 3 Reference image and the six modified variations

IV. RESULTS, DISCUSSION, AND CONCLUSION

To validate the framework, a survey-based evaluation was conducted using a pairwise comparison approach. Participants were presented with the same six images and asked to compare them based on their visual perception of the urban environment. The goal was to obtain a human-based evaluation of the images to assess not only the order of preference but also the degree to which participants favored one image over another.

The survey was administered online and distributed through social media platforms, ensuring accessibility in both Arabic and English. Participation was entirely voluntary. Data collection took place from January 21st to March 5th, 2025, during which 490 participants reflected their perceptions of the urban environment. Table 4 presents a summary of the demographic distribution of the participants.

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Table 4 Demographic distribution of survey participants

Demographic Factor	Categories	Number of Participants (N=490)	Percentage (%)
Age Group	<18	0	0%
	18-24	57	12%
	25-34	146	30%
	35-44	115	23%
	45-54	119	24%
	55-64	40	8%
	>64	13	3%
Gender	Male	340	69%
	Female	150	31%
Education Level	High School	132	27%
	Bachelor's	268	55%
	Master's	73	15%
	Doctorate	10	2%
	No Degree	7	1%
Nationality	Saudi	439	90%
	Non-Saudi	51	10%

The findings indicate that a significant portion of the participants were relatively young, with 30% falling within the 25-34 age range, representing 30% of the total sample. The gender distribution was 69% male and 31% female. Regarding education, 55% held a bachelor's degree, making it the most common qualification. Additionally, while the majority of participants were Saudi nationals 90%, the inclusion of 10% non-Saudi participants contributed additional perspectives to the urban environment evaluation. Following the collection of demographic data, participants completed a pairwise comparison survey of the six predefined images. Each participant was presented with 15 paired comparison questions and asked to select the image they personally preferred from each pair. The final ranking was determined by counting the number of times each image was preferred in these comparisons. A Win/Loss Matrix of participant preferences is presented in Table 5, showing how often each image was selected, along with its corresponding rank based on the normalized participant preference scores.

Table 5 Pairwise comparison survey results: win/loss matrix

Image	A	B	C	D	E	F	Total wins	Normalized Score (-1 to 1)	Rank
A	-	48	25	454	55	41	623	-0.435	5
B	442	-	149	475	396	119	1581	0.579	3
C	465	341	-	477	450	205	1938	0.958	2
D	36	15	13	-	5	21	90	-1	6
E	435	94	40	485	-	86	1140	0.112	4
F	449	371	285	469	404	-	1978	1	1

The results of the pairwise comparison survey provided a clear representation of participant preferences across the six images. Image F: All Positive received the highest number of total wins (1,978 wins; normalized score = 1), making it the most frequently preferred image. This was closely followed by Image C: Greenness (1,938 wins; score = 0.958), while Image B: Orderliness (1,581 wins; normalized score = 0.579) occupied a higher-tier position. Image E: Standard and Image A: Enclosure were positioned in the mid-tier range, with (1,140 wins; normalized score = 0.112) and (623 wins;

normalized score = -0.435), respectively. In contrast, Image D: Visual Pollution received the fewest preferences, with only (90 wins; normalized score = -1), indicating it was the least favored among participants.

DECLARATIONS

Conflict of interest: The author declares that there is no conflict of interest.

Ethical statement: The author declares that he followed the ethical responsibilities.

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