

## Article

# Integrating Space Syntax and Emotional Mapping to Assess Visual Pollution in Urban Environments

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## Abstract

Visual pollution in urban environments has a significant impact on aesthetic quality, level of environmental complexity, coherence, and emotional well-being. Due to that, it needs to be analysed considering not only physical environment features and indicators but also aspects of environmental psychology and human emotional needs towards the urban environment. Taking into account this approach, in this research, it is studied applying a genotype-based framework using space syntax analysis and emotional mapping. Spatial analysis tools, such as space syntax and visibility graph analysis (VGA) provide reliable tools for statistically analysing this phenomenon. This method evaluates visual exposure and connectedness to polluting components across the map, resulting in locations with the most obvious pollution (The research examines spatial metrics such as integration, connectivity, and visibility, as well as emotional responses, to reveal significant links between urban spatial configurations and the visual pollution index (VPI). Zones with great accessibility and reachable by people, such as parks and public spaces, have positive emotional responses and low VPI scores, suggesting accessibility and visual harmony. On the contrary, low-integrated and fragmented areas have high VPI ratings, suggesting visual clutter, poor maintenance, and user dissatisfaction. Visual pollution affects the quality of urban surroundings by filling the visual space with contrasting and varied elements, resulting in visual dissonance. Common sources of visual pollution include architectural forms, billboards, advertising boards, signage, and poorly maintained building façades, particularly in modernist neighbourhoods. The Dainava neighbourhood in Kaunas city is used as a case study to apply this integrated methodology, revealing spatial and emotional aspects of the neighbourhood relevant to the VPI assessment. The findings highlight the relevance of a complex methodological approach that integrates spatial and emotional qualities of the environment and the importance of targeted actions, such as improving visibility, creating visual relations, and reducing visual clutter, in establishing inclusive, legible, and visually harmonious urban spaces. This methodological framework provides urban planners with a practical tool for the evaluation of visual pollution that integrates egzogenous (physical) and endogenous (emotional) factors and has predictive capacities to indicate the environment that is the most sensitive to visual pollution.



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conditions of the [Creative Commons](https://creativecommons.org/licenses/by/4.0/)[Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.**Keywords:** visual pollution; human perception; environmental psychology; space syntax; emotional mapping; visual pollution index (VPI)

## 1. Introduction

Human behaviour, emotions, and well-being are greatly influenced by the surrounding visual environment, whereas visual pollution can cause severe psychological and health-related damage. Unattractive, overloaded, or chaotic visual elements such as billboards, litter, dissymmetric structures, and excessive advertisements are the reason why environmental aesthetics are diminished; it is related to an increase in stress, anxiety, distraction [1,2], and a decrease in both physical and psychological well-being. High-risk groups, including children and the elderly, are extremely vulnerable. Visual pollution can disrupt attention and concentration, provoke responses to physical stress, and undermine mental well-being [3,4]. In urban and rural areas, the monotony of visual clutter can cause fatigue and distraction, which in turn affects their well-being [5]. The negative effect of visual pollution is exacerbated in underprivileged areas [6], where underprivileged areas refer to urban districts characterised by lower socioeconomic status, limited public investment, poorer maintenance of the built environment, conditions that often intensify visual disorder through neglected façades, unregulated signage, and infrastructural decay.

Visual pollution in residential areas can significantly affect the quality of the urban environment and human well-being. Modern construction's streamlined modelling methods can produce repetitive elements on high-rise buildings' facades, well-maintained landscapes, and well-designed urban areas, creating an unattractive visual environment. This can result in deterioration of the quality of the visual environment and contribute to problems such as increased stress and anxiety. Many other elements can also affect the aesthetics of cities. Visual pollution is believed and known to have an impact on the urban environment and social well-being. Despite the fact that contemporary construction adopts well-defined, effective principles of design, it may lack uniqueness and harmony. This is due to excessive architectural consistency, which may lead to what we call visual fatigue and perceptual overload. Therefore, emotional discomfort and weak maintenance systems may influence concern and raise concern.

For example, a case study in Athens [7] has shown that inappropriate façade illumination can adversely impact both individuals and the environment, underscoring the need for more stringent lighting regulations to mitigate light pollution. Furthermore, visual pollution in urban environments disrupts aesthetic harmony and negatively impacts the experience by cluttering visual spaces with discordant architectural elements, billboards, signage, and deteriorated façades. To objectively assess and predict this problem, tools such as space syntax and visibility graph analysis (VGA), and emotion mapping provide useful methods for the analysis of the visual pollution index. These tools enable the evaluation of visual exposure and the correlation of pollutants, identifying the areas most affected by visual disorder.

Despite its considerable impact on the quality of the living environment, there are limited quantitative methods for assessing visual pollution in urban settings. Original attempts tended towards a subjective estimation regarding visual distress; however, current methods focus on objective, repeatable indices. The state of the art is moving towards the creation of graphic analytical instruments to measure visual complexity and unity, by combining techniques such as motif frequency analysis, isovist-based space descriptions, and façade integration measurement [8,9]. Empirical research has shown that specific visual attributes indicating order, legibility, and material coherence in the built environment have powerful effects on mental and emotional states [10]. Furthermore, current methodologies are focused on balancing aesthetic environmental properties and functional needs, as demonstrated by studies related to the use of façade colours in rural areas [10], and the incorporation of devices, such as building integrated photovoltaics (BIPV), into urban environments without losing visual integration [11]. In short, visual pollution assessment is

moving more and more towards the development of objective, quantitative, and comparable indicators that integrate subjective (human) and objective (environmental physical) aspects.

According to space syntax analysis, the “urban genotype” is the spatial structure of the built environment, including street networks, visual fields, and integration. This study also includes elements of urban design. The “urban phenotype” encompasses the consequences of the spatial structure’s impact on the individual, such as emotional reactions, perceived visual quality, and VPI. By linking these components, we show how the aesthetic and perceived psychological impact of a city are influenced by its spatial DNA. This paper aims to present and further develop a genotype-based methodological framework for the evaluation and minimisation of urban visual pollution that includes subjective and objective aspects. In this study, spatial syntax analysis works as a method for the quantitative evaluation of spatial configurations and their impact on human movement and social interactions. The concepts of integration, connectivity, and visibility graph analysis (VGA) are used. Emotional mapping represents the subjective side of visual pollution evaluation, and the visual pollution index (VPI) integrates environmental and human aspects developed using the urban genotype concept, which describes the spatial arrangement of the fabric of the cityscape or even the literal form and characterises it by establishing how social spatial structures can affect visual and perceptual outcomes [12].

The research questions that we will try to answer are the following.

- (1) How can a genotype-based approach that combines space syntax and emotional mapping be applied to identify and assess visual pollution in urban environments?
- (2) What spatial characteristics (integration, connectivity, and visibility) contribute the most strongly to the emergence of visual pollution?
- (3) How do different spatial configurations influence residents’ emotional responses and perceptions of visual comfort?
- (4) How can the visual pollution index (VPI) integrate objective spatial metrics with subjective emotional perceptions?

This work constitutes an initial methodological contribution towards the development of a wider research agenda on visual pollution assessment in urban settings. It is not aimed at generating a definitive repertoire of urban design prescriptions or methods for automatic detection, but rather to test and validate an analytical framework based on genotype that includes space syntax analysis, emotional mapping, and visual pollution index (VPI). The paper lays the theoretical and methodological basis for follow-up activities in the areas of theoretical and experimental validation, and the development of technological measures for visual pollution assessment.

## 2. Review of the Literature

### 2.1. Urban Space Analysis: Genotypes and Phenotypes

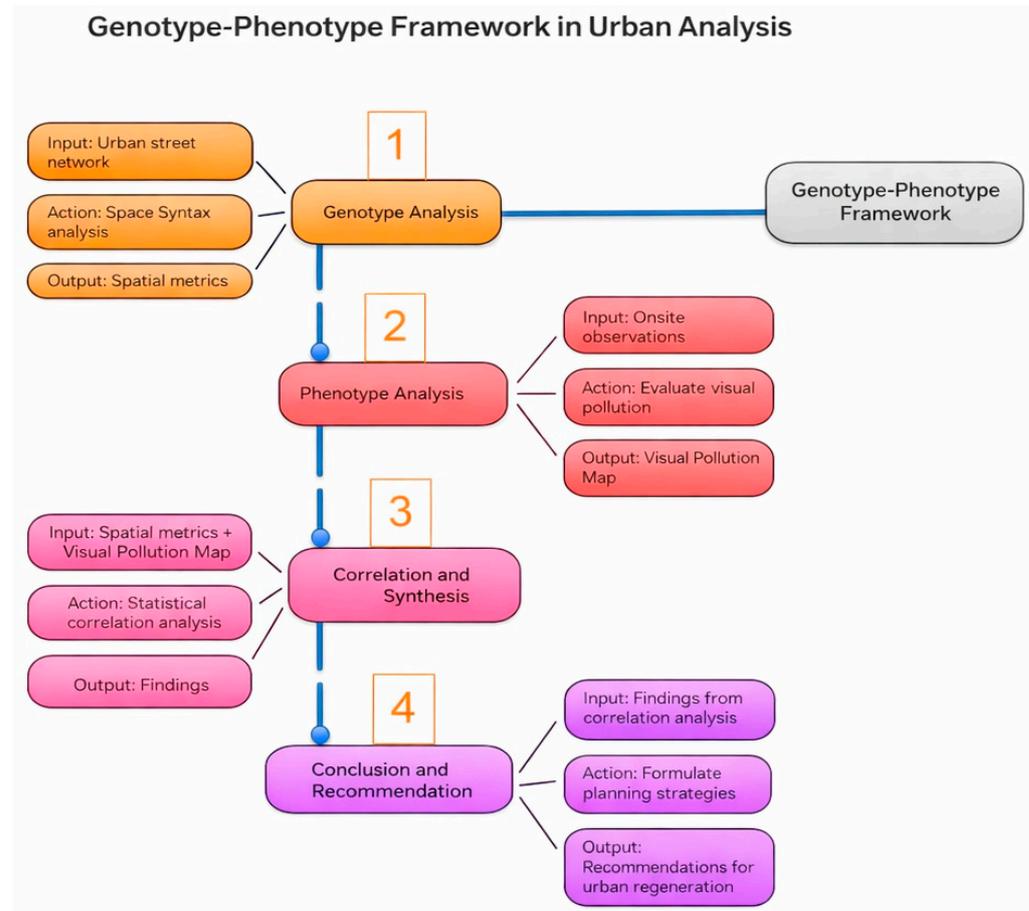
The scientific concepts of genotype and phenotype are used as a tool to develop a methodological framework for urban space analysis that allows understanding of the relationships between spatial configuration and its resulting impact [13]. Here, the genotype stands for the infrastructure that underlies urban realities, while the phenotype refers to its appearance, circulation of pedestrians, land use, or aesthetics of sight (among others) [14]. This section reviews the relevant literature and discusses the relationship of these ideas with urban studies, in particular, with the study of them through the lens of space syntax. The syntactic approach to space draws on biological notions such as genotypes and phenotypes and applies them to social science in general and architecture in particular. Genotypes are abstract relational frameworks that define spatial organisation and its principles. Phenotypes are the concrete manifestations of genotypes in a physical context, particularly

architectural creations [15,16]. According to space syntax theory, genotype reflects both spatial organisation and the characteristics of social and cultural processes [15,16]. Spatial genotypes can be identified by studying similarities and differences in the internal arrangements of buildings [17]. In genetic analysis, one common observation is the incorporation of culture into residential spatial patterns. The spatial configuration represents the cultural genotype resulting from the encoding of social meaning in architecture [15,16]. Cultural structures can be passed down through generations, yet they also alter significantly. Biologists refer to the permanent structure behind this as genotype, rather than phenotype, which is an observable and changing shape [18]. Genotypes are widely defined as characteristics or behaviours that persist over time. They are reproduced over generations and repeated multiple times. The domestic spatial genotype is defined as a spatial pattern that is regularly observed in specific situations [13]. In architecture, resistance to change is deeply rooted in structures known as archetypes. Archetypes can be viewed as fundamental components in architecture. This can develop a resilient framework in which changes in function, technology, and aesthetics conform to Vitruvius' three principles. To understand the archetypes within the realm of local architecture, it is necessary to study building designs through many case studies and typological assessments [19].

Applying it for urban visual quality assessment, the contribution that Space syntax can make is visibility analysis, where it utilises isovist fields and visibility graph analysis to measure what can be seen from points within urban space, in this way providing planners with clearer understandings of the space and helping them to deal with visual obstructions or clutter problems [20,21]. Visual integration in a city due to its physical connectedness allows space syntax to identify areas where inadequate integration can result in overlooked or visually polluted spaces [20–22].

Combining space syntax, deep learning, and perception studies supports large-scale quantitative evaluations of how people perceive street quality, relating spatial configuration to negative or positive visual experiences [21]. To solve this problem, the study offers the visual pollution index (VPI) as a phenotypic measure. Measure emotional distress and perceptual disorder in relation to spatial genotype patterns. The study shows that some genotypic configurations, such as high visibility with low legibility, can be the reasons for psychological discomfort. This combination of methods lets us look at both how space is set up (the genotype) and how that set up affects the real-life emotional experiences of users (the phenotype). Research contributes to our understanding of the spatial origins of visual pollution and provides a solid basis for actions that improve both structural legibility and people's health in cities. This flow diagram (Figure 1) represents the methodological framework connecting spatial structure (genotype) and visual aspects (phenotype).

The genotype study is carried out by space syntax, using axial maps and visibility graph analysis (VGA) to obtain fundamental spatial properties such as integration and connectivity. Phenotype analysis is based on emotion mapping (geotagged) through the visual pollution index (VPI). Both these analysis results are linked in the correlation and synthesis stage, comparing statistically spatial metrics to VPI values that allow discovering the relationship between spatial configuration and visual pollution. The conclusions and recommendations section transforms the findings into planning measures to reduce visual pollution and increase urban legibility and coherence.



**Figure 1.** Methodological framework based on genotype and phenotype for the assessment of visual pollution in urban environment and development of planning measures.

## 2.2. Space Syntax Theory and Its Application to Visual Pollution Assessment

Public urban areas are essential environments for promoting social interaction between individuals. However, understanding how spatial configurations might foster desirable social behaviours continues to be a significant and contentious task for urban designers and planners who strive to develop socially sustainable places. Space syntax, a recognised theory and research methodology, examines the impact of spatial arrangements on social dynamics. Notwithstanding its considerable contributions, there is an absence of comprehensive systematic evaluations of its efficacy in improving social interaction in public areas [23].

Ref. [16] established the space syntax theory, which provides a unique perspective on how spatial patterns affect what people perceive and how they navigate through constructed settings. The concepts of integration, connectivity, and visibility graph analysis (VGA) are essential for measuring the relationships between places and people. The ease with which a space can be accessed from every other place in a system is measured by integration. Low integration denotes isolation or distance within the spatial network, while high integration implies that a space is very accessible and likely to attract mobility [24–26]. The location of central or strategic areas in urban or building layouts is calculated using graph-based techniques, often using axial or segment maps [24–26]. According to Ref. [25], connectivity is the quantity of direct links of a space to its neighbours; i.e., the number of other spaces that are directly accessible from a specific point [25,26]. High-connectivity can affect social interaction and movement patterns and is often associated with high local accessibility.

Using the concepts of integration, connectivity, and visibility graph analysis (VGA), we can assess how spatial structures influence human perception [16] and how people are affected by visual pollution. The genotype-based approach refers to a deeper examination of spatial patterns (or urban DNA) that dictate how visual elements are distributed and perceived [27].

Visual pollution can be understood as a gene mutation in the city's DNA. Just as mutations in a living being disrupt its healthy functioning, mutations of the spatial codes that govern city life (for example, obstructed vantage lines, visual clutter, chaotic façades, etc.) compromise the legibility of urban spaces. These 'genotypic errors' manifest themselves most clearly in the areas most used and circulated, identified by the space syntax analysis. Their effects are expressed in the phenotype, such as stress, discontent, or disorientation, quantified by the visual pollution index (VPI). Here, the urban genotype is the code, pollution is its mutation, and the phenotype is the emotional expression of those disturbances. The negative influence of the visual burden will prevent people from seeing reasonable attractions. It is obvious that well-connected and reachable environments attract pedestrians from all aspects of life; this will mean greater exposure to visual displays. Therefore, the public will experience the negative effects of visual stress.

Since this research intends to address this through the integration of space syntax analysis, emotional mapping, and the visual pollution index, it is important here to weave the concepts to reflect on the impact of visual pollution. We have evidence that current research on visual pollution focuses primarily on subjective perception-based assessments or isolated physical indicators of visual disorder. On the other hand, previous studies have confirmed the psychological and aesthetic impacts of visual pollution. The gap is the deficiency of integrative frameworks for spatial configuration in relation to emotional perceptions. This gap is tackled here in this research to novel the idea of integration between all factors mentioned earlier.

A principal strength of space syntax is that it links spatial layouts to human movement and behaviour. It shows that well-linked or eye-friendly environments can bring more footfall and that people are more prone to the negative effects of visual overload.

This allows us to better address the issue of visual pollution, such as excessive advertising, crowded ads, inadequately preserved building facades, neglected landscaping, and low-maintenance cities. These elements reduce the visual appeal and integrity of public spaces, particularly in urban areas. In this case, space syntax, for example, can help determine sensitive zones, such as busy roads, public squares, or parks, where visual pollution is the most influential due to the high level of exposure [28].

Visual pollution can hinder navigation, decrease the visual attractiveness of space, and also affect social and economic functions [29]. The space syntax method analyses the relations of visibility and movement to explore the most problematic areas of visual pollution and suggests site-specific designs. Design solutions such as unified elements of buildings/repeated building line, or regulated signpost setback may be helpful for locations having limited visibility and integration. But highly connected subsystems may require more stringent controls against excessive stimulation to maintain adequate visual performance [28].

What distinguishes space syntax is its comprehensive approach. Instead of seeing visual pollution as individual pieces, it investigates how these characteristics interact in a geographical and cultural context. This wider perspective enables urban designers and planners to create solutions that improve the visual quality of public areas while maintaining overall utility and design logic. As cities expand and evolve, particularly in fast-emerging cities, the uncontrolled growth of visual clutter may degrade both the attractiveness and usefulness of public places. Space syntax analysis provides practical and

efficient insights for the design solution to these issues, ensuring that cities remain visually appealing and useful for those who use them.

Urban planners can use space syntax tools like spatial integration and visibility analysis to reduce visual pollution by designing more coherent, connected landscapes that enable functional variety. These spatial techniques improve physical activity, social engagement, cognitive performance, and aesthetics [30]. Similarly, strategically located green spaces in highly integrated and visually accessible places, as defined by space syntax, are more likely to be used and appreciated, improving relaxation and emotional well-being [31].

### 2.3. Visual Environment, Public Perception and Urban Well-Being

The visual environment is a crucial factor that contributes to the ways in which people perceive, interpret, and react to urban environments. The interiors of aesthetic landscapes improve emotional bonds, aesthetically enrich urban environments, and improve the economic vitality of urban areas through tourism and investment. On a personal level, visually pleasing environments promote psychological comfort and mental health by providing opportunities for relaxation and social interaction [32]. Studies such as in Ref. [33] show the relationship between subjective well-being and environmental pollution (visual, olfactory, and noise pollution have been examined by Ref. [34]. The use of ordinal logistic regression in a survey conducted in Quito, Ecuador, showed the strong effects of perceptions of foul smells and noise pollution on self-reported health, happiness, and satisfaction with life. These results highlight the need to incorporate public feelings into urban planning to improve understanding of environmental issues and the establishment of sustainable urban development patterns. On the other hand, visual pollution, defined as chaotic, unpleasant, or imposing visual elements, reduces the quality of urban life by negatively impacting the viewer's emotional response. Visually polluted environments are perceived by most city dwellers as disturbing and unpleasant, also with a negative impact on their psychological well-being [35]. Negative visual elements should be minimised and urban design should also attempt to reduce negative stimuli by creating environments that produce a positive emotional response. Visual perception of the environment has a strong impact on daily lives and, in general, on their satisfaction with urban life [36]. Private urban spaces, meanwhile, are anthropogenic spaces characterised and defined by the creation of physical structures with sensory interaction patterns. Therefore, emotional relationships with urban spaces from a perspective are essential for the well-being and identity of communities [37].

In summary, it can be stated that visual pollution has a major effect on the quality of life and well-being in urban environments (Table 1). It shatters the aesthetic cohesion of cities and has negative psychological and emotional effects, such as stress, irritability, and, as a consequence, reduced happiness. On the contrary, visually pleasing cities featuring harmoniously integrated green spaces and well-designed environments are fundamental to improving mental health, social cohesion, and economic vitality.

**Table 1.** Comparison between visual pollution and visual aesthetics.

| Characteristic        | Visual Pollution                                  | Visual Aesthetics                       |
|-----------------------|---|---|
| Psychological Effects | Stress, irritability, reduced happiness           | Improved mental health                  |
| Social Impact         | Shatters aesthetic cohesion                       | Improves social cohesion                |
| Economic Impact       | Negative effect on urban vitality                 | Improves economic vitality              |
| Overall Impact        | Negative effect on physical and mental well-being | Promotes physical and mental well-being |

This duality underscores the urgent need for urban planners and policymakers to address visual pollution and visual aesthetics simultaneously. In this sense, tools such as space syntax and public participation are crucial for achieving these objectives, as they are evidence-based and can be used to assess and redesign areas of urban spaces. Finally, including citizens in the urbanisation process guarantees that the designed urban environment aligns with the desire or necessity of citizens living within the environment, leading to more successful inner cities or neighbourhoods. Visual perception moulds daily experiences and the presence of visual pollution adds to cognitive dissonance [38]. On the other hand, visual quality could affect environments on both emotional level: supporting psychological health [39] and on an economic level, increasing vitality by attracting activity and investment activities/capital into the area [40]. Beauty creates emotional connections, social integration [41], and fosters civic participation [42]. Lastly, incorporation of visual quality into planning promotes sustainable urban futures [15]. This approach reinforces the systemic nature of the role of aesthetics in creating livable cities.

In general, combating visual pollution is not just an aesthetic problem; it is a public health issue. Cities play a significant role in people's lives as places that can be both visually attractive and physically reassuring, not only by eliminating negative visual stimuli but also by providing positive physical and mental well-being. This integrative approach that anchors well-being across the three spheres of environment, public perception, and health is vital for a sustainable urban future.

### 3. Methodology

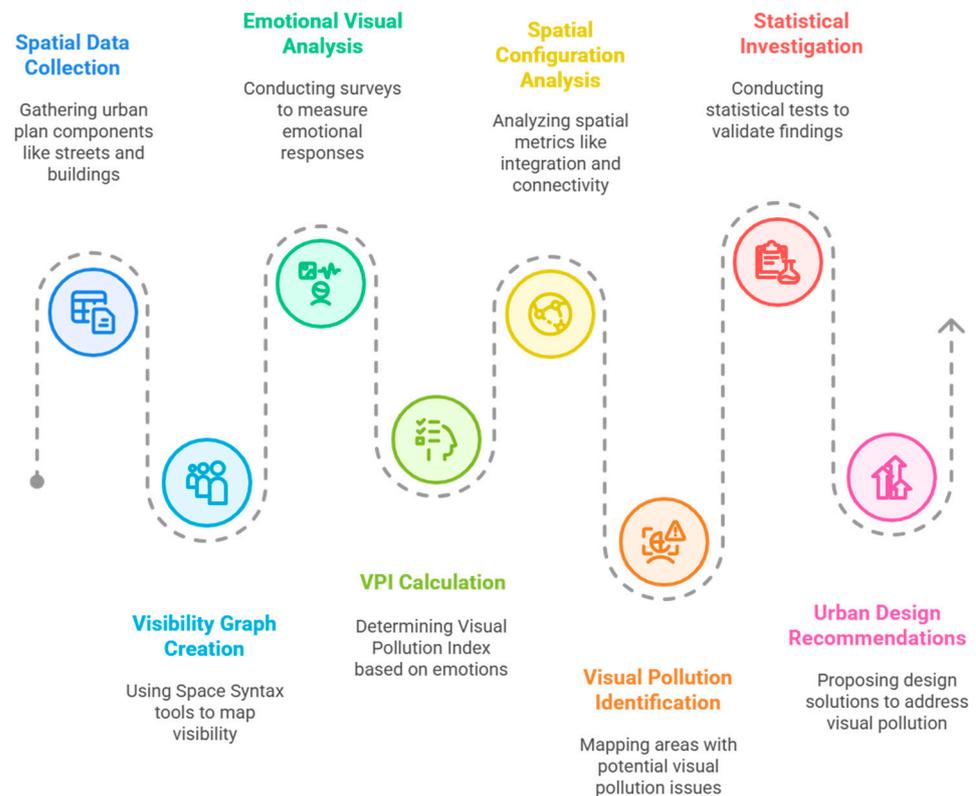
This study employs visual graph analysis (VGA) to examine perceived spaces from the user's perspective. Additionally, VGA enables the analysis of genotypical aspects of urban structure, which can facilitate future research linking pollution patterns with specific urban typologies and combining the identification of spatial configuration through emotional mapping. The methodological structure integrates objective spatial indices based on space syntax with subjective emotional dimensions from a visual-perceptual survey. The combination of these approaches provides a complete understanding of how spatial structure (urban genotype) influences human perception, emotional well-being, and visual pollution. This study moves the syntactic method forward by combining emotional mapping and visual perception with genotype-based analysis. Traditional space syntax does not let you directly access the phenotypic experience, which is how people really feel, see, and react emotionally to different spatial arrangements. It uses space syntax to connect integration, connectivity, and visibility to spatial genotypes [15]. These are the main signs that show how urban areas are built and interpreted. Syntactic metrics are not just based on geometry; they are also based on culture and society. This illustrates how spatial arrangements both influence and are influenced by the behaviour of groups of people. For example, the Dainava neighbourhood has spatial characteristics that are common in late-modernist design, such as hierarchical street layouts, open green spaces, and separate residential areas. When these structural features are seen over and over again in comparable situations, they act as spatial archetypes, which are stable and identifiable genotypic forms. In this study, space syntax is applied to analyse and address urban visual pollution by measuring space configuration, visibility, and accessibility that directly affect how people perceive/feel about the visual quality of cities. It offers a variety of analytical methods to predict and quantify the spatial design of urban space, accounting for the ordering of streets, open spaces, and built forms in relation to visibility, accessibility, and movement patterning. Space syntax by means of cut lines and lines, visibility and integration (isovists), can be used to detect areas with broken or blocked visual connections or simply excessive visual complexity—significant causes of urban visual pollution [20–22].

These results demonstrate how spatial arrangement affects the rise in unattractive, non-eligible visual elements (billboards, barriers, poorly designed street furniture).

Thus, visual pollution can be interpreted as a mutation in the urban genotype. Deformation of spatial DNA (which is composed of integration, connectivity, and visibility) into the form of disrupted layouts, blocked views, or visual excess causes maladaptive genotypic states. These disruptions manifest phenotypically as harmful perceptions and feelings that are assessed based on VPI. In other words, the genotype sets the codes for structure, pollution is a distortion of such codes, and the phenotype indicates how they are lived out in terms of visual discomfort and diminished well-being. Since visual pollution research has not produced weighting criteria, the research constructed a ‘visual pollution index’ as a mixture indicator considering emotional responses related to visual comfort, environmental satisfaction and perceived disorder. This could be considered an investigative tool rather than a standard measurement method.

By the concept ‘urban genotype’, which is applied in this research, we mean the invisible but formative spatio-genetic DNA that constructs a city in terms of its street networks, the layout of buildings, and visual fields. This genotype influences spatial qualities such as accessibility, visibility, and potential for movement, which can be assessed through integration and connectivity, as well as visibility graph analysis (VGA). Visibility graph analysis (VGA) is a technique that creates a graph with nodes for locations and edges for lines of sight by mapping and analysing the intervisibility between points in a space. VGA is particularly helpful for assessing accessibility, wayfinding, and spatial experience [43]. In this study, visibility graph analysis is used to measure how much people can see and connect with the space. Subsequently, the results of VGA are linked to emotional responses and visual pollution in the area.

These factors constitute the architectural structure of “urban experience”, integrating how space is perceived and experienced, how space is traversed, and where visual disorder clusters. The method is structured in five interrelated phases (Figure 2):



**Figure 2.** Methodological framework of visual pollution analysis.

Phase 1 is the collection of emotional and perceptual data in a structured survey that integrates three dimensions reflecting how respondents feel about their area: (1) preference to live in the area; (2) sense of community; (3) perception of street maintenance assessed using the Likert scale. The emotional survey used a standardised questionnaire distributed to adults in the study area. Participants were recruited by participating on site and responses were collected anonymously to ensure reliability. The survey questionnaire used Likert scale questions to assess impressions of visual quality, emotional ease, and environmental satisfaction. The emotional mapping survey saw between 61 and 65 people take part, all of whom were between the ages of 18 and 65. About 85% of the people who answered the survey lived in Dainava, and the rest lived in Kaunas and knew the area. Participants were recruited through voluntary participation and completed the questionnaire using an online georeferenced mapping technology, allowing them to pinpoint specific sites linked to emotional responses. The sample comprised both long-term residents and recent arrivals, guaranteeing diversity in familiarity and lived experience. Geotagged responses were spread throughout the district in an online format, including both the core and the outer sections. Each marked place had X and Y coordinates saved with it, which made it possible to make precise spatial maps and then use those maps with spatial syntax metrics.

Possible methodological constraints include convenience sampling, self-selection bias, and potential temporal or environmental influences on emotional perception. These limitations are intrinsic to exploratory perception research and are properly recognised.

- The second phase is the analysis of the VPI (Equation (1)). This index is a measure of the negative emotional load of the urban environment.

$$VPI = \frac{\text{Living Score} + \text{Sense of Community Score} + \text{Street Maintenance Score}}{N} \quad (1)$$

where  $N$  is the count of valid responses per respondent. Higher  $VPI$  values predict greater visual discomfort, community fragmentation, and a more neglected environment. The  $VPI$  is geo-located and becomes a perceptual layer to be fused with the spatial metrics in the following stages.

The visual pollution index ( $VPI$ ) represents a composite perceptual indicator of visual discomfort in the urban environment. Higher  $VPI$  values indicate a stronger negative perception, reflecting dissatisfaction with living conditions, a weaker sense of community, and poorer perceived street maintenance. Lower  $VPI$  values indicate more positive emotional responses and greater perceived environmental coherence. The  $VPI$  therefore reflects a mixture of perceived environmental quality and emotional affect, rather than purely physical pollution intensity. It captures the phenotypic expression of spatial conditions, linking subjective perception to spatial configuration.

- In the third phase, the spatial configuration of the analysed area is explored using space syntax analysis. A 200-metre radius can be taken to obtain the visibility graph that simulates pedestrian-level vision. Three primary spatial indicators are generated by the analysis of integration that shows how easy a space can be reached in the overall spatial system; connectivity that represents the amount of direct spatial connection of an area with the immediate vicinity; and the visual graph axis that estimates the visual openness or accessibility around each location from a specific viewpoint. These spatial dimensions reflect the genotypical structure of the urban realm, objective and measurable attributes of spatial formation that affect the perception and experience of space. They shed light on how physical configurations create pedestrian zones, freedom or restrictions of line of sight, and potential hotspots for visual clutter.

- To connect these spatial properties with human affective responses, in the fourth stage, the factor of tangibility is calculated. Tangibility is derived from the multiplication of integration and connectivity (Equation (2)).

$$\text{Tangibility} = \text{Integration} \times \text{Connectivity} \quad (2)$$

The product of integration and connectivity describes the compromise between global accessibility and local visibility. In terms of concepts, tangibility is spatial centrality and local accessibility (high connectivity). As a consequence, makes the spaces visible, highly used, and somehow perceptually strong in the urban system. When such a space also has a high VPI value, it reflects the dangerous situation, high exposure, and negative perception. From a practical planning perspective, these spaces are considered priority zones for visual pollution treatment, as they have higher visibility and, with it, an increased spatial impact on users. This research employs the integration and connectivity metrics from space syntax to assess the tangibility of the urban environment, utilising distinct formulas for each parameter. Real Relative Asymmetry (RRA) is the formula for integration, a global measure of accessibility.  $\text{Integration} = (k - 2)/2(\text{MD}_p - 1)$ , where  $\text{MD}_p$  is the mean depth (the average number of steps from space  $p$  to all other spaces) and  $k$  is the total number of spaces in the system. Connectivity, a local metric, is just the number of direct connections from a certain place, which is shown as  $C_i = k$ , where  $k$  is the number of spaces that are directly related to space [22,43]. These two indicators give a complete picture. Integration shows the general importance of a space and how likely it is to attract activity throughout the city network. Connectivity measures accessibility and legibility of a space, which is a direct reflection of how people experience visual and physical connections in real life. The analysis uses both global and local measures to make a strong case for how the layout of the city affects both its overall function and how people feel about the surroundings [22,44,45]. The tangibility index is derived from space syntax theory and measures the collective influence exerted by spatial integration and connectivity on perceptual clarity. When considered together, tangibility reveals the extent to which urban spaces are visually permeable and cognitively decipherable. Sensitivity analysis was used to test the stability of this index in different spatial patterns.

This measure of tangibility represents how readable and visible a location is in public spaces. Higher scores indicate that these spaces are high in tangibility, both functionally and perceptually, since tangibility reflects the urban spaces that are the most accessible and visible while moving through the city. Therefore, these regions are also the most sensitive to visual disorder and represent critical targets for pollution abatement. The tangibility map can also be a map of the visible and used areas in space.

- The final step is data mapping and integration. VPI scores (visual pollution index), emotional survey measures, and space metrics (integration, connectivity, tangibility) are overlaid using GIS data and DepthmapX results. This provides a way of pinpointing those areas that are critical for the intersection between spatial structure and negative emotional perception: locations with high visibility and high VPI. These ‘visual pollution hotspots’ are frequently located in well-connected, but poorly maintained zones or in places with too many signs, too much visual noise, or too much fragmented spatial arrangement. In contrast, parks and green spaces are linked to lower VPI values and a more positive emotional perception.

The methodological decisions taken in this study are purposely exploratory and ground-laying. The emotional mapping survey and the space syntax analysis are used as intelligible tools to establish the correlation between spatial layout and visually perceived pollution. These approaches produce structured, human-centred reference data that can be

used to inform and support innovative experimental paradigms such as psychophysiological measurement and automatic visual analysis.

#### 4. Application and Validation

The proposed methodological framework is tested to analyse visual pollution in the Dainava modern neighbourhood, which was built in the second half of the 20th century. The research was carried out in Dainava due to its status as one of the oldest soviet neighbourhoods in Kaunas and a quintessential representation of the modernist era, featuring a variety of morphotypes. The study used a questionnaire that assessed the quality of life in Dainava through non-spatial inquiries and urban societal engagement via spatial enquiries [45]. The data from this questionnaire were used to generate the VPI (visual pollution index). An urban visual analysis was performed to categorise and improve the feelings of people about their neighbourhood by pinpointing preferred emotional locations by geotagged emotion mapping [45].

This research includes quantitative genotypical analysis, space syntax, and visibility graph analysis (VGA) in parallel to emotional visual analysis to measure VPI through emotional response (Figure 3). Research integrates spatial synchrony theory with emotional mapping, thus drawing on environmental psychology [46] to relate spatial organisation to human emotional responses. Space syntax lacks effective data, but its configurational logic is a good starting point for understanding the extent to which spatial configuration affects emotional well-being, which is particularly the case when the visual coherence is disturbed by pollution.



Figure 3. Emotional response to urban setting in Dainava (by the author).

The focus of the research is on analysing spatial configurations and visibility connections to implicitly infer probable regions of visual pollution. The investigation begins with spatial data collection, which focuses on components of urban planning such as street networks, building footprints, and open spaces. Visibility graphs are created using space syntax tools such as DepthmapX, with an emphasis on the 200 m visual radius to capture the spatial context impacting pedestrian movement and visual perception. This research builds on Hillier and Hanson's (1984) space syntax theory [15], which argues that spaces are organised in relation to one another as a totality of spaces computed with spatial metrics, such as integration (measuring spatial accessibility) and connectivity (the density of directly

connected spaces). Integration is the World-space, that is, the global depth of space, and connectivity is the World-time, that is, a local access. Visibility graph analysis (VGA), although emerging after [47], is used to quantify visual accessibility in DepthmapX and is consistent with the syntactic notion of visibility as an attractor.

The data was also collected by a visual and perceptual survey, which measured people's emotions in Dainava when perceiving and evaluating buildings, streetscapes, and other local visual spaces. The assessed aspects were the following: living preferences (1 to 4 points, where 1 is the highest preference); sense of community (1 to 4 points, where 1 is the strongest feeling); street maintenance (1 to 4 points, where 1 is the best maintenance). The analysis shows that higher VPI values correspond to negative emotional perceptions, linking poor maintenance and weak community ties to increased visual pollution. The VPI values highlight critical areas of concern within the Dainava neighbourhood, as another layer is analysed, applying the space syntax. The technique focuses on essential space syntax metrics. Connectivity, or the number of direct links between places, is used to identify locally accessible areas. Second, the measured integration values indicate how effectively places are linked to the larger system, with high-integration zones suggesting urban centres that will support pedestrian activity and aesthetic harmony. Tangibility, which was obtained by multiplying connectivity by integration, represents the visual legibility of environments that also correlates with user behaviour and psychology. The tangibility connects space syntax's abstract metrics to real-world impacts on user behaviour and experience. For example, a space with low visibility due to dense and unregulated advertisements can increase cognitive stress, which is measurable through tangible assessments. Ref. [46] emphasises areas that can facilitate or impede spatial navigation. These metrics enable mapping of spatial links, as well as the identification of places where inadequate integration or connectedness may be associated with visual issues such as fragmented spatial organisation or decreased wayfinding clarity.

Visual pollution is estimated by finding low-integration zones, which often have poor spatial legibility and disjointed layouts, and then mapping these locations against high-connectivity or high-tangibility zones to discover mismatches. Statistical investigations of these indicators involve looking at their distributions, detecting outliers, and calculating correlations to confirm the results. Spatial clustering identifies zones with possible visual difficulties, which gives useful information for urban design initiatives. In areas with low integration, the connectivity between improved road layouts and pedestrian paths is introduced as a priority. High-tangibility zones are maintained by ensuring visual coherence, along with repeated areas with mismatches of connection in space. A viewing radius of 200 m ensures that both localised and extended spatial dynamics are incorporated into the analysis, allowing a detailed examination of spatial configurations that modify visual perception. This methodology establishes an explicit quantitative basis for assessing and/or remediating visual pollution through spatial analysis despite the general absence of rigorous visual data.

#### *4.1. Visual and Perceptual Survey*

Urban elements (buildings, local visual spaces, and streetscapes) are considered the most important in generating emotional experiences toward the urban environment, and most of them are based on the quality and visual coherence of the elements. This aspect is analysed using emotional mapping to identify and address visual pollution hotspots within urban areas (Figure 3) [48].

Based on the results of the emotional response of a survey (Figure 3) [45], the study of the evaluation of buildings, spaces, and streetscapes, linking it to the urban genotype, demonstrates how people assign distinct emotional connotations to various architectural

and urban characteristics. Similar incidents have a substantial correlation with neutral and positive feelings (between 31% and 35% neutral and 25% to 30% positive) in existing residential and commercial structures in a modernist neighbourhood. Open and recreational environments, especially green spaces and parks, have a moderate degree of happiness (>46–50%), with a low number of negative feelings. The findings revealed that streetscapes often produce mixed emotional responses, with satisfaction levels positively associated with green features and declining in largely developed environments. Such emotional reactions are closely related to phenotypic urban traits, as spatial regions with certain types of green spaces regularly report a higher positive score. On the other hand, typical urban plans with fewer natural components generate more mixed or negative emotions, while mixed-use places tend to achieve a healthy emotional balance.

These results emphasise the necessity of designing cities that benefit from nature, are human-scaled, and have a balanced ratio of greenspace to built environment. Visual pollution, for example, should be reduced and optimised to increase the emotional well-being and living ability of metropolitan places in the long run. Based on research results [45], it is discovered that urban genotypes of spatial structural configurations have significant implications for our emotional responses in urban settings. Integrating green spaces into genotypic urban structures promotes pleasant emotional experiences because vegetation has traditionally been associated with health and psychological well-being, and it is favourably integrated in the environment, minimising visual pollution. In comparison, functional diversity leads to mixed-use genotypes that balance emotional responses by serving a wide range of user needs as a better platform for emotional experience, whereas traditional urban areas characterised by high density with tree deprivation lead to neutral (in natural and residual) or negative correlation.

The same result occurs when there is absence of adequate greenery and the absence of built-in settings. Green elements are associated with higher levels of happiness, supporting the idea that the harmonisation of aesthetic and natural surroundings in urban corridors can provide more connectedness. The latter results of the analysis of streetscapes without greenery and emotional estrangement. Furthermore, well-balanced urban genotypes that connect the built and natural worlds reduce visual pollution in an aesthetic scene plagued by semantic congestion while increasing visual harmony and emotional well-being. Our results suggest that the urban genotype should prioritise the balance of functions, ecological net, and human-centric design to provide emotional support to sustainable urban space.

#### *4.2. Visual Pollution Index: Analysis of Emotional Mapping and Visual Pollution in Urban Environments*

The research adopts a quantitative method to calculate VPI based on three key variables:

- general evaluation of the neighbourhood;
- sense of community;
- street maintenance.

These key variables were collected from previous research data collected using emotion mapping for the Dainava neighbourhood in the winter season and the survey conducted for 65 people in the neighbourhood who were 20 to 65 years old and were 45% men and 55% women [45,46]. Later, after a year, the data were integrated with space syntax analysis based on genotype and emotion mapping to extract spatial characteristics of urban configuration to study human behaviour and social interaction, which was also conducted in the winter period, which helped to extract the vegetation and helped to test the method on buildings and urban environment. This would allow urban designers and planners to have a more in-depth approach to urban planning by implementing emotional mapping and visual pollution embedded in this framework. Advantages of this integration:

- Better perception of space: VPI can be used alongside traditional space syntax metrics to find zones where the configurations of space and visual quality overlap. The relationship between elevated VPI scores and visually cluttered or poorly integrated spaces, for example, VPI can highlight the need for targeted interventions.
- Synthesis of genotypes and phenotypes: As emotional genotypes are defined similarly to spatial genotypes, they connect specific spatial configurations to consistent emotional responses. As an example, parks and green spaces often provide positive feelings, while poorly maintained streets may produce negative feelings each time.
- Predictive modelling: Integrating VPI data with spatial syntax metrics for predictive modelling allows planners to judge how proposed alterations in the urban fabric may impact the emotional well-being and social behaviour of residents.

Genotype-based space syntax expanded by visual pollution analysis and affective mapping is an efficient multidimensional toolset for urban design that enables more human-centric urban design. For the next quantification of VPI, there are similar studies that used indices and calculations to attempt to quantify visual pollution and other measures of quality of life related to urban planning [49]. The authors proposed a quantitative assessment of visual pollution due to unmanned aerial vehicles (UAVs) through a multistep process starting with an expert workshop that helped identify key contributors to visual pollution.

Public perceptions of visual pollution in various scenarios were investigated using an image-based questionnaire. Although this method does not employ the same components as the suggested VPI (it integrates the living score, the sense of community score, and the street maintenance score), it has the potential to be a basis for measuring visual pollution based on several aspects, including public sentiment based on the questionnaire.

The VPI values highlight critical areas of concern within the Dainava neighbourhood (Table 2). For example:

- Respondents with high VPIs often express dissatisfaction with street maintenance and a desire to be seen.
- A weak sense of community is one of the contributing factors.

Lower VPIs are associated with better perceptions of maintenance and community ties, indicating that these factors significantly influence emotional well-being.

Table 2 presents the visual pollution index (VPI) scores calculated from three evaluative variables: liking living in the neighbourhood, sense of community, and street maintenance. Each variable is measured using a three-point scoring system, where 3 indicates a positive assessment, 2 represents a neutral perception, and 1 reflects a negative perception. The VPI value is derived as the average of these three scores, providing an overall indicator of perceived environmental quality and visual pollution for each respondent. As a conservative check of robustness, we also performed correlation analyses of VPI with spatial metrics. A strong 99-positive relationship ( $r = 0.99$ ) was found between connectivity and visual polling exposure, suggesting that easily seen places produce a stronger perceptual response. Furthermore, the average VPI scores were compared between the high- and low-visibility regions, which were consistent with statistical significance for higher mean values in highly exposed areas. Although exploratory, this validation confirms that the spatial configuration relates to perceived visual pollution.

**Table 2.** The survey data on emotions toward the Dainava neighbourhood.

| Residence                         | Happiest Place                                   | Like Living | Sense of Community | Street Maintenance | VPI  |
|-----------------------------------|--|-------------|--------------------|--------------------|------|
| Dainava Pasimatymo g.             | In Dainava park                                  | 1           | 3                  | 3                  | 2.33 |
| K. Donelaičio g.                  | Park   | 2           | 3                  | 2                  | 2.33 |
| Dainava, V. Krėvės pr.            | Draugyste park                                   | 2           |                    | 2                  | 2    |
| Kaunas, Pasimatymo g.             | No specific place                                | 2           | 3                  | 3                  | 2.67 |
| Kaunas                            | Gym plus   |             |                    | 2                  | 2    |
| Kaunas, Dainava                   | Maybe where I see greenery and parks             | 2           | 3                  | 3                  | 2.67 |
| V. Krėvės Pr. 5                   | The parks  | 1           | 1                  | 2                  | 1.33 |
| Kaunas J. Tonkūno g. 5            | Dainava park                                     | 1           | 1                  | 1                  | 1    |
| Kaunas, Sv. Gertrudos g.          | I am not well acquainted with this neighbourhood |             |                    | 2                  | 2    |
| Kaunas-Dainava-Europos pr         | In the garden                                    | 1           |                    | 1                  | 1    |
| Gričiupis, Gričiupio g. 9         | Park   | 2           | 1                  | 2                  | 1.67 |
| Krėvės pr., Kaunas                | Draugyste park                                   | 2           | 3                  | 2                  | 2.33 |
| Gričiupio g. 9                    | Draugyste park                                   | 2           |                    | 2                  | 2    |
| P. artizanų                       | Dainava park                                     | 1           | 1                  | 2                  | 1.33 |
| Gričiupis, Pašilės str.           | Parks  | 1           |                    | 2                  | 1.5  |
| Sanciu                            | parks  | 2           |                    | 3                  | 2.5  |
| Pasimatymo                        | Dainava park, KTU area, Fitness club             | 1           | 1                  | 2                  | 1.33 |
| Kaunas Old Town, Vilniaus gatvė   | I don't know this district very well             | 2           |                    | 1                  | 1.5  |
| Partizanų street                  | In Dainava park.                                 | 1           |                    | 2                  | 1.5  |
| Dainava, Savanori Pr., Kaunas     | Park behind Molas                                |             | 1                  | 2                  | 1.5  |
| Pramonės pr. 44                   | Pramonės pr. 44                                  | 2           |                    | 3                  | 2.5  |
| Kovo 11-osios g. 112              | Parks  |             |                    | 3                  | 3    |
| Dainava                           | Draugyste park                                   | 2           |                    | 2                  | 2    |
| Pramonės pr. 59                   | Dainava park, maybe as I can see people          | 2           | 3                  | 2                  | 2.33 |
| Kapsų g., district of Žaliakalnis | Draugyste park                                   |             | 3                  | 2                  | 2.5  |
| V. Krėvės pr                      | near the green areas                             |             | 3                  | 3                  | 3    |
| V. Krėvės pr                      | Draugyste park                                   | 2           |                    | 2                  | 2    |
| Birželio 23-osios g               | parks  |             | 3                  | 2                  | 2.5  |
| Dainava                           | no place   |             | 3                  | 2                  | 2.5  |
| Pramonės pr                       | no place, maybe near the parks                   | 2           | 3                  | 3                  | 2.67 |
| Pasimatymo aklg pasimatymo        | parks  | 2           | 3                  | 2                  | 2.33 |
| V. Krėvės pr.                     | Batu kalnas, Urmas                               |             | 1                  | 1                  | 1    |
| V. Krėvės                         | café, and restaurant                             | 1           | 1                  | 2                  | 1.33 |
| A. Baranausko gatvė, Kaunas 50235 | Draugyste park                                   |             | 1                  |                    | 1    |
| V. Krėvės pr.                     | when I am in the GYM                             | 1           |                    | 2                  | 1.5  |
| Gričiupio g. 9, Kaunas 51373      | When im walking                                  | 2           | 3                  | 2                  | 2.33 |
|                                   | Mall   |             | 3                  | 2                  | 2.5  |

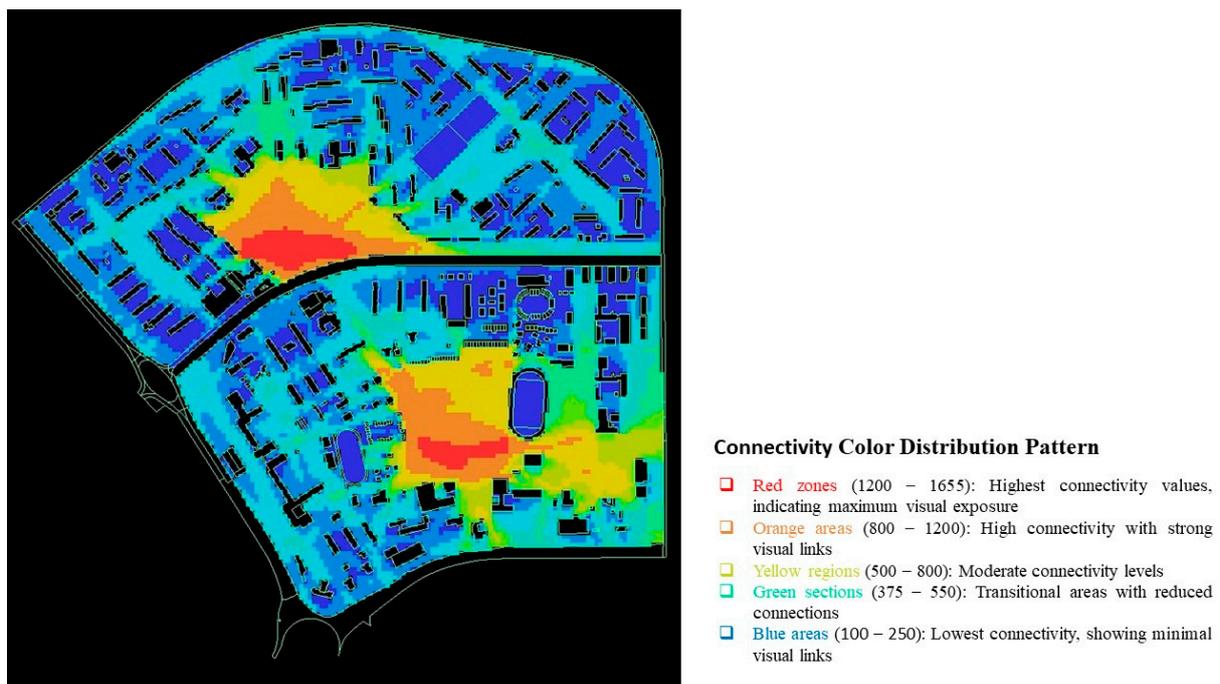
#### 4.3. Genotype-Based Space Syntax Analysis

The genotype-based approach in urban analysis emphasises the underlying spatial configuration, often referred to as ‘urban DNA’ that governs movement, visibility, and legibility within a city [49,50]. By using space syntax as a methodological framework, spatial integration, connectivity, and visibility influence urban functionality and aesthetic experience. These spatial “genotypes” not only shape the structural accessibility of urban environments, but also significantly impact human perception, behaviour, and emotional well-being [51,52].

This study uses a genotype-based lens to analyse visual integration, highlighting how these spatial configurations correlate with visual pollution and urban quality. Through metrics such as integration, connectivity, and tangibility, the research identifies critical areas for intervention. The analysis underscores how spatial configurations can create both opportunities and challenges for urban legibility, visual comfort, and overall quality of life, providing a robust framework for mitigating visual pollution and improving urban environments.

#### 4.3.1. Connectivity Analysis

Connectivity analysis investigates the relationship between urban connectivity and visual pollution, providing information on its geographical distribution and consequences for urban quality of life. Research uses connectivity assessments within a visual distance. Connectivity measurements from a distance of 200 m reveal a strong correlation between urban connectivity levels and the presence of visual pollution. The analysis of the Dainava modernist neighbourhood (Figure 4) reveals important aspects of urban dynamics. The average connectivity grade in our sample was 512.54 (Table 3), reflecting a moderate urban connectivity as expected, with organised layouts that operate on the principles of modernist planning ideals. However, the broad spectrum of connectivity ratings from 2 to 1.655 is indicative of considerable geographic variability, revealing that while some places are accessible and linked to one another, others are isolated or poorly connected.



**Figure 4.** Connectivity analysis showing areas with the greatest visual exposure in the Dainava neighbourhood.

**Table 3.** Connectivity values of Dainava neighbourhood.

| Level   | Value   | Location                     |
|---------|---------|------------------------------|
| Maximum | 1.655   | central core areas           |
| Minimum | 2       | peripheral zones             |
| Average | 512.542 | moderate integration average |

This statement is consistent with the idea that most regions are moderately connected, as the median value of 375 illustrates, and as can also be conjectured from the intermediate urban layouts of modernist neighbourhoods. This relatively low level of connectivity reflects a typical modernist urban design attempt to walk a tightrope between openness and accessibility. However, the distant connectivity among each zone could reflect how difficult it can be to maintain continuous phenomena of integration in changing urban conditions.

These findings highlight the importance of addressing connection inconsistencies in Lithuania's modernist communities to advance functional coherence and equity while remaining consistent with the urban design concepts that have shaped them. These data can be used by urban planners to integrate areas with low connectivity into the broader neighbourhood network, improving accessibility and liveability for all residents.

Such complex connection patterns cause great problems with visual pollution in modernist neighbourhoods such as Dainava. The analysis results show the extremely high correlation (0.99) between connectivity and visual pollution, which means that highly connected areas are more vulnerable to visual pollution. This near-linear relationship, where a clearer visual indication brings a harsher overall visual impact, suggests that infrastructure and urban density create a lot of visual pollution. In areas with connections beyond the 75th percentile (678), there is a considerable amount of severe visual pollution, with very high connections at coordinates (1090, 4330) and a consequence of associated visual problems. Conversely, low-connection regions, like coordinate (1130, 4150), are less visible and make fewer effective streets.

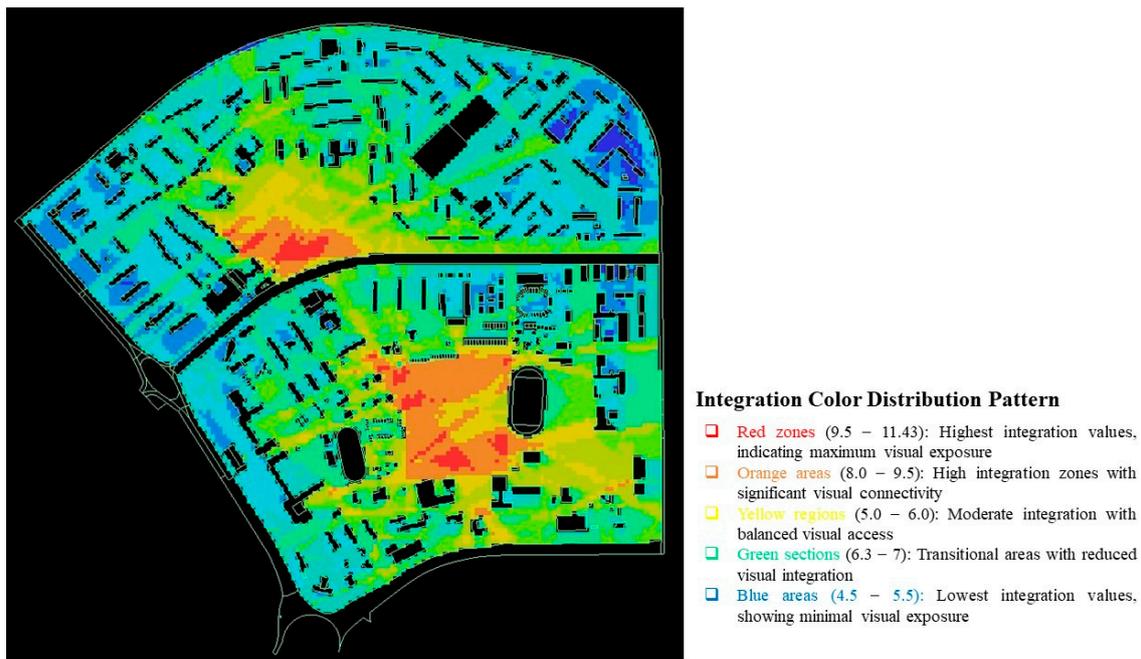
These findings reveal an ambivalence of connectedness in modernist neighbourhoods. As visual pollution impacts the residents' quality of life, to follow the modernist creed of functionally as well as aesthetically balanced urbanity, urban planning must then move to the other side of this question, and work out how to implement visual pollution mitigation measures in high-connectivity zones, optimising signage and controlling the height of buildings near sensitive areas, maintaining green space, etc.

#### 4.3.2. Integration Analysis

The integration analysis of the Dainava modernist neighbourhood (Figure 5, Table 4) shows that central areas have the highest vulnerability to visual pollution, with the predominant activity nodes being the most affected (7.0–11.43). The red zones in Figure 6 represent the humanised urban environment in which we need to avoid visual pollution. Transition areas with medium integration (6.0–7.0) provide a visually permeable buffer and have moderate sensitivity to visual pollution. These are the places where we can improve by increasing connectivity. Visual relief and protection from pollution are provided by three peripheral "blue zones" with the lowest integration values (4.5–5.5), naturally decreasing from visual exposure. These fields are relatively dense and serve as protective formations from visual pollution that increases the visual quality of the neighbourhood.

**Table 4.** Integration Values of the Dainava neighbourhood.

| Level   | Value   | Location                     |
|---------|---------|------------------------------|
| Maximum | 11.4308 | central core areas           |
| Minimum | 3.178   | peripheral zones             |
| Average | 6.93    | Moderate Integration Average |



**Figure 5.** Integration analysis showing areas with the highest visual exposure in the Dainava neighbourhood.

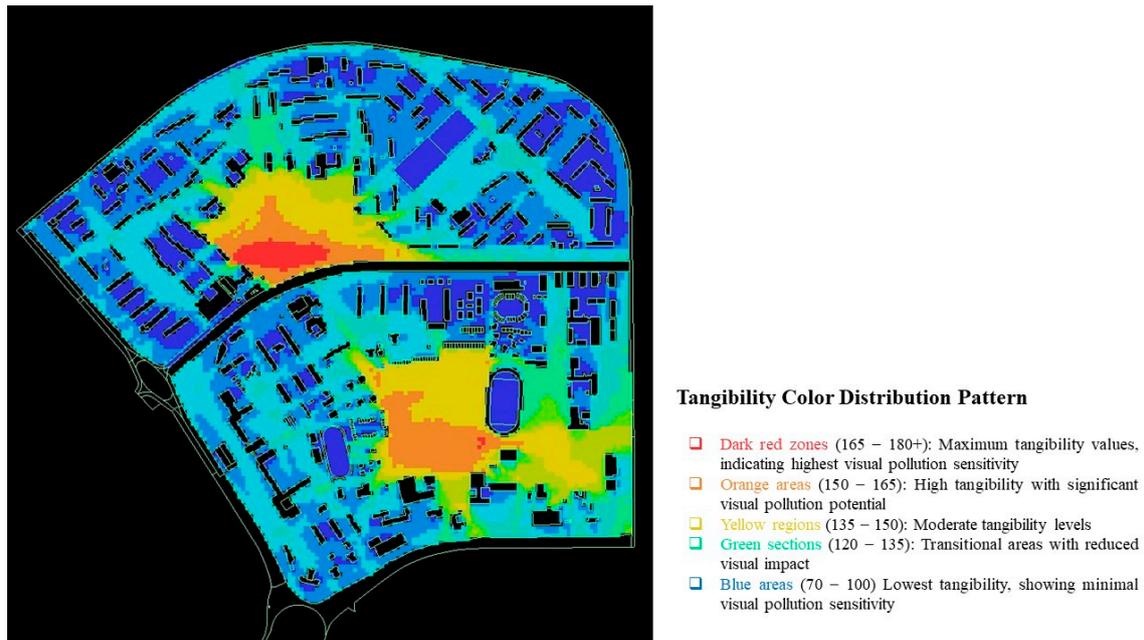
The analysis emphasises the necessity of forming urban areas without deviating from the modernist doctrine of function and spatial clarity, while not submitting to visual pollution during high exposure. Effectively maintaining the balance between neighbourhood liveability and visual harmony as planners address visual pollution across central parts, while harnessing the natural benefits of peripheral zones goes a long way toward having a physically viable ecosystem.

The result highlights the important role of spatial integration as an indicator of potential exposure to visual pollution, with high levels of visual pollution in central areas indicating the need for higher visual quality standards.

This analysis also reveals how spatial metrics, such as integration and connectivity, correlate with emotional responses. High-VPI zones, characterised by weak connectivity and fragmented spatial layouts, are identified as areas of emotional and visual discomfort. Emotional mapping highlights the stress and dissatisfaction related to these zones, highlighting the need for interventions to improve spatial legibility and reduce visual clutter [15,46].

#### 4.3.3. The Tangibility Analysis

According to the tangibility analysis (Figure 6), modernist neighbourhoods in Lithuania possess a specific spatial dynamic in terms of connectivity, visual integration, and perception of visual pollution. The results suggest that visibly polluted areas are mainly characterised by their centrality and high connectivity, which are reflected in high visibility scores. The areas with the strongest connectivity and highest visual integration are thus highlighted red-orange on the tangibility map and are hotspots for potential visual interference.



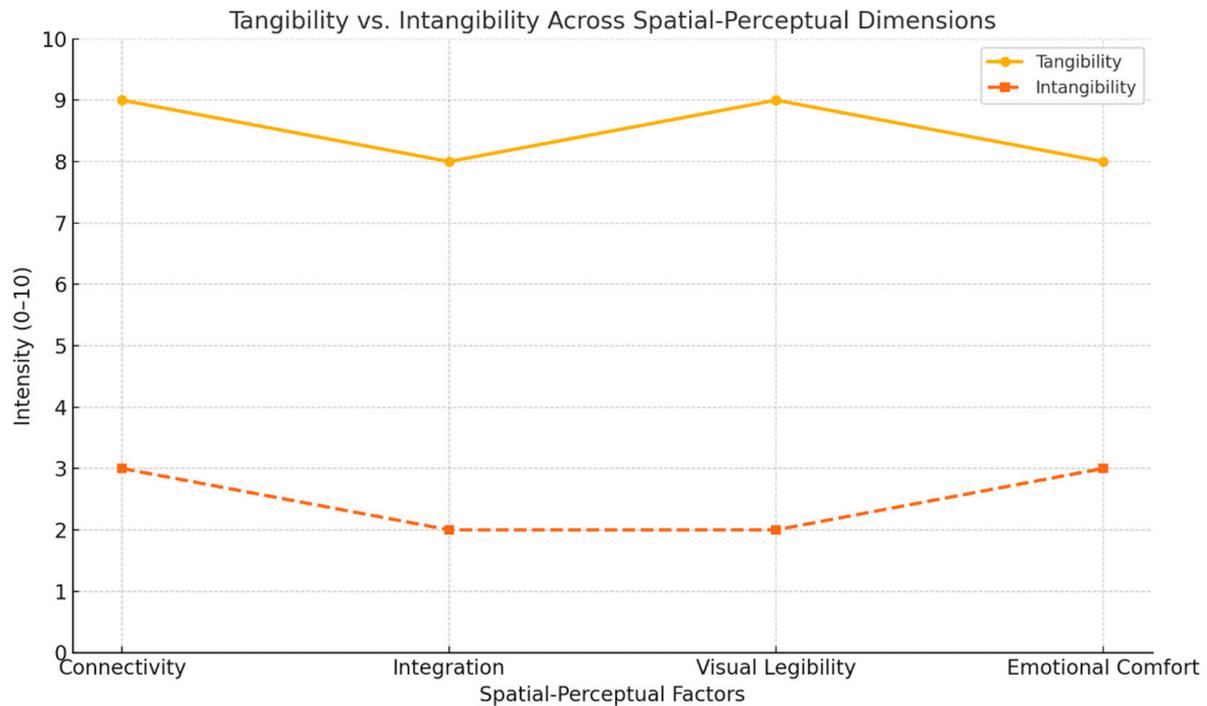
**Figure 6.** The Tangibility analysis showing the most sensitive areas to visual pollution in Dainava neighbourhood.

Tangibility, as conceived in this paper, stands for the degree of perceptual and spatial definition or clarity of an environment, which is quantified by a composite measure of two fundamental metrics in space-synchrony theory [16]: integration and connectivity. Research showing here the mirror image of intangibility itself, which is implicitly considered by Hillier and Hanson in their exposition of spatial configurations that lack perceptual coherence, legibility, and cognitive taxation, is insufficient.

The diagram illustrates (Figure 7) the difference in tangibility and intangibility along four major spatial-perceptual dimensions: connectivity, integration, visual legibility, and emotional comfort. Physical environments achieve high scores in all dimensions, allowing clarification and positive experience, whereas virtual environments lack spatial consistency and induce cognitive dissonance. These peripheral or edge areas have lower levels of connectivity and integration, rendering them significantly less tangible and therefore have a negligible visual impact. Medium tangibility values, which correspond to transition zones, act as buffers between high- and low-impact areas, reflecting the hierarchical layering of space within modernist urban design.

As shown in Table 5 and Figure 7, the correlation between tangibility, connectivity (0.99), and visual integration (0.80) emphasises the cumulative impact of these aspects on the perception of visual pollution in space. The tangibility value ranged from 5.18 to 1666.12, showing considerable variation, with a mean of 519.27 (SD: 411.36), strengthening the notion that the risks of visual pollution are unevenly distributed in the studied region.

This analysis focuses on strategic urban interventions in modernist neighbourhoods. To prevent visual pollution, planners must look for central locations or well-connected areas that can be designed in a way that reduces the potential for visual pollution by improving visual coherence in the surroundings (emphasising urban structure, reducing clutter, and bringing natural components). Simultaneously, insights can serve as a possibility to readjust the aesthetic and functional balance imposed by modernism, so urban designs can maintain harmonious and livable spaces accordingly.



**Figure 7.** Tangibility vs. intangibility across spatial–perceptual dimensions.

**Table 5.** Tangibility values of the Dainava neighbourhood.

| Level   | Value  | Location                     |
|---------|--------|------------------------------|
| Maximum | 1.666  | central core areas           |
| Minimum | 5.188  | peripheral zones             |
| Average | 519.27 | Moderate Integration Average |

#### 4.4. Normalisation Rationale for Connectivity, Integration, and Tangibility

Connectivity and integration in space syntax are represented on distinct numerical scales, which can be strongly related to network size, the selection of measure (global vs. local integration), and geometric or topological features of the street system. As such, raw values for connectivity and integration are not comparable in a direct sense: While a ‘high’ value of connectivity can equal a ‘high’ value of integration in the numerical sense, these values would reflect conditions at the extremes (but within) their respective distributions.

To compare these measures, connectivity and integration were expressed as a fraction of their own standard deviation (SD). For every segment, the raw value of a metric was divided by the DZ. RESULT: Per segment, the unitless value describes how extreme/on average admitted segment is compared to all centre distributions. The standard deviation is a measure of how widely the values for the variable are spread about the mean: high SD means large variation; low SD means tightly clustered.

For most data sets (Table 6), with the range being several times larger than the standard deviation, 68% of the values are within one standard deviation of the mean. Values between 1 and 2 SD are less common and describe more exceptional or less extreme examples. Therefore, the use of SD-based normalisation is justified in our study: it allows one to compare connectivity and integration on a common interpretative scale where common conditions are clustered around  $\pm 1$  SD, and more specialised ones can be found further away. This detaches relative scales and levels of variation between connectivity and integration, whilst preserving the internal distributions and spatial semantics of each separately.

**Table 6.** Resulting SD values and normalised ranges for Dainava.

| Metric       | SD Size | Norm Max | Norm Mean | Norm Min |
|--------------|---------|----------|-----------|----------|
| Connectivity | 409.745 | 4.039    | 1.251     | 0.005    |
| Integration  | 1.607   | 7.113    | 4.185     | −0.622   |
| Tangibility  | 6.353   | 4.436    | 0.982     | −0.023   |

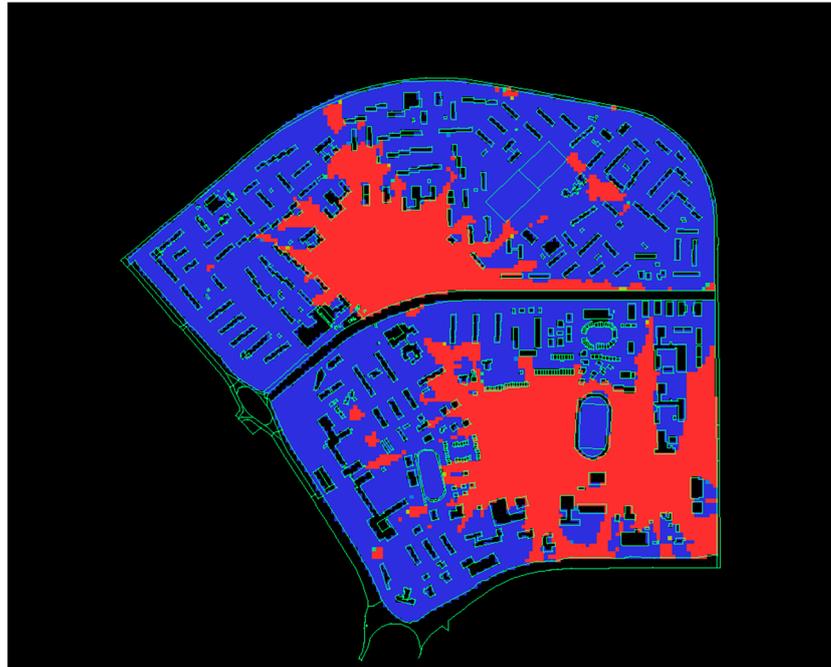
On that basis, tangibility is the joint perceptive result of connectivity and integration. (1) Connectivity and integration are individually normalised by dividing by the standard deviation (SD) value. Normalised tangibility is then computed as the product of normalised connectivity and normalised integration, with these two latter quantities multiplied by each other and divided by their SD to ensure that tangibility too can be expressed in terms of a unitless scale based on SD. This ensures that the three measures (connectivity, integration, and tangibility) are comparable and mapable together as proxies for how typical or uncommon each spatial segment is in its degree of visual exposure and vulnerability to large amounts of visual pollution.

This reveals that connectedness has a very large SD and is characterised by a small number of segments near 4SD, which serve as dominant visual anchors; integration is less heterogeneous, however, characterised by few highly powerful global integrators; and tangibility emphasises an important set of highly tangible locations being more sensitive to visual pollution, while the rest concentrate around a mean band closer to 1 SD.

#### 4.5. Interpretation Based on Normalised Connectivity Values

Normalised connectivity analysis (Figure 8), which measures local visibility, also indicates a spatial hierarchy in the neighbourhood. Connectivity values have a very high standard deviation, so different regions of the spatial network have significantly similar visual open boundaries. Blue areas (1.25 SD and below) indicate regions with average or less visibility, while red areas (1.26 SD and above) indicate the main visual spaces. Most strikingly in the upper block, the red zone is concentrated around the ‘Saul tekis’ shopping centre and its neighbouring small park, which favours that location, close to the functional centre, and also as more visually accessible. Some smaller red pouches act as secondary local centres or micronodes of visibility. However, in the southern block, the most exposed space lies within an inward (non-functional) open area, indicating a spatial–functional discrepancy. This indicates that visibility is not always consistent with programmed land uses and raises the question of whether there may be opportunities for tactical upzoning or public amenity investment.

On average, the connectivity value is more than 1 SD (1.25) larger compared to a random segment of equal length in the system. The value of 0.005 SD shows that even the most disconnected areas are still visible in a normal range; there are no extremely visually isolated or hidden parts. The upper threshold is conversely set at a maximum of nearly 4 SD, indicating very few unusually visible patches being treated as dominant visual elements or strong sightlines, most commonly open green spaces/plazas or focal public realms.



**Figure 8.** Normalised connectivity.

#### 4.6. Integration of Reachability

The integration values are much less variable (low SD), meaning that the reachability structure is more homogeneous. The mean of 4.185 SD is unusually high: This means that most of the integration values lie far above the standard deviation mark, suggesting the following:

- overall high depth efficiency,
- a well-connected global structure,
- very few segregated areas.

The minimum of  $-0.622$  SD indicates that even the least accessible segments are not truly segregated. The extremely high maximum of 7.11 SD suggests the presence of a dominant integrator (or a small group of them) that plays a central global organising role—in essence, the same zones with high visibility with the same aspects pointed out: a functional centre well reachable in the northern part and well reachable in the southern case.

The normalised visual integration map (Figure 9) shows big differences in the shape of the two modernist blocks. The blue-shaded segments correspond to grid cells where the normalised integration value is  $\leq$  system mean,  $\pm 4.18$  SD, and therefore represent typically or below average levels of global reachability within the network. However, red segments have a presence up to values  $>$  mean and show integration with values extensible to 7.11 SD in the best distinguishable/reachable spaces of the system.

At the top, red cells coalesce in a coherent core around the main functional centre to create a compact zone with values between about 5 and 7 SD of integration and highly integrated connections that lead to this node. This design displays a clear hierarchy of integration, where typical movement paths are directed, in an obvious way, via a few main lines towards a readable spatial focus. It is in the bottom block that more highly integrated segments are somewhat diffusely distributed: many streets belong to the  $>4.18$  SD band without any clearly dominating core, creating an excess of main routes and less contrasting core vs. background space. This discontinuous integration pattern may reflect a less legible spatial arrangement, in which pedestrian movement and visual attention are not simply focused, with implications for wayfinding, functional zoning, and the regulation of exposure to views.



**Figure 9.** Integration normalisation.

Figure 10 shows the normalised tangibility of the Dainava neighbourhood (tangibility is calculated as the product of SD-normalised connectivity and visual integration values). Blue cells correspond to segments for which tangibility is at or below the mean (0.98 SD), meaning that in these spaces, local visibility and global reachability are relatively ordinary and therefore less affected by visual pollution. Red cells indicate segments whose tangibility values exceed the mean by approximately 4.44 SD and identify the most tangible areas of the system: spaces where the spatial structure is clearly readable and visual change is highly perceptually important.



**Figure 10.** Normalised tangibility.

In the northern block, high-tangibility areas are highly concentrated within the functional centre while forming several separated clusters, and a half ring of separated spots encircling the central public spaces. These concentric areas are the most perceptually distinguished and visually sensitive areas that overlap with the main activity nuclei. The map also shows that there is a logical and clear priority in visual pollution control around people in an environment where they feel it the most. In the southern block, on the other hand, the most tangible values are located not in functionally central spaces but rather in some peripheral or residual ones where they do not belong. This means that a few more peripheral areas turn coarser red, despite having average-relevant programmatic value. Thus, there is a structural discrepancy between functionality and visibility, so visually exposed spaces are not necessarily the most urban, complicating strategies for identity management of visual pollution, while drawing attention to the necessity of rebalancing spatial functions and visual salience.

## 5. Evaluation of the Results

### 5.1. Integrating Emotional Mapping and Genotype-Based Space Syntax Analysis for Visual Pollution Mitigation

The convergence of emotional mapping with a genotype-disposition framework based on space syntax metrics offers a multilayered approach to combating visual pollution in urban settings. Emotional mapping tracks subjective perceptions such as satisfaction, stress, or discomfort, which tend to correlate with the underlying spatial genotype, the substrate of street networks, building layouts, and visibility patterns [15]. According to the findings, positive emotions arise in places with higher integration and connectivity values (usually parks and public squares that are accessible and organised in a cohesive manner have lower VPI scores) [53,54]. On the other hand, such low-integration, low-connectivity zones, typically present continuous fabric with limited accessibility and potential for visual clutter, are mostly emotional hotspots with high VPI values, indicating dissatisfaction and neglect that turn into chaos [47,55]. Through combining emotional mapping data with space syntax attributes, such as integration, connectivity, and visibility, planners can recognise regions with spatial organisations that intensify negative emotions, also identifying visual pollution hotspots. These composite maps, which integrate VPI scores and spatial metrics, underscore the fundamental disconnects that can be prioritised with effective treatment to resolve not just spatial disjoints but also perceptual inefficiencies. For example, in the Dainava neighbourhood, high-VPI areas were related to poorly maintained streets, low visibility, and poor social cohesion, while parks and green spaces with high connectivity and visibility respond with positive feelings and lower VPI [56]. These findings emphasise the importance of genotype-based planning in improving emotional well-being and spatial quality.

By highlighting how specific spatial configurations influence emotional responses, the framework offers usable and practical information for urban planning. Specific interventions such as clearing sight lines or improving connectivity and redressing fragmented layouts can eliminate visual pollution and promote inclusive and visually coherent space. The in-depth approach of urban planners that addresses spatial and emotional deficiencies could help shape vibrant, accessible regions, increase quality of life, and limit visual pollution [15,53].

When one looks at the standard deviation, it is evident that visual pollution in Dainava is strongly dependent on differences in visibility and the same level of accessibility. The high SD of connectivity is a further indication that few very connected spaces are acting as large hotspots of visual exposure and, correspondingly, are the most susceptible to clutter and physical attack. However, low SD values in integration reflect homogeneous

reachability, and a visual disturbance at central places may affect a great number of nodes around. This pattern of results also showed that areas with higher tangibility are the more sensitive and affected areas; indeed, these combine those where visual pollution has the greatest possibility of provoking strong negative visual–perceptual and emotional reactions. Taken together, these patterns suggest that controlling visual pollution demands attention to visible places that are well-linked and tangible.

As in Table 7, the comparison confirms that the highly integrated and highly connected central zones correspond to elevated VPI scores, while the peripheral and green areas exhibit lower VPI values. The extremely strong correlation ( $r = 0.99$ ) between connectivity and visual pollution supports the structural link between spatial exposure and perceptual response. These findings indicate that the observed spatial–perceptual patterns are not purely interpretive but quantitatively supported.

**Table 7.** Exploratory Quantitative Comparison of Spatial Metrics and VPI.

| Metric/Comparison                                 | High-Visibility/<br>Central Zones                           | Low-Visibility/<br>Peripheral Zones | Interpretation                                   |
|---|---|-------------------------------------|--|
| Connectivity (VGA,<br>200 m radius)               | Max = 1.655   | Min = 2                             | Central areas show<br>stronger visual exposure   |
| Average Connectivity                              | 512.542   | —                                   | Moderate overall<br>connectivity                 |
| Integration                                       | Max = 11.4308   | Min = 3.178                         | Central areas more<br>spatially integrated       |
| Correlation<br>(Connectivity–Visual<br>Pollution) | $r = 0.99$  | —                                   | Extremely strong positive<br>association         |
| VPI (derived from 3<br>emotional variables)       | Higher values associated<br>with high-connectivity<br>zones | Lower values in<br>green/park areas | High visibility amplifies<br>negative perception |

### 5.2. Relationship of VPI to Emotional Mapping

This integrated framework not only reveals the spatial and perceptual drivers of visual pollution but also guides targeted urban design interventions. Addressing high-VPI zones through strategies such as clearing sightlines, improving connectivity, or improving urban aesthetics can reduce visual pollution and promote emotional well-being [56,57]. For example, in neighbourhoods like Dainava, emotional mapping and VPI analysis show that poorly maintained streets and fragmented layouts generate negative perceptions, while parks with high connectivity and visibility align with lower VPI scores and positive emotional responses. Therefore, the relationship between VPI and emotional mapping highlights how spatial design can mitigate visual pollution and improve quality of life by prioritising visually coherent, accessible, and emotionally supportive environments. The VPI is a quantitative value that connects the physical characteristics of urban structures with subjective perspectives obtained by emotional mapping.

First, emotional mapping records how residents feel, for example, stress, comfort, dissatisfaction, about urban spaces, and second, the VPI pools those emotional reactions into a quantifiable metric of visual pollution. The connection between VPI and emotional mapping is established by examining the ways in which spatial and visual attributes of the built environment affect human feelings. Research by Ref. [57] states that poorly maintained spaces with excessive signage and negative visual clutter are often stress traps that elicit negative human emotions, resulting in higher VPI scores. Similarly, urban environments perceived as lacking aesthetic coherence and spatial legibility are reported to

induce perceptual disorientation and dissatisfaction. In contrast, spaces that are coherent, well-preserved, and integrated in space are often associated with positive feelings, such as satisfaction and comfort, and correlate with low VPI scores [58]. Areas with high integration, according to space syntax, facilitate positive affect by virtue of legibility and accessibility [16]. By combining emotional mapping, VPI, and spatial parameters such as integration, connectivity, and visibility, urban planners can recognise whether negative emotions coalesce with high VPI, which requires further investigation to improve urban well-being. For example, Turner, in his research [59] also points out that humans dislike low-visibility spaces with obstructed sightlines because such environments disrupt spatial legibility and generate visual stress hot spots in terms of visual pollution. This unified framework not only discloses the spatial and perceptive drivers of visual pollution, but also delineates targeted interventions through urban design.

Restoring visual balance in high-VPI areas through obstruction clearance, accessibility improvement, or urban beautification can help reduce visual pollution and cultivate mental well-being [56,57]. In neighbourhoods such as Dainava, the emotional map and the VPI analysis reveal that strategic streets and fragmented layout evoke negative impressions, while parks with high connectivity and visibility correlate with lower VPI scores and positive emotional reactions. So, the main idea is that VPI and emotional mapping can inform how to mitigate visual pollution and improve living quality through spatial design by indenting the emotionally supportive, visually coherent content first and then by making it an accessible environment.

### 5.3. Mapping and Visualisation

The results of the mapping process that combined the tangibility layers showing the areas most sensitive to visual pollution and the visual pollution index were used to perform the analysis of visual pollution of the Dainava district. The results of the analysis showed that there are several highly hot spots of visual clutter that are located around vehicular zones, quasi-destroyed infrastructure, and dense residential blocks. In these places, several tangible problems can be identified, including full parking, facades in desolation, infrastructure decomposition, and chaotic structures. As a result, the mapping of emotions revealed that such areas cause tension and dissatisfaction. Therefore, the presence of visual disturbance in the environment reduces the effect of green areas, although they still provide comfort. This visual pollution and the subsequent emotions can be eliminated by certain measures, such as infrastructure repair, ensuring the policy of the car parking policy, improved integration of greenery, etc. These measures will not only enhance the visual appearance of the environment but will also change the emotions of the people who live in it, as shown in Figure 11.



**Figure 11.** The results of integration of the visual pollution index and the tangibility index: the hot-spots of visual pollution.

#### 5.4. Methodological Implications and Directions for Further Research

The presented work should be seen more as a contribution to visual pollution research in terms of methodology and concepts than as an ultimate or comprehensive analysis. By coupling space-syntax analysis with emotional mapping and VPI estimates, this study offers evidence for the possibility of a genotype-based method to connect spatial configuration and perceptual and emotional response to cities.

Emotional mapping and space syntax metrics together contribute to an original method of approaching visual pollution by explicitly relating spatial configurations to positive and negative human emotions. Space syntax can represent spatial characteristics by dimensions of visibility, integration, and connectivity that are related to visual pollution. For example, in places characterised by high connectivity that accommodate pedestrian mobility, spaces might be visually overloaded due to the uncontrolled display of signs and advertisements that cause distraction as well as visual noise. On the contrary, low-integrated areas are more likely to correlate with perceptive uncertainty and emotional responses toward neglect or discomfort. The use of emotional mapping helps transfer subjective human perceptions into an organised form of information, which can contribute to urban analysis.

By combining the genotypic configuration of the urban form and phenotypic affective responses, the proposed method establishes a rational diagnosis framework for visual pollution. It shows how abstract and space-forming qualities connect to human-life experiences and how intelligible, maintained, and visually coherent spaces affect emotional health. In this sense, the framework contributes to an approach to visual pollution that goes beyond physical condition and can be seen as a lived experience of urban life.

#### 5.5. Methodological Limitations and Directions for Future Development

The scenario (architecture genotype) and the visibility graph analysis (VGA) used here purposely exclude any vegetative layers of trees and shrubs. This decision extracts an "Architectural Genotype" of the district and delivers a visual status, so-called "Winter View", in which visibility exclusively relies on the built environment configuration. Even for this drawback, it implies that the present model has not considered the transparency blocking effect of vegetation, but it provides a structural basis line. Future research should apply an "Ecological Phenotype" cover (including the tree canopy through LiDAR) to calculate a comparable "Visual Permeability Index," quantifying exactly how much vegetation reduces visual exposure found in this study.

Exploratory Validation (Sample Size): Data with a sample  $n = 65$  serve as an exploratory pilot validation exercise of the VPI model. This sample size was adequate to establish the strong relationship between spatial metrics and emotional responses, which satisfied the methodological purpose. In the future, other applications will be able to take advantage of this validated VPI framework and use it more safely in more extensive study-specific demographic datasets to improve statistical generalisability.

Horizontal vs. Vertical Analysis: Finally, although this work identifies the horizontal spatial determinants of visual pollution (2D movement and visibility), it paves the way for future integration for 3D studies. The present study can help map what people are (the horizontal stage); hence, future research could take inventory of vertical surfaces (billboards and facades) to produce a complete up-to-the-minute, three-dimensional dumper in an urban environment.

One advantage of this is that it enables qualitative emotional insights to be integrated with quantitative spatial data. In contrast to traditional urban analysis that focuses mainly on physical form, this integrated approach allows a more comprehensive understanding of how spatial configuration and visual information participate in shaping the everyday

urban experience. The findings suggest that both survey-based emotional mapping and spatial configuration metrics are robust and insightful for visual pollution assessment.

Ultimately, the proposed methodology encourages opportunities for automation and data-driven integration. The VPI could be used as a benchmark in the development and validation of image-based or hybrid analytical models, while space syntax variables such as integration, connectivity, and tangibility could serve as spatial descriptors in these systems. Using the framework in different urban situations could allow comparable and predictive studies of visual pollution.

## 6. Conclusions

1. Integration of emotional mapping, VPI, and space syntax metrics offers a holistic understanding of urban entities. Emotional responses are closely related to integration, connectivity, and visibility, which can trigger increased visual pollution and negative emotional reactions in areas of low spatial quality. This framework allows urban planners to conceptualise interventions that not only improve spatial and visual quality but also positively affect emotional well-being.
2. The research showed that by applying space syntax indicators, network analysis, and grain analysis, the spatial organisation plays a crucial role in determining the visual appearance of urban space and the concretion of the urban structure. The results of this research suggest a requirement for urban planners to intervene in areas with low spatial integration and low tangibility, to minimise the occurrence of visual pollution and improve urban legibility, and, at the same time, to create informal urban spaces that are dynamic and of good quality.
3. The findings suggest that urban planners can use emotion mapping as a diagnostic tool to identify and mitigate visual pollution. Interventions may include improving street maintenance to improve the aesthetic appeal, redesigning public spaces to create a more visually cohesive and socially integrating environment.
4. The visual pollution index offers a quantitative approach to understanding how visual and social elements of urban environments affect emotional well-being. By linking negative perceptions with visual pollution, this study underscores the importance of aesthetic and functional improvements in the promotion of emotionally positive neighbourhoods.
5. By linking emotional mapping, VPI, and space syntax metrics, urban planners can identify problematic areas such as low-integration, low-connectivity zones that correlate with high VPI scores where they can propose targeted interventions that can improve spatial legibility and visibility in visually cluttered areas; and strengthen connections to integrate isolated zones into the broader spatial network, etc., enhance urban aesthetics by prioritising cohesive designs in high-visibility zones to reduce visual pollution; moreover, incorporate features that foster positive emotions, such as greenery or well-maintained facades.

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## Abbreviations

The following abbreviations are used in this manuscript:

|      |   |
|------|---|
| BIBV | Building Integrated Photovoltaics           |
| GIS  | Geographic Information System               |
| RRA  | Real Relative Asymmetry                     |
| SD   | Standard Deviation                          |
| UAV  | Unmanned Aerial Vehicle                     |
| VGA  | Visibility Graph Analysis                   |
| VPI  | Visual Pollution Index                      |
| VPU  | Visual Pollution Utility (for construction) |

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