

Article

Determinants of Urban Greenery Quality—A Case Study of Slovakia

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Abstract

Urban greenery represents a crucial component of green infrastructure, influencing ecological stability, aesthetic quality, and the quality of life of urban residents. The aim of this study was to characterise the functional–spatial structure of urban greenery in the city of Nitra and to quantify the effects of selected urban, vegetation, and management factors on its aesthetic appearance and health status using an integrated statistical approach. The analysis was conducted on green spaces covering a total area of 1116.5 hectares, classified into 20 functional categories. The most dominant categories were residential greenery (31.47%), greenery at healthcare facilities (19.25%), and greenery at recreational facilities (15.72%). To identify the factors influencing greenery quality, statistical models were applied to assess the determinants of vegetation aesthetics and health status. The result demonstrated that maintenance intensity is one of the most significant determinants of greenery quality. An increase in maintenance level by one unit increased the probability of achieving a higher aesthetic rating by 112% and improved health status by 161%. The strongest positive effect on aesthetic evaluation was observed for the proportion of coniferous trees. Conifers species increased the likelihood of achieving a higher aesthetic rating by 3.7 times, while a positive effect was also observed for greater woody vegetation coverage. In contrast, the total area of green spaces did not represent a significant predictor of their quality. These findings confirm that the quality of urban greenery is determined primarily by vegetation structure and management intensity rather than by total green space area. They also highlight the need to move toward more targeted and scientifically based maintenance strategies consistent with nature-based solutions principles, integrating the ecological, aesthetic, and social functions of urban greenery. This study provides an empirical basis for more effective planning and management of urban greenery aimed at enhancing ecological functionality, aesthetic value, and climate change adaptability.

Keywords: urban landscape; urban greenery; quality of greenery; determinants of quality; municipal government

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1. Introduction

Urban greenery represents a multifunctional component of the urban environment that provides environmental, social, and economic benefits [1]. It contributes to ecological stability, enhances the aesthetic quality of the urban landscapes, and improves the quality of life of urban residents [2,3]. The importance of urban vegetation is increasingly recognised in relation to ecosystem service provision, biodiversity conservation, climate change mitigation, and the psychological well-being of city dwellers [4].

In addition to these functional benefits, considerable research has focused on the aesthetic aspects of urban greenery. The visual quality of urban green spaces has become an important research topic in landscape architecture, urban ecology, and environmental planning.

Contemporary studies emphasise that the quality and aesthetic value of urban greenery result from the interaction of urban factors (functional spatial structure), ecological factors (species composition, woody vegetation cover, and stand maturity), and management factors (maintenance intensity). Together, these factors influence not only the visual appearance of urban environments but also their ecological functions and residents' quality of life [5–7]. Accordingly, modern approaches to urban green space planning and management seek to integrate aesthetic, ecological, and social objectives to create sustainable, multifunctional, and visually attractive urban environments [8,9]. Within the broader context of sustainable urban development, urban greenery has become an essential component of discussions on the sustainability of urban structures. Boutreux et al. [10] describe the so-called “sustainable urbanism paradox,” which reflects the conflict between increasing urban density and the simultaneous need to preserve and expand green infrastructure. The authors identify critical “tipping points” at which substantial changes in urban environmental quality occur and emphasise the importance of integrated planning that combines built-up areas with green and blue infrastructure. Similarly, Rui et al. [11] based on fine-scale monitoring of urban green spaces, demonstrated that urban greenery provides multiple synergistic ecosystem services, particularly in environmental regulation and biodiversity conservation. Their findings further indicate that trade-offs among individual ecosystem services are relatively limited, highlighting the importance of integrated urban green space management by local government for simultaneously achieving ecological and social objectives.

Modern technologies, including GIS-based analysis, remote sensing, ecosystem service assessment, and artificial intelligence (AI)-based applications for monitoring biodiversity and vegetation quality, play an increasingly important role in assessing the structure of urban greenery. These approaches enable more comprehensive evaluation of urban green infrastructure and support more effective planning and management of urban green spaces [12]. Sentinel-2 satellites provide detailed information on the spatial structure of urban greenery and have become an important tool for urban planning and green space management [13]. Current developments also increasingly emphasise the digitalization of urban green space management. The use of smart technologies and Internet of Things (IoT) systems allows vegetation maintenance to be optimised in real time, thereby reducing operational costs while improving the quality of urban green spaces [14].

Increasing the proportion of green spaces has a positive effect on urban environment quality [15]. However, the structure of urban greenery, which is closely related to urban form and the degree of vegetation fragmentation, also plays a crucial role [16]. In residential areas, urban greenery is particularly important for mitigating the urban heat island effect and improving residential quality, with evenly distributed vegetation and a higher proportion of tree cover providing the greatest benefits [17]. Multilayered vegetation composed of diverse woody and herbaceous species creates environments that are both ecologically more stable and aesthetically more valuable. Greater tree cover and higher pro-

portion of natural vegetation positively influence biodiversity, carbon sequestration, temperature regulation, and air quality, while also enhancing residents' perception of the urban environment [18,19]. Improving the quality and functionality of urban greenery further enhances ecological well-being [20]. In addition, appropriately designed plantings increase the ecological functionality of urban parks, support biodiversity, improve microclimatic conditions, and contribute to higher visitor numbers and more positive perception of public spaces [21]. Species composition is another important determinant of urban green space quality. Greater plant species diversity positively influences aesthetic evaluation, psychological restoration, and biodiversity conservation [4]. These authors further argue that urban natural areas with higher biodiversity provide a broader range of ecosystem services while increasing the attractiveness of public space. Tree cover is a key determinant of urban environmental quality because its extent and spatial configuration significantly influence microclimatic conditions, aesthetic perception, and the ecological stability of urban areas [22,23]. Other important factors influencing urban greenery quality are functional spatial structure and vegetation cover within urban environments. Hanna et al. [24] demonstrated that the ecological and aesthetic value of urban green infrastructure depends on vegetation naturalness, functional land use, and the proportion of impervious surfaces. A greater proportion of vegetation improves ecological stability and microclimatic conditions while simultaneously enhancing the visual quality of urban space. Seasonal stability represents another important factor affecting the aesthetic value of urban greenery and is largely associated with the presence of coniferous trees. These species ensure year-round visual continuity and contribute to structural and colour diversity during periods when deciduous vegetation is less visually attractive. The combination of deciduous and coniferous trees also improves the compositional quality of urban landscapes while supporting the stability of ecosystem functions [18,24]. Greater structural, species, and colour diversity positively influence both the aesthetic value and restorative potential of urban green spaces, with more complex vegetation structures increasing users' satisfaction [25]. Urban vegetation also contributes to shaping local identity, recreational potential, and the perceptual quality of the urban environment [26]. Furthermore, qualitative characteristics of urban greenery, including vegetation structure, spatial legibility, and aesthetic organisation, may be just as important as species diversity in shaping positive perceptions of the urban environments [27]. Moreover, the aesthetic perception of vegetation varies throughout the year, with seasonal diversity in vegetation forms and colours enhancing both visual attractiveness and public acceptance [28].

Recent research highlights the importance of the structure and connectivity of urban greenery. Higher levels of green connectivity increase its multifunctionality, particularly in relation to climate regulation, biodiversity conservation, and recreational ecosystem services [29]. The importance of linear habitat elements has also been demonstrated, as they significantly influence biodiversity and cultural ecosystem services while directly affecting the aesthetic perception of urban spaces [30]. Within a comprehensive understanding of green infrastructure, increasing attention is being devoted to the concept of blue-green infrastructure, which integrates vegetation and water elements within urban environments. This integrated "biodiversity-inclusive" approach supports ecological connectivity, species diversity, and ecosystem functionality while simultaneously enhancing the aesthetic quality and climate resilience of the urban areas [31]. Song et al. [32] further contribute to this perspective by proposing a comprehensive framework for assessing the ecological health of blue-green infrastructure, integrating landscape structure, ecological process, and functional linkages. Their findings demonstrate that maintaining a balance among these components is crucial for the stability and sustainability of urban ecosystems. Consequently, recent studies have increasingly focused on the integration of blue-

green infrastructure, particularly urban water elements, which represent an important component of nature-based solutions in urbanised environments [33].

Maintenance intensity represents another significant factor affecting the aesthetic quality and health condition of urban greenery. The intensity of maintenance and the quality of governance are among the key determinants influencing the functionality of urban green spaces [8,34]. While excessive maintenance practices may reduce biodiversity, integrated management approaches based on nature-based solutions and green infrastructure principles can enhance ecological stability and support the long-term sustainability of urban ecosystems [34]. Conversely, differentiated management approaches and reduced maintenance intensity can promote greater biodiversity and a more natural appearance of vegetation, which may also increase aesthetic value [8]. Even less intensively managed areas with wildflower plantings can provide substantial ecological benefits, particularly by supporting pollinators and enhancing biodiversity in urban environments [35]. Moreover, vertical greenery has the potential to significantly increase pollinator diversity in highly urbanised areas and partially compensate for the limited availability of horizontal green spaces [36]. However, the implementation of biodiversity-oriented management measures is often constrained by limited municipal capacities, particularly financial and human resources, resulting in considerable differences in the quality and functionality of urban greenery among settlements [37]. Vogt [38] further develops this perspective through the concept of “refined wilding,” which integrates spontaneous vegetation into the urban landscapes while maintaining a balance between functional biodiversity and socially accepted aesthetic standards. More broadly, effective green infrastructure management requires appropriate governance mechanisms and participatory planning processes. Vaňo et al. [39] emphasise that the implementation of green infrastructure in Slovakia is strongly influenced by management quality and public participation in planning processes, which contribute to higher social acceptance and improved functional performance of urban greenery.

Based on the identified findings, recent research suggests three dominant relationships: (1) the spatial structure of urban greenery significantly influences biodiversity and ecosystem functions through connectivity and fine-scale heterogeneity [10,11,29–31]; (2) the intensity and type of management are key factors affecting both ecological and social outcomes of urban greenery, with the importance of adaptive and “smart” governance approaches increasingly recognised [8,9,20,33,34,38]; and (3) aesthetic preferences demonstrate non-linear and context-dependent relationships with vegetation complexity, reflecting a trade-off between “wild” and intensively managed forms of greenery [25,28]. Current research in Slovakia [16,17,22,26,39] indicates that the quality of urban greenery results from interactions between several interconnected factors. First, urban structure determines the spatial framework of green spaces, while tree vegetation represents a key ecological and aesthetic component. Second, management and maintenance practices substantially influence biodiversity and ecological stability, and the long-term performance of urban greenery. Third, participatory approaches and governance mechanisms play an important role in the implementation and acceptance of green measures. Fourth, connectivity and fragmentation are fundamental determinants of ecological functionality. Overall, existing studies indicate that the quality of urban greenery is primarily determined by vegetation structure, management practices, and spatial configuration rather than by the total amount of green space alone. Slovak studies are largely consistent with international research trends, particularly regarding three main aspects: the importance of tree vegetation, the effects of fragmentation and connectivity on ecological functions, and the role of management and maintenance in shaping ecological and social outcomes. These findings correspond with the international literature [8,25], which identifies management intensity and vegetation structure as major determinants of biodiversity and human perception of

urban greenery quality. A detailed overview of recent international and Slovak studies is provided in Supplementary Tables S1 and S2.

Nevertheless, studies integrating urban, vegetation, and management factors into a unified quantitative framework to explain the aesthetic quality and health status of urban greenery remain relatively rare. This limitation is important because urban green spaces are neither experienced nor managed through isolated attributes. Their aesthetic quality and ecological condition emerge from the interaction between vegetation structure, urban context, and maintenance practices. This integrated perspective is increasingly important as cities face growing pressures related to climate change, urban densification, biodiversity loss, and increasing demands for multifunctional green infrastructure. Evaluating these dimensions separately may therefore overlook the combined effects that determine the overall performance of urban green infrastructure. Although previous research has examined individual aspects of urban greenery, empirical evidence on how urban, vegetation, and management factors jointly influence aesthetic quality and health status remains limited, particularly in Central European cities. Most studies focus on vegetation characteristics, management practices, or spatial context separately rather than within an integrated analytical framework. Consequently, urban planners and managers have limited scientific evidence to support evidence-based planning, maintenance prioritisation, and climate adaptation strategies. Furthermore, previous research has relied predominantly on spatial analyses, ecological indices, and remote sensing techniques, whereas econometric approaches have been applied less frequently, particularly for the integrated assessment of aesthetic quality and vegetation health at the level of individual urban green spaces. This study addresses this research gap by applying ordered logit models to quantify the effects of urban, vegetation, and management characteristics on these two key quality indicators within a unified quantitative framework, thereby providing evidence to support urban green infrastructure planning and management. Therefore, the aim of this study was to characterise the functional–spatial structure of urban greenery in the city of Nitra and to quantify the effects of selected urban, vegetation, and management factors on its aesthetic appearance and health status using an integrated statistical approach.

To achieve this aim, the study was structured around three specific research objectives and corresponding research questions. Specific Research Objectives:

1. To characterise and evaluate the functional–spatial structure of urban greenery in the study area based on specific green space categories, vegetation types and their spatial coverage.
2. To assess statistically significant differences in aesthetic appearance, health status, and maintenance levels among different functional–spatial categories of urban greenery.
3. To identify and quantify the influence of selected urban, vegetation, management (including maintenance), and functional–spatial factors on the aesthetic appearance and health status of urban greenery.

Based on these objectives, the study addressed the following research questions:

RQ1: *What is the functional–spatial structure of urban greenery in the city of Nitra in terms of the distribution and representation of different green space categories?*

RQ2: *Are there statistically significant differences in aesthetic appearance, health status, and maintenance levels among different functional–spatial categories of urban greenery?*

RQ3: *Which urban, vegetation, management, and functional–spatial factors significantly influence the aesthetic appearance and health status of urban greenery?*

2. Materials and Methods

2.1. Research Framework and Methodological Design

The overall research framework and methodological workflow are presented in Figure 1. The research procedure consisted of four interconnected stages: (1) definition of the study area and identification of investigated urban green spaces, (2) classification of urban greenery into 20 functional–spatial categories (G1–G20) followed by field inventory and expert assessment, (3) evaluation of vegetation, spatial, management, and functional indicators, and (4) statistical analysis using descriptive statistics, Kruskal–Wallis tests, and ordered logistic regression models to identify determinants of aesthetic quality and tree health status.

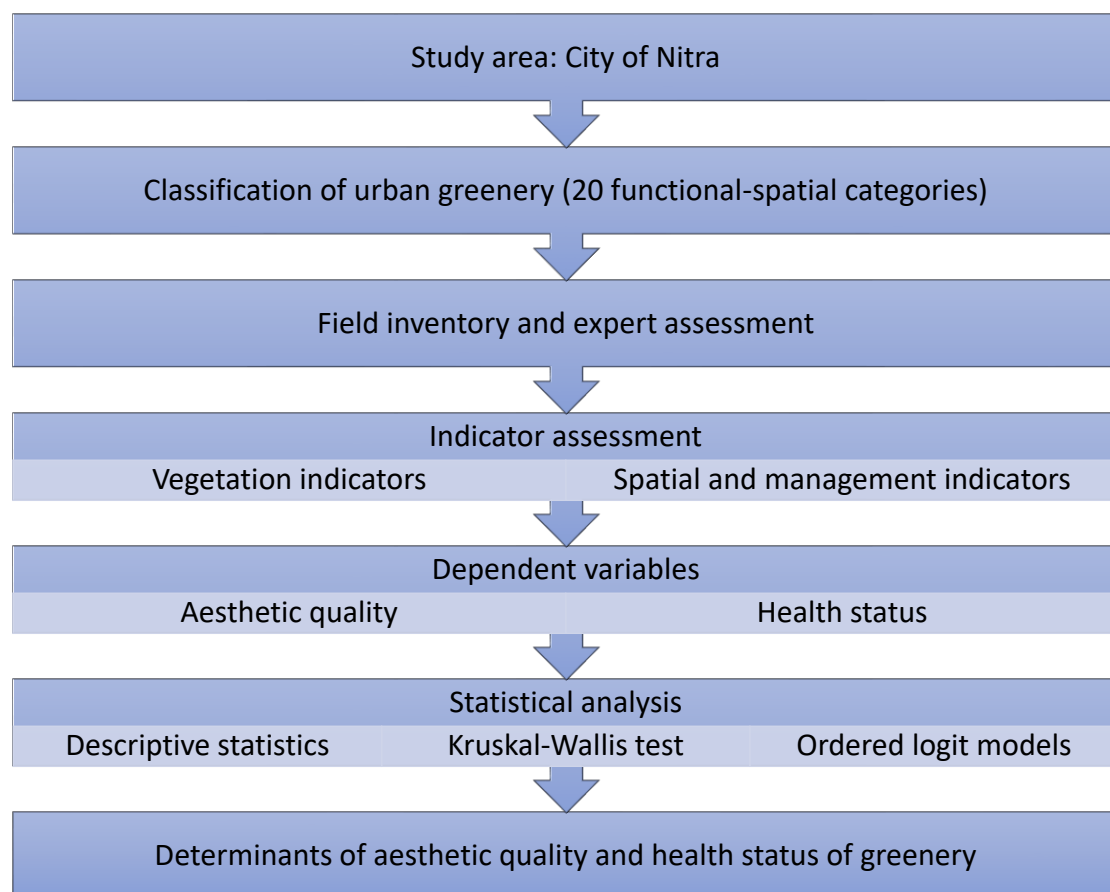


Figure 1. Research framework and methodological workflow of the study.

2.2. Data Sources

Empirical field data were collected over a three-year period (2023–2025). The study conducted in the city of Nitra, Slovakia, focusing on selected urban green spaces representing characteristic types of urban landscape. The research area covered the entire built-up area of the city. Peripheral areas with low vegetation density, as well as locations characterised by dispersed development that did not meet the defined criteria for urban density, were excluded from the analysis. The total built-up area of Nitra covers 1392.8 ha, of which 1116.5 ha were included as investigated urban green spaces. The population of Nitra was 75,301 inhabitants in 2025 [40].

Initially, target areas were identified using the official city map and subsequently subjected to spatial and field-based assessment. The spatial extent of individual green spaces was derived from cartographic baseline data. Each green space was classified using a numerical code (G1–G20) and an associated descriptive category label (e.g., Urban Park,

Pocket Park, Housing Estate Greenery) according to the functional–spatial classification framework [41]. Data collection was conducted through systematic field surveys aimed at the current condition and functional characteristics of urban greenery within the selected localities. Following the field assessment, the condition of greenery was evaluated using a five-point ordinal scale (1–5) based on predefined assessment criteria. The use of an ordinal scale ensured consistent differentiation among assessed sites while reducing potential observer-related variability. Each score corresponded to clearly defined qualitative thresholds, supporting transparency and reproducibility of the evaluation process. The resulting ordinal data structure was suitable for subsequent application of Ordered Logit Models. All field observations were recorded in a structured inventory database. The assessment of aesthetic–architectural impact was based on standardised expert evaluation protocol derived from established landscape architecture and urban forestry approaches in Central Europe [41–43].

To enhance reproducibility and reduce subjective interpretation, each site was evaluated according to predefined criteria:

- **Spatial Composition and Scale:** Assessment of whether vegetation structure, size and spatial arrangement corresponded to the proportions and character of the site (e.g., compatibility of tree dimensions with formal historical compositions or visual openness requirements).
- **Visual Integrity and Dominance:** Assessment of the preservation of important visual axes, sightlines, and relationships between vegetation and architectural features.
- **Functional–Aesthetic compatibility:** Assessment of whether vegetation supported or conflicted with the intended function and character of the site (e.g., formal parks, residential greenery, recreational areas).

The expert assessment was performed by a team of three landscape architects specialising in dendrology, arboriculture, and phytopathology, each with approximately 20 years of professional experience. All experts conducted field evaluations simultaneously. Differences in scoring were discussed and resolved through a predefined consensus procedure based on the established evaluation criteria.

Urban greenery within the study area was classified into 20 functional–spatial categories (G1–G20), reflecting differences in ecological function, spatial structure, management regime, and social use. A detailed description of all categories is provided in Supplementary Table S3. The classification included major categories such as public parks (G1–G2), residential greenery (G3, G18–G20), transport-related greenery (G4–G6, G17), protective and ecological greenery (G7–G9, G16), and institutional/recreational greenery (G10–G15).

The overall quality of urban greenery was evaluated using a multi-criteria framework integrating functional characteristics, vegetation structure, health condition, and management intensity, as shown in Table 1. The assessment considered the proportion of functional green areas, the potential for woody vegetation enhancement, vegetation maturity, current vegetation health, and maintenance practices. These parameters were considered key determinants influencing both ecosystem service provision and the visual–spatial quality of urban greenery.

Table 1. Overview of evaluation classifiers divided into three functional pillars.

Functional Pillar	Evaluated Indicator	Data Collection Method
I. Criteria Determining the Quality of Vegetation	Classification of Green Space Ratio Within the Analysed Area	On-site inventory and expert visual health assessment
	Maturity of Vegetation	
	Woody Vegetation Coverage	
	Classification of Vegetation Health Status	
	Aesthetic and Architectural Impact of Greenery	
	Maintenance Intensity and Management Quality Classification	
	Urban Density and Context Intensity Classification	
II. Criteria for Correcting the Analysis Results of Determining Vegetation Quality Indicators	Spatial Distribution Relative to Anthropogenic Stress	On-site inventory and expert visual assessment; spatial proximity and infrastructure analysis
	Classification of Non-native Woody Species Proportion	
	Classification of Coniferous Woody Species Proportion	
	Primary Function of Vegetation	
III. Relational Criteria (for the decision-making process)		Expert visual assessment

Source: Own processing and [41].

The scoring criteria employed for the subsequent analyses are summarised in Table 2.

Table 2. Evaluation criteria and scoring scale.

Evaluation Criteria	Score
Classification of Green Space Ratio (GSR) Within the Analysed Area	1- The area covered by (or suitable for) functional vegetation—as opposed to unmaintained, degraded, or weed-infested plots—accounted for less than 25% of the total assessed area ($\leq 25\%$);
	2- The proportion of functional (or potentially functional) vegetation cover falls within the range 25% to approximately 33% of the total assessed area ($25\% < x \leq 33\%$);
	3- The proportion of functional vegetation cover remains at or below 50% of the total assessed area ($\leq 50\%$);
	4- The proportion of functional vegetation cover ranges from 50% to approximately 67% of the total evaluated area ($50\% < x \leq 67\%$);
	5- The proportion of functional vegetation cover is predominant, exceeding 66% threshold of the evaluated area ($> 67\%$).
Maturity of Vegetation	1- Juvenile: Predominantly newly planted vegetation (age ≤ 10 years); mature tree projected crown coverage does not exceed 10% of the total stand area;
	2- Active Growth: Most vegetation stands are in the phase of active growth and development (age approx. 10–50 years); mixtures of older or younger categories do not exceed 25% of the total area;
	3- Mature/Old-Growth: Predominantly mature vegetation (age > 50 years); earlier successional stages represent a maximum of 20% of the total area;

	4-	Heterogeneous/Mixed: Vegetation stands comprising all three maturity categories (Classes 1, 2, and 3), with each category occupying at least 20% of the total area;
	5-	Senescent/Degrading: The stand is in a state of senescence and decline; mature/senescent specimens cover more than 25% of the total area, with the remainder consisting of younger stands.
Woody Vegetation Coverage	1-	<25%;
	2-	25–33%;
	3-	33–50%;
	4-	50–67%;
	5-	>67%.
Classification of Vegetation Health Status	1-	Severely damaged: >33% of the stand is affected by desiccation, fungal/pest infestation, or decay; >33% of lawn/flowerbed area overgrown with weeds.
	2-	Moderately damaged: Significant damage present but affecting <33% of plants or total area.
	3-	Visibly damaged: Visible signs of stress or damage; affects <33% of the total area.
	4-	Significantly impaired: Localised damage/impairment in specific criteria only.
	5-	Healthy: Negligible damage; does not exceed 5% in any assessment criteria.
Aesthetic and Architectural Impact of Greenery	1-	Inappropriate: Vegetation is aesthetically and functionally unsuitable for the given site (e.g., massive trees in formal historic parterres or chaotic overgrowth blocking key vistas).
	2-	Negative (Obstructive): Vegetation impairs the architectural design, e.g., by obstructing views of urban landmarks or causing undesirable optical reduction in space.
	3-	Neutral: Vegetation is aesthetically neutral, though it may still provide functional (hygienic/ecosystem) benefits.
	4-	Significant: Vegetation is aesthetically important; its absence or poor health would impoverish the space but not critically degrade its overall quality.
	5-	High potential/Critical: Vegetation is aesthetically highly valuable or has significant potential for high aesthetic impact through improved maintenance/management. Its absence or poor condition significantly degrades the urban space.
Maintenance Intensity and Management Quality Classification	1-	Neglected: Minimal/no maintenance; spontaneous woody encroachment; proliferation of invasive species (<i>Ailanthus altissima</i> , <i>Acer negundo</i> , <i>Lycium barbarum</i> , <i>Amorpha fruticosa</i> , <i>Solidago canadensis</i> , <i>Fallopia</i> sp., etc.); unmaintained paths and structures.
	2-	Low-intensity: Basic upkeep; mowing 1–2x/year; removal of dead wood only; uncontrolled sapling encroachment; paths maintained only for basic access; weed-dominated flowerbeds (if present).
	3-	Standard/Adaptive: Essential maintenance; mowing 2–3x/year; sanitary pruning and training; removal of diseased/hazardous trees; routine maintenance of paths and furniture; basic flowerbed care.
	4-	High-intensity: Systematic maintenance; regular mowing; active canopy management (pruning/shaping); periodic rejuvenation of shrubs; well-maintained, clean paths and furniture; high-quality, aesthetic flowerbeds.
	5-	Intensive/Premium: Exemplary care; specialised turf management; full suite of silvicultural treatments (fertilisation, irrigation, enrichment planting); daily cleaning; premium, seasonally updated flowerbeds.
Urban Density and Context Intensity Classification	1-	High density (≥ 250 inhabitants/ha): Predominantly built-up area; extensive impervious surfaces; high-density housing or workplace concentration.
	2-	Medium density (<250 inhabitants/ha): Dense urban fabric; significant share of impervious surfaces; moderate population density.
	3-	Lower density, urban (~100 inhabitants/ha): Open urban structures (e.g., residential estates, villa quarters, cultural/sports facilities).

	4-	Suburban/green (50–100 inhabitants/ha): Sparse development; large parks and green infrastructure areas.
	5-	Low density/periurban (<50 inhabitants/ha): Very sparse development; predominantly un-built-up or natural landscapes.
Spatial Distribution Relative to Anthropogenic Stress	1-	Extreme: Very high pollutant/salinity levels; prevents the survival of sensitive woody species.
	2-	High: Significant stress; sensitive species die off; more resilient species show severe damage.
	3-	Moderate: Clearly detectable stress; most species survive with minor visible damage.
	4-	Low: Negligible stress; damage is limited only to the most sensitive species.
	5-	None: No observable impact of anthropogenic stress on any vegetation.
Classification of Non-native Woody Species Proportion	1-	Predominantly native species; introduced species present as negligible trace elements. (<1%);
	2-	Stands with minor admixtures of introduced species (1–10%);
	3-	Mixed stands with a moderate share of introduced species (10–30%);
	4-	Higher proportion of introduced species (31–50%);
	5-	Predominantly non-native species. (>50%).
Classification of Coniferous Woody Species Proportion	1-	Negligible occurrence of coniferous species (<5%);
	2-	Minor occurrence of coniferous species (5–10%);
	3-	Notable representation of coniferous species (10–30%);
	4-	A significant proportion of coniferous species (>30%).
Primary Function of Vegetation	1.	Representative Greenery—Located in prominent locations (e.g., in front of landmarks, squares, central parks, and historical gardens).
	2.	Recreational Greenery—Designed for short- to medium-term stay (e.g., leisure parks, woodland parks, outdoor pools, and sports facilities).
	3.	Hygienic and Bioclimatic Greenery—Primarily functional areas (e.g., protective buffer zones, housing estate alleys, and riparian vegetation along watercourses).
	4.	Restricted/Private Greenery (Hygienic/Bioclimatic Focus)—Privately held or restricted areas influencing local microclimate and environmental hygiene.
	5.	Restricted/Private Greenery (Aesthetic/Visual Focus)—Privately held or restricted areas contributing primarily to the urban visual quality and aesthetic character.

Source: Own processing and [41]. Notes: UGS, Urban Green Spaces; GSR, Green Space Ratio; ha, Hectares.

2.3. Methods

To evaluate the functional–spatial structure of urban green spaces and identify the determinants influencing their aesthetic quality and health condition, a combined statistical approach integrating descriptive and inferential analysis was applied

First, descriptive statistics were used to characterise investigated variables and spatial structure of urban greenery. The analysis included the calculation of area extent, percentage representation, and the distribution of functional–spatial structure of urban green spaces (G1–G20). The results were presented using tables and figures to provide a comprehensive overview of the spatial composition of the studied green spaces.

Second, statistically significant differences among functional–spatial categories were examined using the non-parametric Kruskal–Wallis test. This method is appropriate for comparing multiple independent groups when the assumptions of parametric tests are not fulfilled and when variables are measured on ordinal scales. The test was applied to assess differences in aesthetic quality, vegetation health condition, and maintenance intensity among the identified categories. Statistical significance was evaluated at the $p <$

0.05 level. Where significant differences were detected, post hoc pairwise comparisons were performed using Dunn's test with Bonferroni correction for multiple comparisons.

Third, ordered logistic regression models were applied to identify the factors affecting the aesthetic quality and health condition of urban greenery. The method was selected due to the ordinal character of the dependent variables. Ordered logit models assume the existence of an urban unobserved continuous latent variable underlying the observed ordinal categories, which are separated by threshold parameters. The model was estimated using the quasi-maximum likelihood (QML) method with heteroskedasticity—robust standard errors. The estimated coefficients were interpreted according to their direction and magnitude, indicating the effects of explanatory variables on the probability of higher or lower outcome categories. The explanatory variables included urban, vegetation, management, and functional–spatial characteristics of urban green spaces (Table 2). The proportional odds assumption was tested using the Brant test and was not rejected, supporting the application of the ordinal logistic regression framework. Multicollinearity among the explanatory variables was evaluated using the variance inflation factor (VIF).

All statistical analyses were performed using R (version 4.5.2; R Foundation for Statistical Computing, Vienna, Austria), Gretl (version 1.9.92), and Statgraphics Plus for Windows 3.1 (Statistical Graphics Corp., Rockville, MD, USA), while Microsoft Excel (Microsoft Excel for Microsoft 365, version 2606; Microsoft Corporation, Redmond, WA, USA) was used for data preprocessing and database preparation.

3. Results

3.1. Functional–Spatial Structure of the Study Area

The total area of the analysed green spaces is 1116.5 ha. In terms of functional–spatial structure, housing estate greenery (G03) was the dominated category, covering 351.34 ha (31.47% of the total area). The second largest category was healthcare facility greenery (G12), comprising 214.89 ha (19.25%), followed by recreation facility greenery (G14) with 175.48 ha (15.72%). A relatively large proportion was also represented by erosion control greenery (G07), covering 97.98 ha (8.78%). Together, these four categories represented approximately three-quarters of the total analysed green space area.

Moderately represented categories included urban parks (G01) and accompanying greenery (G06), each with a share of 3.83%, followed by boulevard greenery (G05) (3.61%), sports facility greenery (G13) (2.90%), and pocket parks (G02) (1.86%). The remaining categories, including protective greenery (G08), forest parks and park forests (G09), school ground greenery (G11), and cemetery greenery (G15), each representing less than 2% of the total analysed area.

The smallest category was the arboretum (G10), covering only 0.29% of the analysed area. Similarly, productive residential gardens (G19) and allotment gardens (G20) accounted for only 0.57% and 0.56%, respectively (Figure 2).

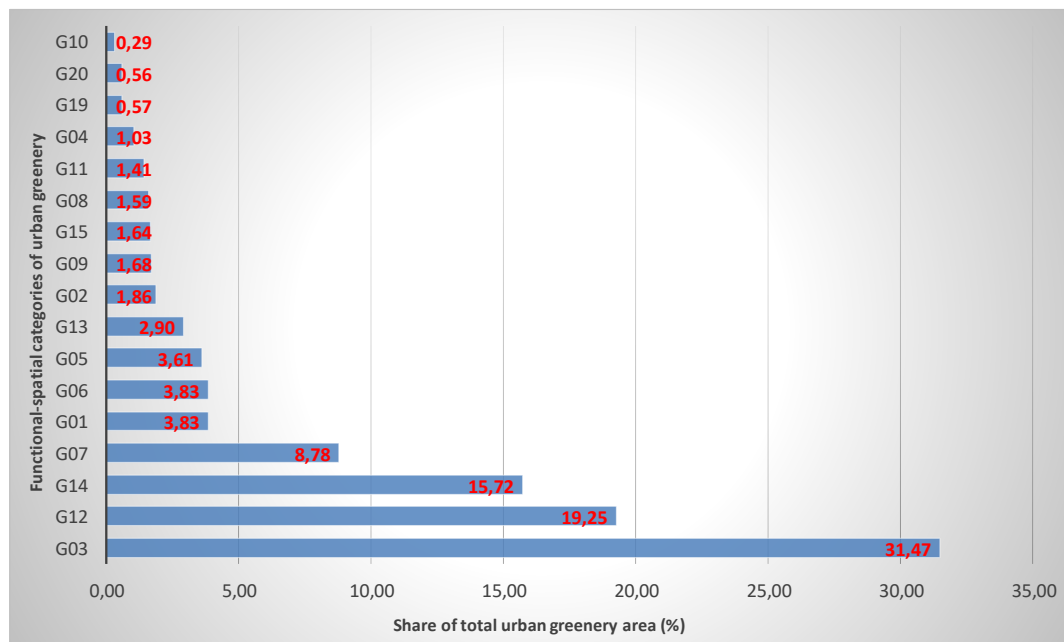


Figure 2. Functional–spatial structure of urban green spaces (%). Source: Own processing. Note: G1–G20 are explained in Table S3.

The predominance of public green spaces, particularly housing estate greenery and greenery associated with healthcare and recreational facilities, indicates that urban greenery in the study area is primarily concentrated within highly urbanised and institutionally managed environments, whereas specialised green space types constitute only a marginal component of the overall green infrastructure. As the dominant structural category, housing estate greenery (G3, 31.47%) plays a key role in the provision of regulating ecosystem services, particularly by mitigating the urban heat island effect in residential areas. Owing to its extensive spatial coverage, it also makes a substantial contribution to cultural ecosystem services by supporting everyday recreation and enhancing the aesthetic quality of the residential environment. Healthcare facility greenery (G12, 19.25%) and recreation facility greenery (G14, 15.72%) primarily provide cultural ecosystem services, where vegetation performs therapeutic, restorative, and psychohygienic functions that contribute to mental well-being and human health. In addition, the institutional character of these green spaces is often associated with well-developed tree vegetation, which further supports ecosystem services. Erosion control greenery (G7, 8.78%) mainly provides regulating ecosystem services by stabilising slopes, preventing soil erosion, and improving the ecological stability of the urban environment.

Although urban parks (G1, 3.83%) and forest parks and park forests (G9) occupy a relatively small proportion of the total area, they play a disproportionately important role in supporting biodiversity and ecological connectivity. Their structurally diverse and mature vegetation creates valuable habitats for urban flora and fauna while simultaneously providing important recreational and cultural ecosystem services. Accompanying greenery (G6, 3.83%) and boulevard greenery (G5, 3.61%) primarily deliver regulating ecosystem services within transport corridors by improving air quality, reducing noise, and mitigating other adverse environmental impacts associated with urbanisation. Overall, the predominance of publicly accessible green spaces, particularly housing estate, healthcare, and recreational greenery, provides a strong basis for the delivery of multiple ecosystem services. Together with the remaining functional–spatial categories, these green spaces form an integrated urban green infrastructure that supports ecological functioning, climate resilience, and human well-being. The functional classification of urban green spaces

reflects a broad range of ecosystem services that play an essential role in urban environments and contribute significantly to human well-being and quality of life. Ecosystem services are commonly defined as the benefits that humans derive from ecosystem functions [44,45] or, more broadly, as the direct and indirect contributions of ecosystems to human well-being [46–48]. Among the most important regulating ecosystem services provided by urban greenery is stormwater management and the mitigation of the adverse effects of urbanisation on the urban hydrological cycle. In this context, green infrastructure represents an effective alternative or complement to conventional engineering solutions. Whereas traditional grey infrastructure focuses on the rapid conveyance of stormwater, vegetated urban systems operate on the principle of source control by retaining, infiltrating, and gradually releasing rainfall, thereby improving the functioning of the urban hydrological cycle [49]. This approach is closely associated with the concept of nature-based solutions (NbSs), which provides a broader conceptual framework for integrating ecological processes into urban planning. According to Cohen-Shacham et al. [50], elements such as rain gardens or urban parks should not be regarded merely as aesthetic features but as components of ecosystem engineering that simultaneously deliver multiple ecosystem services. Rain gardens represent particularly effective elements of green infrastructure because they combine several regulating, supporting and cultural ecosystem services. Their principal functions include increasing water retention, reducing surface runoff into drainage systems, and mitigating the risk of local flooding during intensive precipitation events. Biological filtration and sedimentation processes improve water quality, while vegetation evapotranspiration contributes to local microclimatic regulation. Depending on their spatial configuration and vegetative structure, rain gardens may also reduce soil erosion, enhance carbon sequestration, and improve air quality through pollutant filtration. In addition to these regulating functions, they support urban biodiversity and pollinator communities. While simultaneously enhancing the aesthetic quality of public spaces, thereby contributing to the creation of resilient and attractive urban landscapes.

Urban green infrastructure also includes vegetated elements whose importance extends beyond regulating ecosystem services and particularly reflected in provisioning and cultural ecosystem services. These include community gardens and allotment gardens, which, in addition to their environmental benefits, provide opportunities for social interaction, local food production, and strengthening residents' attachment to the urban environment. Their contribution to social cohesion is increasingly recognised, although it has often been overlooked in traditional technical and economic assessments [51–53]. Community gardens and allotment gardens represent multifunctional components of urban green infrastructure. While traditional allotment gardens are generally located on the urban periphery, contemporary community gardens are increasingly being incorporated into compact urban neighbourhoods and inner-block spaces. From the perspective of ecosystem service classification, these green spaces simultaneously provide provisioning, regulating, cultural, and economic benefits. Provisioning services are reflected in the local production of food and biomass, whereas regulating services include enhanced stormwater retention and reduced surface runoff. Cultural ecosystem services are expressed through opportunities for social interaction, environmental education, and recreation. Furthermore, these green spaces may generate indirect economic benefits by reducing public maintenance costs through active community participation in their management. Alongside community and allotment gardens, urban parks represent another key component of urban green infrastructure. According to Warren et al. [54], drawing on the theory of island biogeography proposed by MacArthur and Wilson, parks and gardens embedded within the urban matrix function as ecological stepping stones that enhance connectivity for pollinators and other urban wildlife, thereby mitigating the adverse effects of urbanisation on biodiversity. Urban parks and landscaped park areas are strategic ele-

ments of green infrastructure because their spatial complexity and vegetation diversity support the delivery of multiple ecosystem services. In terms of regulating ecosystem services, they play an important role in climate adaptation by enhancing evapotranspiration and shading, thereby reducing the urban heat island effect. They also function as natural retention areas that promote stormwater infiltration and reduce pressure on urban drainage systems during heavy rainfall events. Their supporting ecosystem services include the provision of structurally diverse habitats that facilitate the persistence and movement of flora and fauna across the urban landscape, thereby strengthening urban biodiversity. From the perspective of cultural ecosystem services, parks serve as multifunctional public spaces that combine recreational, educational, and aesthetic functions. Their contribution to mental well-being, physical activity, and social cohesion is increasingly recognised as a key determinant of urban quality of life. The integration of these ecological and social functions makes urban parks as indispensable component of resilient and sustainable urban environments.

Overall, the results demonstrate that urban greenery in the study area forms a highly heterogeneous yet functionally complementary system. The interaction among residential, institutional, ecological, and recreational green spaces ensures the provision of diverse ecosystem services and enhances the ecological resilience, environmental quality, and overall sustainability of the urban environment.

3.2. Typologically Driven Differences in the Health Condition, Aesthetic Quality, and Maintenance Level of Urban Greenery

Given the differences in function, management intensity, and ecosystem service provision among urban green space types, it was hypothesised that they differ significantly in terms of vegetation health conditions, aesthetic quality, and maintenance intensity. Accordingly, this section examines whether the individual functional–spatial categories of urban green spaces exhibit statistically significant differences in these three attributes. To test this hypothesis, the non-parametric Kruskal–Wallis test was applied, as it enables comparisons among multiple independent groups based on ordinal data. Where statistically significant differences were identified, pairwise post hoc comparisons were performed using Dunn’s test with a correction for multiple testing. Owing to the limited number of observations in several functional–spatial categories, individual green space types were aggregated into broader functional groups prior to the statistical analysis. (Table 3).

Table 3. Aggregation of Functional–Spatial Types of Urban Green Spaces (G1–G20).

Name of Aggregated Type of Urban Greenery	Functional–Spatial Types of Urban Greenery
1—Public recreational greenery	G1, G2, G9, G10
2—Residential and housing greenery	G3, G6
3—Linear and transport-related greenery	G4, G5
4—Protective and stabilising greenery	G7, G8
5—Institutional greenery	G11, G12, G13, G14, G15
6—Private and productive greenery	G19, G20

Source: Own processing. Note: *The definitions of G1–G20 are provided in Table S3.*

The health condition of urban green spaces was assessed using a five-point ordinal scale based on the original data without transformation. The Kruskal–Wallis test revealed statistically significant differences among the analysed functional–spatial categories ($H = 12.16$; $p = 0.03$). Dunn’s post hoc test indicated significant differences between linear and transport-related greenery and protective and stabilising greenery ($p < 0.05$). No other pairwise comparisons showed statistically significant differences.

The aesthetic and architectural quality of urban green spaces was evaluated using the same five-point ordinal scale. The Kruskal–Wallis test confirmed statistically significant differences among the functional–spatial categories ($H = 15.26$; $p = 0.01$). The subsequent Dunn’s post hoc test revealed significant differences between institutional greenery and protective and stabilising greenery ($p < 0.05$), while all other pairwise comparisons were statistically non-significant.

The maintenance intensity of urban greenery was assessed using a five-point ordinal scale. The Kruskal–Wallis test identified statistically significant differences among the analysed categories ($H = 19.54$; $p < 0.001$). Dunn’s post hoc test showed significant differences between protective and stabilising greenery and both residential and housing greenery as well as linear and transport-related greenery ($p < 0.05$). No other pairwise comparisons reached statistical significance.

Table 4 presents the mean ranks, Kruskal–Wallis H statistics, and corresponding p -values for the assessment of vegetation health, aesthetic quality, and maintenance intensity across the individual functional–spatial categories of urban greenery.

Table 4. Comparison of health, aesthetic, and maintenance aspects across urban greenery categories (Kruskal–Wallis test).

Aggregated Type of Urban Green Space (Categories)	Health (Higher is Better)	Aesthetics (Lower is Better)	Maintenance (Higher is Better)
1	84.10	64.30	89.80
2	79.00	73.50	58.90 *
3	67.80 *	76.60	63.00 *
4	98.20	55.80	95.00
5	68.90	93.50 *	84.90
6	66.30	81.20	86.80
Test statistic	12.16	15.26	19.54
p -Value	0.03	0.01	0.00

Source: Own processing Note: *Bold*—the best results in the individual dimension; *Bold **—statistically significant differences with Category 4.

The results of the non-parametric analyses demonstrate that functional–spatial categories of urban greenery differ significantly in terms of vegetation health condition, aesthetic quality, and maintenance intensity. Statistically significant differences were identified for all three evaluated indicators, confirming that urban greenery types exhibit distinct qualitative characteristics.

Among the analysed group, Category 4 (protective and stabilising greenery) achieved the most favourable mean ranks across all three evaluated dimensions, indicating the highest overall performance in terms of vegetation health, aesthetic quality, and maintenance intensity.

Pairwise comparisons using Dunn’s post hoc test further revealed significant differences between Category 4 and Category 3 with respect to vegetation health condition and maintenance intensity, between Category 4 and Category 5 for aesthetic quality, and between Category 4 and Category 2 for maintenance intensity.

Overall, these findings indicate that the functional–spatial type of urban greenery is an important determinant of qualitative characteristics. The observed differences highlight the heterogeneous nature of urban green infrastructure, where individual greenery types perform distinct ecological and social functions and therefore require differentiated management strategies.

3.3. Quantification of the Influence of Selected Determinants on the Aesthetic–Architectural Quality and Health Condition of Urban Greenery

Based on theoretical framework that conceptualises urban green spaces as complex socio-ecological systems, the following analysis focuses on urban, vegetational, and management-related determinants that influence the functional and visual quality of urban greenery. The relationships between selected explanatory variables and urban greenery quality were identified and quantified using two key response variables: aesthetic–architectural quality and vegetation health condition.

By applying ordered logistic regression models, this study moves beyond descriptive evaluation to identify the key determinants influencing the quality of urban greenery. The analysis provides an empirical basis for understanding how individual site characteristics including vegetation composition, spatial attributes, and maintenance intensity, affect the aesthetic quality and health condition of urban greenery, thereby contributing to the sustainability and resilience of urban green infrastructure in the city of Nitra.

3.3.1. Quantification of the Influence of Selected Determinants on the Aesthetic–Architectural Quality of Urban Greenery

In the first ordered logistic model, the dependent variable was the aesthetic–architectural quality of urban greenery, originally assessed on a five-point scale (1–5). In the original coding, a value of 1 represented the highest aesthetical quality, whereas a value of 5 indicated the poorest aesthetic quality. To facilitate interpretation of the regression coefficients, the scale was reserved so that higher values corresponded to better aesthetic quality. In addition, because of the low frequency of observations in the last two highest categories (4 and 5 after reordering), these categories were merged. Consequently, the dependent variable entered the model as a four-level ordinal value (1–4), where 1 represents the poorest and 4 the highest aesthetic quality.

The explanatory variables comprised four groups of determinants: (1) Urban (spatial and contextual) determinants, describing the spatial characteristics of the study area, including green space area (areas; continuous variable), green space coverage (%; continuous variable, green space ratio within the analysed area (ordinal scale 1–5), vegetation location according to urban density (ordinal scale 1–5), and vegetation location according to the level of anthropogenic pressure (ordinal scale 1–5). (2) Vegetation-related determinants, describing the biological and structural characteristics of vegetation, including vegetation maturity (ordinal scale 1–5), woody vegetation coverage within functional areas (ordinal scale 1–5), proportion of non-native woody species (ordinal scale 1–5), proportion of coniferous woody species (ordinal scale 1–5), and vegetation health condition. The latter variable was originally assessed on a five-point ordinal scale but was recoded to a three-level scale because Category 2 contained no observations and Category 4 contained only one observation, which was merged with the highest category. (3) Management-related determinants, represented by maintenance intensity and management quality, both evaluated on a five-point scale, where 1 indicated minimal or no maintenance. (4) Functional–spatial determinants, represented by the typological classification of urban greenery (G1–G20). For modelling purposes, these categories were aggregated into three broader groups (residential, protective, and institutional greenery) and included in the model as dummy variables. A detailed description of all explanatory variables and their coding is provided in Table 2.

The ordinal logistic regression model was estimated independently in two statistical software environments (Gretl and R) to ensure the robustness and reproducibility of the results. Both implementations produced consistent parameter estimates and statistical inference. The initial model specification included all selected explanatory variables. However, based on diagnostic tests and convergence assessment, the final model was refined

by excluding variables that caused estimation instability, thereby improving model stability and overall goodness of fit. The final model results are presented in Supplementary Table S4 and Figure 3. In the ordered logistic regression model, odds ratios greater than 1 indicate that a given explanatory variable is associated with a higher probability of belonging to a higher category of aesthetic quality, whereas odds ratios below 1 indicate a higher probability of belonging to lower aesthetic quality categories.

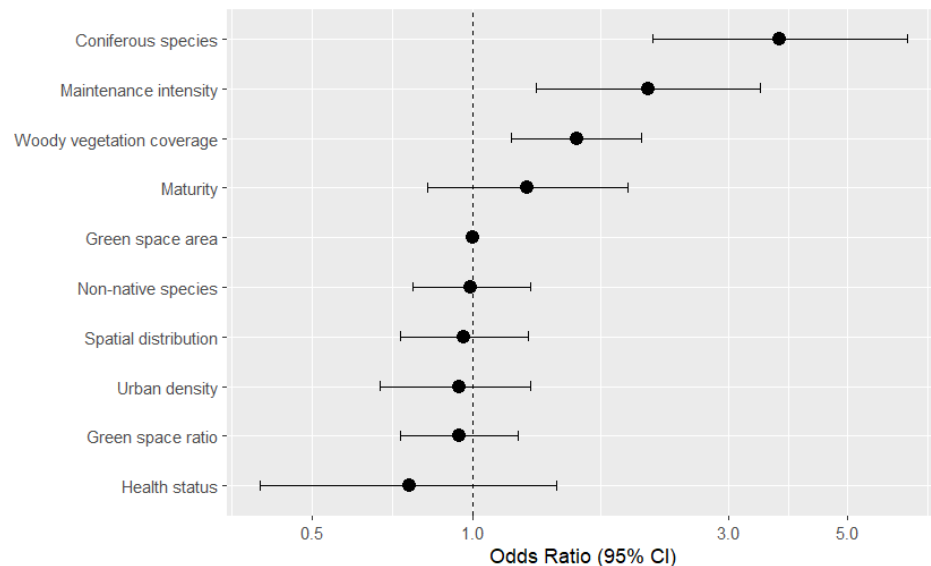


Figure 3. Determinants of aesthetic quality of urban greenery: ordered logit regression results. Note: OR > 1 indicates higher odds of higher response categories; OR < 1 indicates lower odds. The dotted vertical line indicates the line of no effect (odds ratio = 1).

The likelihood ratio (LR) test confirmed that the ordered logistic regression model was statistically significant ($\chi^2 = 55.31$, $df = 10$, $p < 0.001$). The proportional odds (parallel regression) assumption was subsequently evaluated using the Brant test. The omnibus Brant test did not indicate any violation of this assumption ($\chi^2 = 17.30$; $df = 20$; $p = 0.63$), confirming the sustainability of the ordered logistic regression for the analysed data.

Multicollinearity among the explanatory variables was assessed using the variance inflation factor (VIF). All VIF values ranged from 1.05 to 1.61, remaining well below the commonly accepted threshold of 10. These results indicate that multicollinearity was not a concern and support the stability and reliability of the estimated model.

The aesthetic quality of urban green spaces was primarily associated with vegetation-related characteristics (woody vegetation coverage and the proportion of coniferous woody species) and management-related factors (maintenance intensity and management quality). As illustrated in the forest plot (Figure 3), the strongest positive associations with higher aesthetic quality were observed for the proportion of coniferous woody species, maintenance intensity, and woody vegetation coverage. Green space area showed only a very weak negative association with aesthetic quality. In the Gretl model, this effect was statistically significant ($\beta = -0.000319$; $p = 0.005$), whereas in the model estimated in R it was only marginally significant ($p = 0.0695$). The estimated odds ratio was close to one (OR = 0.997), indicating a negligible effect size in practical terms. Consequently, green space area cannot be considered a robust predictor of aesthetic quality across model specifications.

In contrast, woody vegetation coverage exhibited a positive and highly significant association with aesthetic quality in both statistical environments. The estimated coefficient was identical in Gretl ($\beta = 0.4439$; $p = 0.0028$) and R ($\beta = 0.4439$; $p = 0.0019$). The cor-

responding odds ratio (OR = 1.54) indicates that a one-unit increase in woody vegetation coverage increased the odds of achieving a higher aesthetic quality category by approximately 54%. The consistency of the coefficient estimates across both software environments confirms the robustness of this relationship.

Among all analysed predictors, the proportion of coniferous woody species exhibited the strongest positive association with the aesthetic quality of urban green spaces. The estimated coefficient was positive and highly significant in both statistical environments ($\beta = 1.3170$; $p < 0.001$). The corresponding odds ratio (OR = 3.73) indicates that a one-unit increase in the proportion of coniferous woody species was associated with an approximately 3.7-times higher odds of achieving a higher aesthetic quality category. Expressed differently, this represents an increase of approximately 273% in the odds of a more favourable aesthetic evaluation. The identical results obtained in Gretl and R confirm the robustness of this relationship. Maintenance intensity and management quality also showed a positive and statistically significant association with aesthetic quality in both statistical environments. The estimated coefficient was $\beta = 0.7516$, with statistically significant results in both Gretl ($p = 0.0095$) and R ($p = 0.0023$). The corresponding odds ratio (OR = 2.12) indicates that a one-unit increase in maintenance intensity and management quality more than doubled the odds of achieving a higher aesthetic quality category. Overall, these findings highlight the importance of appropriate management practices in shaping the visual of urban greenery.

The remaining explanatory variables were not statistically significant at conventional significance levels, indicating that they did not contribute substantially to explaining variation in the aesthetic quality of urban green spaces after accounting for the other predictors included in the model.

3.3.2. Quantification of the Effects of Selected Determinants on the Health Condition of Urban Greenery

In the second ordered logistic regression model, the vegetation health condition was specified as the dependent variable and measured on an ordinal scale. The original five-category scale (1–5) was collapsed into three categories (1–3), where 1 represented the poorest health condition. This recording was necessary because Category 2 contained no observations, whereas Category 4 contained only a single observation and was therefore merged with the highest category. The resulting three-level scale ensured stable model estimation while preserving the ordinal structure of the response variable. The initial model specification included the same set of urban, vegetation-related, management, and functional–spatial determinants as in the first model. The only difference was that vegetation health condition served as the dependent variable, whereas aesthetic quality was included as an explanatory variable.

As in the previous analysis, the model was estimated independently in Gretl and R using an ordered logistic regression framework. The initial specification included all selected explanatory variables; however, following diagnostic testing and convergence assessment, the final model was refined by excluding variables that caused estimation instability. The resulting specification satisfied the proportional odds assumption, as confirmed by the Brant test.

Vegetation maturity (x3) exhibited a strong and statistically significant association with vegetation health condition in the univariate ordered logistic regression model. However, its inclusion in the multivariable model resulted in quasi-separation and convergence instability, indicating an almost deterministic relationship with the response variable. To ensure stable estimation and reliable coefficient estimates for the remaining predictors, x3 was excluded from the final model. The univariate results are reported separately for descriptive and diagnostic purposes.

Model estimation in Gretl and R produced consistent coefficient estimates with respect to both the direction and statistical significance of the main effects. The final model results are presented in Supplementary Table S5 and Figure 4. In the ordered logistic regression model, odds ratios greater than 1 indicate a higher probability of belonging to a better vegetation health category, whereas odds ratios below 1 indicate a lower probability of achieving higher health condition categories.

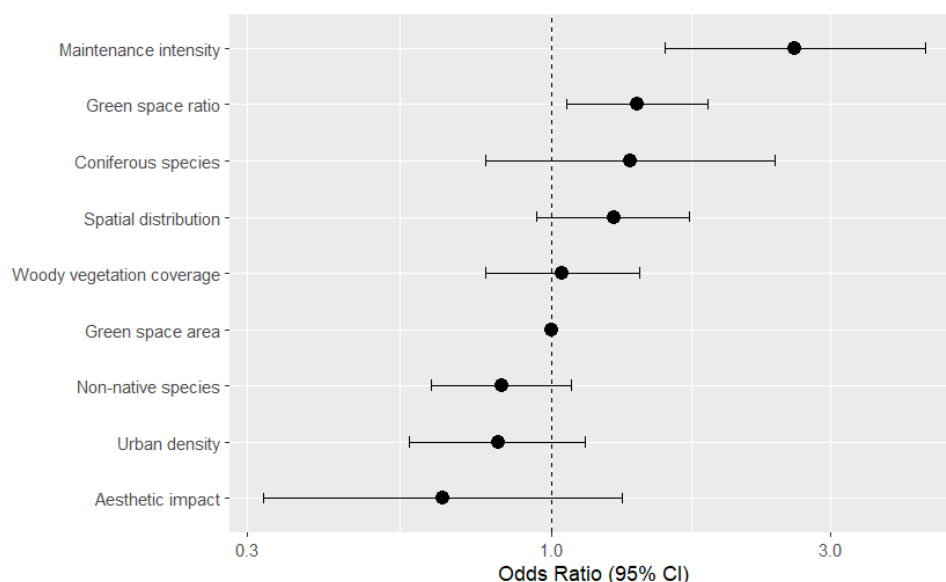


Figure 4. Determinants of vegetation health conditions: ordered logit regression results. Note: OR > 1 indicates higher odds of higher response categories; OR < 1 indicates lower odds. The dotted vertical line indicates the line of no effect (odds ratio = 1).

The ordered logistic regression model was statistically significant (likelihood ratio test: $\chi^2 = 39.26$, $p < 0.001$), indicating that the included explanatory variables significantly improved model fit compared to the null model. The proportional odds assumption was evaluated using the Brant test and was not violated ($p = 0.46$), confirming the suitability of the ordered logistic regression framework. Multicollinearity was not detected, as all VIF values remained well below the commonly accepted threshold of 10.

The results indicate that vegetation health condition was primarily associated with management-related and spatial–structural factors. As shown in the forest plot (Figure 4), maintenance intensity and the green space ratio exhibited the strongest positive associations with higher vegetation health categories. The green spaces ratio within the analysed area showed a positive and statistically significant association with vegetation health condition in both statistical environments ($\beta = 0.3365$; $p = 0.0133$ in Gretl; $p = 0.0179$ in R). The corresponding odds ratio (OR = 1.40) indicates that a one-unit increase in the proportion of functional green space was associated with approximately 40% higher odds of achieving a better vegetation health category.

Maintenance intensity also exhibited a positive and highly significant association with vegetation health condition in both statistical environments ($\beta = 0.9599$; $p = 0.00012$ in Gretl; $p = 0.0003$ in R). The corresponding odds ratio (OR = 2.61) indicates that a one-unit increase in maintenance intensity more than doubled the odds of belonging to a better vegetation health category.

Vegetation maturity was analysed separately using a univariate ordered logistic regression model because its inclusion in the multivariable model resulted in quasi-complete separation. The univariate analysis revealed a statistically significant negative association with vegetation health condition ($\beta = -1.215$; $p < 0.001$). The corresponding odds

ratio (OR = 0.297) indicates that increasing vegetation maturity was associated with approximately 70% lower odds of belonging to a higher vegetation health category.

The remaining vegetation-related, urban, and functional-spatial variables were not statistically significant at conventional significance levels, suggesting that their independent contribution to explaining variation in vegetation health condition was limited after accounting for the other predictors included in the model.

4. Discussion

The significance of maintenance as a key determinant of green space quality, and was quantified in the model as having a strong positive effect on both aesthetic evaluation and vegetation stand health, which aligns with current trends in urban ecology. While earlier approaches to urban greenery often emphasised static design principles, contemporary research increasingly highlights the dynamic role of maintenance practices. In this context, Hu and Lima [8] state that the frequency and expertise of management interventions are among the primary factors distinguishing valuable greenery from areas perceived as visually neglected, regardless of their initial ecological potential. The findings, which demonstrated a more than twofold increase in the likelihood of improved overall quality depending on maintenance standards, can be interpreted within the framework of the “refined wilding” concept developed by Vogt [38]. This concept suggests that aesthetic quality in urban environments is not necessarily in conflict with ecological complexity, provided that natural vegetation development is guided by targeted management interventions. However, aesthetic preferences for urban greenery are not universal and may vary across cultural contexts and social groups. While structured vegetation and visible management interventions are often associated with perceptions of order and care, recent studies indicate that more naturalistic forms of urban vegetation can also generate positive perceptions and emotional attachment. For example, Kowarik et al. [55] demonstrated that residents in Berlin expressed strong positive attitudes not only towards traditional urban forests but also towards novel wild forest types developing on abandoned urban sites. Similarly, Hwang and Lum [56] identified increasing acceptance of spontaneous vegetation in tropical urban environments, challenging the assumption that highly controlled and intensively maintained landscapes are always preferred. Gao et al. [57] further showed that perceived naturalness can be a more important determinant of recreational preferences than the degree of formal management. These findings suggest that the aesthetic evaluation of urban greenery reflects a balance between visual order, ecological complexity, and culturally shaped perceptions of nature. The absence or inappropriate timing of maintenance interventions may contribute to aesthetic dissonance, particularly in contexts where residents expect visible signs of care and management. This interpretation is supported by Wang et al. [25], who argue that perceptions of green space restoration are closely linked to visual cues of human intervention. At the same time systematic green space management in the European context is increasingly confronted with implementation barriers. As highlighted by Zenglein et al. [37], many cities experience a mismatch between strategic planning objectives and their actual maintenance capacities. The analysis of the city of Nitra reinforces this perspective, demonstrating that maintenance is not merely a technical activity but a strategic instrument of public asset management. Consistent with the findings of Rui et al. [11] regarding the high-resolution monitoring of ecosystem services, insufficient investment in regular maintenance may result in significant trade-offs, where greenery becomes a source of liability, such as safety or hygiene concerns, rather than a provider of desired ecosystem benefits. This insight positions management as an integrative element that connects ecological functions with residents’ expectations and the aesthetic standards of urban landscapes.

One of the most significant findings of the study is the strong positive impact of the proportion of coniferous trees on the aesthetic assessment of urban greenery, with this parameter increasing the odds of achieving a higher rating by 3.7 times. This result is consistent with the concept of ‘visual stability’ emphasised in the Central European urban context by Hanna et al. [24]. The authors point out that, under conditions of pronounced seasonality, when deciduous vegetation loses its visual structure during winter and early spring, coniferous trees provide essential year-round structural continuity. This consistency may be perceived by residents as an indicator of well-maintained and high-quality green infrastructure that retains its attractiveness even during the dormant season. This interpretation also corresponds with the findings of Wang et al. [25], who, in their research on urban public preferences, demonstrated that visual preferences are determined not only by species diversity but also by colour composition and vegetation structure. Coniferous trees can function as visual anchor elements in urban landscapes, creating contrast with the dynamic yet seasonally variable appearance of deciduous vegetation. From a management perspective, this finding suggests that coniferous trees should not be considered solely from an ecological perspective but also as a component contributing to perceived landscape quality. However, this benefit should be interpreted within a broader ecosystem services context. Although the proportion of coniferous woody species showed the strongest positive association with aesthetic evaluation in the model, this result should not be interpreted as a general recommendation to increase conifer dominance in urban green spaces. Coniferous trees can contribute to year-round visual stability, structural diversity, and perceived aesthetic quality; however, their ecological effects depend on species composition, planting design, and management practices. Previous studies have shown that simplified coniferous stands may negatively affect soil properties and biodiversity, including changes in soil conditions associated with coniferous litter and reductions in understory species richness [58,59]. In addition, extensive coniferous stands may increase fire vulnerability under specific climatic conditions, highlighting the importance of species diversification and the integration of broadleaved species as part of nature-based solutions [60,61]. Therefore, the integration of coniferous vegetation into urban green spaces should follow nature-based principles by balancing aesthetic preferences with biodiversity conservation, climate adaptation, and long-term ecological resilience. As Rui et al. [11] note, although coniferous stands may provide high aesthetic value and year-round visual comfort, their contribution to biodiversity management differs from that of deciduous species, which often provide greater benefits for local fauna. Based on the results, an appropriate balance between coniferous and deciduous trees appears essential for achieving synergy between visual preferences and the ecological functionality required by urban ecosystems. For urban policymakers, this implies that during the renewal of urban greenery in Nitra, coniferous trees should be considered as one of the important components of urban vegetation, contributing to year-round visual continuity when appropriately balanced with deciduous species.

An important finding of this study relates to the sustainable urbanism paradox [10]. Although the extent of green space did not show a stable predictive influence on aesthetic quality in the model, its functional arrangement, expressed through the green space ratio, was of critical importance for vegetation stand health. This finding supports growing evidence that the quality and functionality of urban greenery may be more important for perceived environmental value than its quantitative extent alone. Van Dillen et al. [62] demonstrated that accessibility, equipment, and maintenance of urban green spaces have a stronger influence on neighbourhood satisfaction than the mere availability of green areas. Similarly, Chang et al. [63] showed that qualitative dimensions of greenery play a more important role in residents perceived benefits than quantitative indicators alone. Therefore, larger green areas do not necessarily provide higher aesthetic value if they lack

appropriate design, vegetation structure, and maintenance. Conversely, smaller but well-designed and properly managed green spaces, including pocket parks, may significantly contribute to urban attractiveness and residents' perception of environmental quality [64,65]. From an urban planning perspective, these findings suggest that strategies should focus not only on expanding green space quantity but also on improving the quality, functionality, and long-term management of existing green infrastructure. Beyond the quantity of green space, spatial configuration and functional arrangement also play critical roles in determining urban green infrastructure performance. This finding supports the argument of Li and Carter [29] that the connectivity and spatial configuration are key factors influencing the multifunctionality of green infrastructure. In comparison with European trends [37], the analysis of the city of Nitra indicates that implementation barriers, such as financial limitations and insufficient management capacities, remain important obstacles to achieving higher greenery quality. The application of the developed model suggests that effective 'smart governance' [14] and targeted allocation of resources for maintenance, rather than the indiscriminate expansion of green areas, can significantly enhance the ecological and social benefits of urban ecosystems. Finally, the results regarding the functional differentiation of greenery (e.g., residential vs. buffer zone vegetation) indicate the need to move from universal management standards towards site-specific strategies. This approach is consistent with the concept proposed by Schwartz et al. [27], who emphasise that the relationship between biodiversity, aesthetics, and human satisfaction is non-linear and requires tailored management interventions.

Maintenance is a significant factor affecting the appearance and health status of urban greenery; however, effective management requires a differentiated approach that considers functional categories and the range of ecosystem services provided. Different types of urban greenery fulfil distinct ecological, hydrological, social, and cultural functions, which necessitate diverse management interventions and maintenance priorities. The findings regarding the ecosystem services of urban greenery are consistent with the theoretical framework of nature-based solutions [50]. While previous studies have primarily focused on technical efficiency, such as stormwater retention capacity, the results of this study highlight the synergy between ecological functions, hydrological performance, and social benefits. This confirms the need for integrated and multifunctional management approaches in urban ecosystems [66].

Several limitations of this study should be acknowledged. First, the cross-sectional design allows the identification of statistical associations between vegetation, management, spatial, and functional characteristics of urban green spaces; however, it does not allow strict causal inference. Second, the findings should be interpreted within the context of the selected case study area. Since the research was conducted in the city of Nitra, the results cannot be directly generalised to all urban areas of Slovakia. Nevertheless, the identified relationships between functional-spatial characteristics, maintenance practices, vegetation factors, and urban greenery quality provide a transferable analytical framework that can be applied in other cities. The specific effects and priorities may vary depending on local environmental conditions, urban structure, demographic characteristics, and available management capacities. Therefore, further comparative studies involving multiple Slovak cities are needed to validate and extend the applicability of the proposed approach. Moreover, future research should include independent expert validation and perception surveys among relevant stakeholders to further assess the reliability of visual evaluations and examine differences between expert assessments and public perception of urban greenery quality.

5. Conclusions

This study aimed to characterise the functional–spatial structure of urban greenery in the city of Nitra and to identify the influence of selected urban, vegetation, and management factors on its aesthetic appearance and health status. The findings provide answers to the three research questions formulated in this study.

Regarding RQ1, the results demonstrated that urban greenery in Nitra forms a heterogeneous functional–spatial system composed of different green space categories with distinct functions and levels of representation. The analysed green spaces covered 1116.5 ha, with housing estate greenery (G03), healthcare facility greenery (G12), recreation facility greenery (G14), and erosion control greenery (G07) representing the dominant categories. Together, these four categories accounted for approximately three-quarters of the analysed green area. The results confirm that urban greenery in the study area is primarily concentrated in residential, institutional, and recreational environments, while specialised categories represent only a minor proportion of the overall green infrastructure.

Regarding RQ2, statistically significant differences were identified among functional–spatial categories in terms of vegetation health condition, aesthetic appearance, and maintenance level. The Kruskal–Wallis tests confirmed that the functional type of urban greenery represents an important factor affecting its qualitative characteristics. Protective and stabilising greenery achieved the most favourable overall ranking across the evaluated dimensions, while differences among categories indicate that urban green spaces cannot be managed using a uniform approach. Instead, management strategies should reflect the specific ecological, social, and functional roles of individual green space types.

Regarding RQ3, the ordinal logistic regression models identified maintenance intensity and vegetation structure as the most important determinants of urban greenery quality. The aesthetic assessment was significantly influenced by woody vegetation coverage, maintenance intensity, and the proportion of coniferous woody species. In particular, the proportion of coniferous species represented the strongest positive predictor, increasing the probability of achieving a higher aesthetic rating by approximately 3.7 times. Similarly, maintenance intensity had a significant positive effect, increasing the odds of achieving a higher aesthetic assessment by more than two times. The health condition of vegetation was primarily determined by management and spatial–structural factors, with maintenance intensity and green space ratio showing significant positive effects. These findings confirm that effective management practices are a key determinant of both the visual quality and ecological condition of urban greenery.

The results demonstrate that the quality of urban greenery is not determined solely by its extent but rather by the interaction between functional–spatial structure, vegetation characteristics, and management practices. Therefore, urban green infrastructure planning should move towards differentiated management approaches that consider the specific functions, ecosystem services, and maintenance requirements of individual green space categories.

Although the study was conducted as a case study of the city of Nitra, the identified relationships between green space structure, vegetation characteristics, management intensity, and quality indicators correspond with broader trends described in the scientific literature. The methodological framework applied in this study can be transferred to other urban areas, while acknowledging that the magnitude of observed effects may vary depending on local environmental conditions, urban structure, and governance capacities. Future research should validate the findings through comparative studies involving multiple cities and through expert-based or stakeholder perception assessments.

Overall, the study provides empirical evidence that maintenance quality and vegetation structure represent key factors influencing the performance of urban greenery. The

findings support the development of targeted and context-specific management strategies aimed at enhancing the ecological functionality, aesthetic value, and resilience of urban green infrastructure.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/land15081337/s1>, Table S1: Overview of actual scientific studies; Table S2. Overview of actual scientific studies from Slovakia; Table S3: Functional-spatial classification of urban greenery used in the study (G1–G20); Table S4. Results of the Ordered Logit Model with Aesthetic Appearance of Urban Greenery as the Dependent Variable; Table S5. Results of the Ordered Logit Model with Health Conditions of Vegetation Stand as the Dependent Variable. References [67–70] are cited in the Supplementary Materials.

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Data Availability Statement: The datasets used in this study were collected by the authors through field surveys and systematic assessment of urban green spaces in the city of Nitra (Slovakia) between 2023 and 2025. The data includes spatial, structural, and qualitative characteristics of urban vegetation, as well as assessments of its aesthetic and health condition. The data sets generated and analysed during the current study are not publicly available due to their ongoing use in further research and potential extension of the database. However, they are available from the corresponding author upon reasonable request.

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