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Application of Hierarchical Clustering for Creating Urban Green Space Typology

Abstract

In the face of rapid urbanization and dynamic changes in the landscape, the role of urban green spaces gains in importance. Developing a comprehensive, regionally tailored typology of urban green spaces is essential for capturing the full diversity of urban ecosystems. This study presents a novel approach to creating urban green space typology, integrating hierarchical cluster analysis as the primary method. This statistical approach utilizes numerous spatial data features, which are characteristics related to their function, morphology, and management. Using a clustering algorithm, elements were grouped into relatively homogeneous classes and the relationships between objects with scaled cluster distances were examined. The main result of this study is a hierarchical typology of urban green spaces, distinguishing two groups and 11 types of urban green spaces. Despite the satisfactory overall results of the hierarchical cluster analysis, an extended typology was proposed because urban gardens are characterized by a very high degree of heterogeneity within a type.

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1 Introduction

Humanity is currently living in an era of global urbanization (Sun et al., 2020), with an estimated four billion people—more than half of the global population—now living in cities (Ritchie et al., 2024). This trend continues to accelerate, as people migrate to urban areas each year (United Nations, 2017). Consequently, cities have become an increasingly prominent subject of scientific inquiry (Koroso and Zevenbergen, 2024; Schuster-Olbrich et al., 2024). Urban landscape studies have traditionally focused on topics such as spatial transformation (Henderson et al., 2020), land use, and aesthetic considerations (Mundher et al., 2022). However, recent research has shifted toward a deeper examination of urban structure, particularly the role of green spaces within the urban environment (Wu et al., 2023; Cheng et al., 2023).

Urban green spaces are integral to the structure of the urban landscape, fulfilling a variety of key roles. These spaces primarily serve ecological, recreational, protective, and sports functions (Haq, 2011; Islam et al., 2024), while also providing valuable ecosystem services that enhance the health and well-being of city residents (leBrasseur, 2022; Pukowiec-Kurda, 2022; Wali et al., 2024).

The definition of urban green spaces can vary, but they are often conceptualized as urban ecosystems that include areas with natural characteristics, regardless of their origins (Pukowiec-Kurda, 2022). Maes (2021) notes that these ecosystems often consist of remnants of natural or semi-natural environments within urban areas. According to Ignatieva and Mofrad (2023), urban green spaces serve a wide range of purposes, including aesthetic and cultural functions, biodiversity protection, and environmental improvement. A growing area of interest in urban ecology involves “novel urban ecosystems”—urban green spaces that incorporate non-native species, creating new ecological systems. These spaces, such as urban gardens, squares, and plantings around key urban structures, represent a fusion of species adapted to the urban environment (Ahern, 2016).

Despite their importance, the classification of urban green spaces remains a relatively underexplored area of research (Bartesaghi Koc et al., 2017). Most existing typologies are region-specific (Jerome et al., 2019), reflecting the diversity of green space types across different locations and the absence of a standardized classification system (Young et al., 2014; Ingatieva and Mofrad, 2023). Factors such as geographical location (Benton-Short et al., 2021; Guo, et al., 2021; Yang et al., 2020), climate (Guo et al., 2016), vegetation zones, local politics (Kronenberg et al., 2020), and city size (Boulton et al., 2020) all influence the types of green spaces found in a given region. For example, smaller cities differ from larger metropolises in terms of green space typology, and the functions of the city—whether a resort, industrial hub, or spa town—also affect green space design and distribution (Hu et al., 2020; Sztubecka et al., 2022).

This diversity underscores the need for region-specific classifications of urban green spaces. Numerous studies have examined urban greenspaces in specific regions, including Europe (Giannico et al., 2021; Buckland and Pojani, 2022), Asia (Mabon and Shih, 2021), Latin America and the Caribbean (Romero-Duque et al. 2020). For many of these studies, regionally tailored typologies are essential for understanding the local variety of green spaces.

To address regional needs, several typologies of urban green spaces have been proposed, often based on different criteria. Ignatieva and Mohrad (2023) and Bartesaghi Koc et al. (2017) provide reviews of existing typologies. Some typologies focus on the status of the green spaces, categorizing them as planned or informal (Ruppreht and Byrne, 2014; Biernacka et al., 2023; Włodarczyk-Marciniak et al., 2020; Sikorska, 2020). Others categorize spaces according to the ecosystem services they provide (Zinia and McShane 2021; Neuenschwander et al., 2014; Cvejič et al., 2015; Jones et al., 2022; Vidal et al., 2022).

In addition, researchers have explored other aspects of urban green spaces, such as data sources (Feltynowski, 2022), their morphological characteristics (Khodadad et al., 2023) and the value of the land on which they are located (Panduro and Lausted Veie, 2013). However, there is limited research on the processes occurring within urban greenspaces. Notably, Zwierzchowska (2008) examined green space fragmentation in the Wielkopolska region of Poland. Yet, up-to-date data on this subject remains scarce, particularly in rapidly developing and transforming urban areas.

This article aims to develop a hierarchical typology of urban green spaces, addressing the gap in existing typologies that often fail to reflect the unique conditions of the study area. The typology will be based on criteria outlined in the literature (multi-criteria approach). The research focuses on the Silesian Metropolis, a unique agglomeration with industrial and mining origins, characterized by significant geographical, landscape, and functional diversity. Due to its post-industrial nature, no current typology fully captures the range of urban green spaces in this area. As a result, the authors identified a research gap in existing typologies, particularly those addressing green spaces in post-industrial areas undergoing metropolitan transformation. Once verified, the proposed typology could be applied to similar post-industrial regions in Central Europe.

2 Materials and methods

2.1 Study area

The study area consists of 13 cities within the Silesian Metropolis area (Fig. 1). These urban communes represent the most highly urbanized landscapes (Myga-Piątek et al., 2021) and form the core zone of the agglomeration (Pytel et al., 2021). The cities also exhibit strong metropolitan functions (Zuzańska-Żyśko, 2012). The total study area covers 106,551 ha (1,065, 51 km^2), with a population of 1,650,190 people (Local Data Bank, 2024).

In terms of the urban green space system, the area is characterized by a diverse range of green space types. Some of these are remnants of natural ecosystems, while others are man-made. The largest forest and the only nature reserve is Murcki Woods (*Las Murcki*) in Katowice.

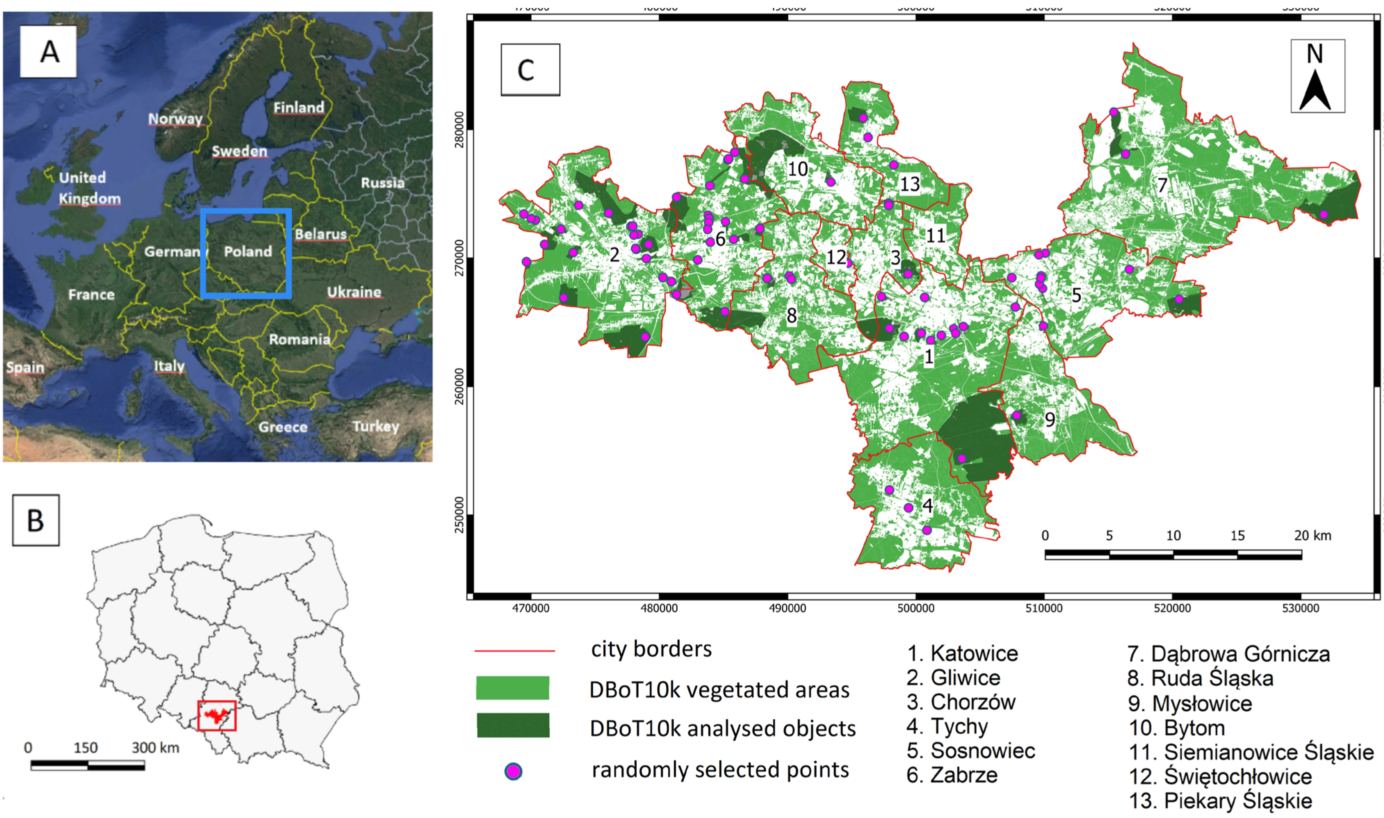

Figure 1. The location of the research area in Europe (A) and in Poland (B), and the areas covered with vegetation against the background of local administrative boundaries (C) (own elaboration based on Database of Topographic Objects (DBoT10k) acquired from the Head Office of Geodesy and Cartography).

In addition to semi-natural ecosystems, the agglomeration has a long history of urban park development. The establishment of Kachl's Park in Bytom (1840) marked the creation of the first urban park, followed by a period of park development across the region (Lis, 2001). The largest and most well-known park today is The Silesian Park (*Park Śląski*) in Chorzów.

With the rise of the garden city movement, many cities in the region were enriched with various forms of horticulture, often linked to family housing, including patronage estates (Chmielewska et al., 2016). In the early 20th century, citizens also began creating garden allotments (Feltynowski and Kronenberg, 2020) reflecting broader Europe trends of the time.

A distinctive feature of the Silesian Metropolis is the presence of numerous brownfields, primarily originating from the coal mining industry (Pytel et al., 2021). Thanks to recultivation efforts, some of these brownfields have been transformed into urban green spaces (Pukowiec-Kurda and Vavrouchová, 2020). However, adapting post-industrial sites remains an ongoing challenge. Overall, the design of the urban green space system is an ongoing issue for urban planners in the Silesian Metropolis, especially with the presence of numerous informal greenspaces that remain un-managed (Pancewicz et al., 2021).

2.2 Data sources and software

In order to distinguish between different elements of urban greenery (UGS) and the surrounding urban fabric, a database of topographic objects (DBTO10k, originally: Database of Topographic Objects, BDoT10k) was used. This data repository is managed by the Head Office of Geodesy and Cartography in Poland and is available at the voivodeship level (Portal PZGiK). The database corresponds to 1:10000 scale maps and undergoes regular updates. The most recent update for the study area was in 2024, but the officially declared up to date data is for 2021.

The dataset is provided in vector format (SHP files) and is structured into nine thematic layers, including:

- Water supply networks;
- Transport networks;
- Utility infrastructure;
- Land cover;
- Buildings, structures and devices;
- Co-existing land-use types;
- Protected areas;
- Administrative units;
- Other objects.

For this study, only the layers relevant to vegetated areas were extracted, specifically: land-use types, protected areas, and other objects. The total number of the extracted objects was equal to 6962 elements. While the database includes attribute tables, complete identification of objects and their morphological characteristics requires additional reference materials. To support this, an orthophotomap was obtained from the National Geoportal.

Licensed ArcGIS v.10.7.1 geoinformation software was used to extract morphological parameters, together with the free V-late plug-in (Vector-based Landscape Analysis Tools, v.2.0). Data clustering was conducted using STATISTICA 12 (StatSoft Inc.) and spatial data analyses were performed in QGIS v.3.14.16.

2.3 Research procedure

2.3.1 Methodology workflow

Figure 2 presents the conceptual framework of this study, which integrates statistical clustering as a key method for developing an urban green space (UGS) typology. To understand the role of statistical clustering in this process, it is important to note that data clustering is designed to group elements into relatively homogeneous classes.

Various techniques exist for clustering objects (Smith, 2018), but the results depend on the specific variables in each case. In this study, these variables represent different features of the objects. Consequently, objects classified within the same type are expected to share similar features.

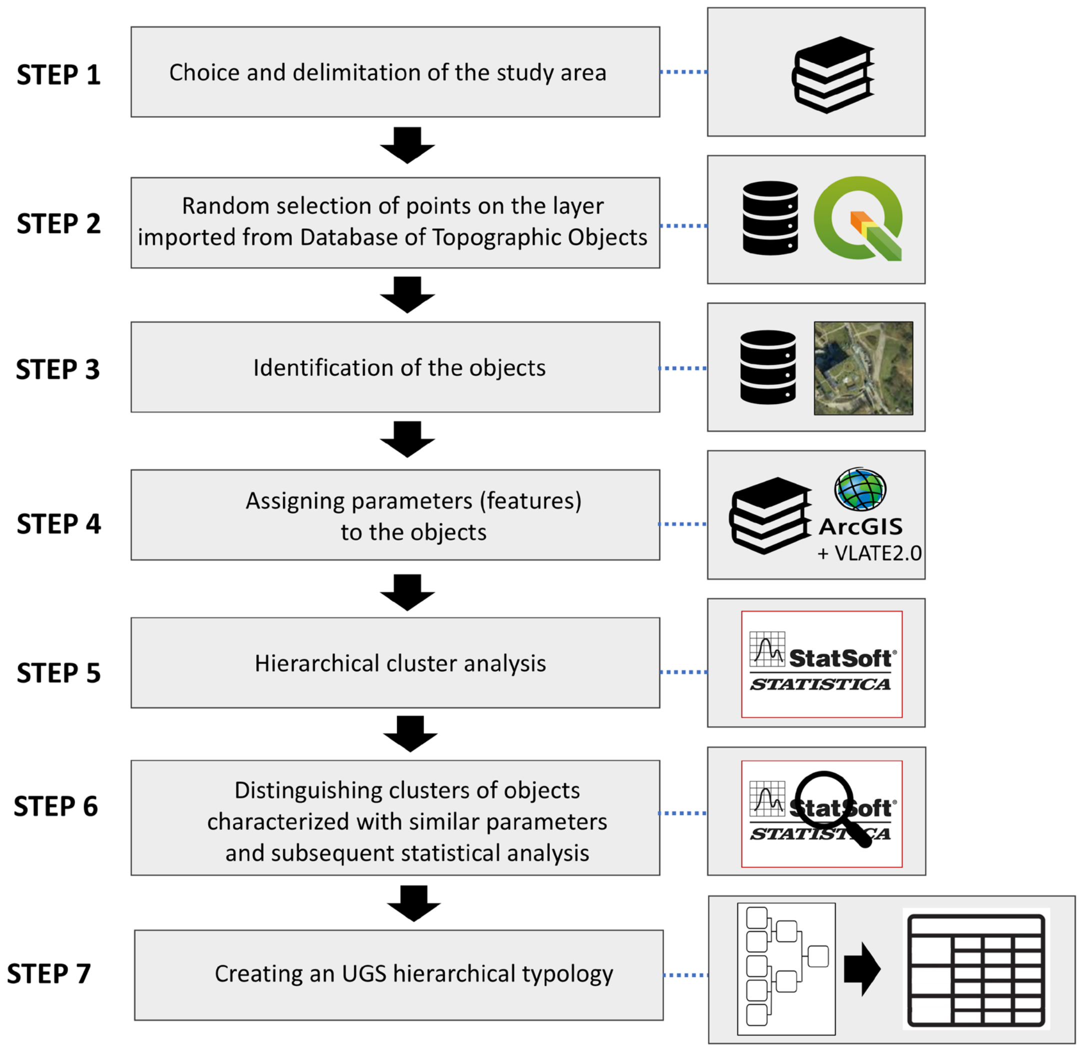

Figure 2. Workflow for creation of an urban green space typology using a statistical clustering method (own elaboration).

2.3.2 Objects selection and identification

Out of thousands of polygons obtained from DBoT10k, a subset was selected as a representative research sample. Specifically, 77 points were randomly distributed within the acquired SHP files and then exported as a separate layer. Each point represented a single UGS element.

To ensure that rare or exceptional UGS elements were not overlooked, some points were manually relocated to different positions. Similarly, duplicate points —those that appeared within the same polygon—were removed to prevent double-counting.

Identifying these 77 objects served as the starting point for feature allocation. Each object was verified using an orthophoto map and a field survey. Additionally, the element was assigned a unique ID and a working name, allowing for clear identification of its location and characteristics—particularly in cases where the UGS had no formal name.

2.3.3 Assigning features to objects

As mentioned earlier, the typologies developed in this study are based on multiple criteria. To ensure a comprehensive classification of UGS, the authors selected various features that might improve the typology's effectiveness. These criteria were derived from a review of scientific publications dedicated to UGS (Bartesaghi Koc et al., 2017; Czarnecki, 1968; Czerwieniec and Lewińska, 2000; Giedych, 2003; Hunter and Luck, 2015). The criteria are divided into three main categories:

I. **Governance, management & operations criteria** – These pertain to the management and maintenance of UGS, which is one of the most common classifications (Belmeziti et al., 2018; Biernacka et al., 2023).
II. **Morphological criteria** – These involve morphological features of UGS, such as size and shape (Kimpton, 2017).
III. **Functional criteria** – These describe how UGS is used and serve as another frequently used classification approach (Ignatieva and Mofrad, 2023; Vidal et al., 2022).

In the statistical analysis, these criteria are referred to as parameters (variables).

- **Governance, management & operations parameters** are presented in Table 1.
- **Morphological parameters** are shown in Table 2.
- **Functional parameters**, which have a more complex classification, are listed in Table 3.

For each parameter, the authors provided an explanation of how objects were categorized accordingly.

The selection and evaluation of functional parameters (ecological, social, health, economic, cultural, and aesthetical) are based on a literature review and expert knowledge about the study area. The primary reference was the book by M. Czerwieniec and J. Lewińska (2000), which categorizes the functions of the UGS system and associates them with some, but

Table 1. The UGS parameters investigated in the study related to their governance, management & operations. Source: own elaboration based on the following literature: Biernacka et al., 2023; Biernacka and Kronenberg, 2019; Rupprecht and Byrne, 2014.

Parameter	Division (class)	Explanation
Formality	I - Formal II - Informal	Considered as formal those objects that are introduced by a legal act, excluding the spatial zoning plan.
Accessibility	I - Fully accessible II - Permitted III - Closed IV - Owner-dependent	Considered as fully accessible those objects that one can enter at any time; if not, it is permitted. If the UGS is inaccessible to the public, it is considered closed. Areas that are owner-dependent and vary in their accessibility belong to class IV.
Ownership	I - Public II - Private	Considered as public all UGS that are governed by the National Treasury, local authorities, and associations (including religious associations).
Maintenance	I - Maintained II - Un-maintained	Considered as maintained those objects for which maintenance work is performed at least twice a year, regardless of who performs it. Agrotechnical treatments are not considered maintenance work.
Associated structure	I - None II - Building III - Road infrastructure IV - Industrial infrastructure V - Waters	The creation of many UGS depends on associated structures. In the context of the constructed typology, an affiliated UGS is considered one that would not have been built or grown without the adjacent element.

Table 2. The UGS parameters investigated in the study related to their morphology. Source: own elaboration

Parameter	Division (class)	Explanation
Shape	I - Compact II - Linear	For each of the 77 objects, a shape index was calculated, providing information about the elongation of the spot. If a patch's shape index exceeds 4.0, it is considered as linear.
Size	Numeric value (ha)	For each of the 77 objects, their size in hectares (ha) was calculated.

Table 3. The UGS parameters investigated in the study related to their functions. Source: own elaboration

Function	Explanation	Evaluation based on:
Ecological Social Health Economic Cultural Aesthetical	The assigned value represents how strong the function of a given UGS element is: 1 - insignificant 2 - low 3 - medium 4 - high 5 - very high	Czerwieniec and Lewińska, 2000; Dymek et al., 2021; Feltynowski and Kronenberg, 2020; Kaczyńska, 2020; Nordh et al., 2017; Pałubska, 2012; Panduro and Lausted Veie, 2013; Pueffel et al., 2018; Rupprecht and Byrne, 2014; Šiftová, 2021; Vidal et al., 2022; Wassenberg et al., 2015; Weerasuriya et al., 2019; Zhao et al., 2024.

not all, types of UGS. Although older publications rarely focus on the health function of UGS, the authors included it as a separate function. This decision was informed by numerous recent studies on the impact of different types of UGS on well-being, allowing for an approximate quantification of the health function using a five-level scale. To quantify these functions, the authors adopted an ordinal five-level Likert scale.

2.3.4 Clustering the objects into urban green space types

In the next step, each object, with 13 parameters assigned was entered into a statistical software spreadsheet. Before running the algorithm, all qualitative variables were recoded to numerical values. To mitigate the risk of disproportionate influence from any variable group, all variables — whether quantitative or recoded qualitative — were standardized (z-scores) prior to clustering. The hierarchical cluster analysis algorithm was then applied, using Ward's method (Ward, 1963) as the linkage rule and Euclidean distance as the distance measure.

The results were visualized in a tree plot (dendrogram), which displayed clusters of similar objects. While the dendrogram illustrated the relationship between objects, manual separation of groups was required. The authors defined the boundaries between clusters whenever two elements were clearly distinct, adhering to the general rule of grouping objects that belong to the same tier.

During the clustering process, two conditions were met: separability (each element belongs to only one type), and completeness (each object belongs to a type, with no category labelled as "other").

After determining the clusters, the authors analyzed which variables were most influential in explaining cluster variability. The identification of parameters that significantly differentiate the clusters was carried out using the Kruskal–Wallis test (with the H-statistic examined for ordinal variables) and one-way ANOVA (with the F-statistic evaluated for the continuous variable). This stage provided insights into the relationship between the degree of homogeneity within individual clusters and the differentiation of specific variables.

Finally, the constructed typology was spatially explored in terms of proportions of particular types and their spatial distribution in the study area. The authors applied the typology to the remaining objects (from the DBoT10k database) through a supervised classification process. Each of 6962 objects was reassigned to one type, which enabled the authors to define where are the different types concentrated and what is their share (%).

3 Results

3.1 Clusters determination

The result of the hierarchical cluster analysis, presented in Fig. 3 as a dendrogram, shows the rescaled distance between clusters on the Y-axis and the 77 analyzed objects on the X-axis.

Based on the adopted separation principles, 14 clusters were manually identified. According to the rule that a lower rescaled cluster distance indicates a stronger association between objects, the identified clusters exhibit varying degrees of homogeneity. As shown in Table 4, clusters A, C1 and J are the most homogenous, while cluster C3 is the least homogenous.

Table 4. Clusters identified in the study ranked by degree of homogeneity (low RCD = high homogeneity; high RCD = low homogeneity). Source: own elaboration

Rescaled Clusters Distance	Clusters	Number of Objects
1	A	9
	C1	3
	J	2
2	H	4
	D	5
3	B	3
	I	9
4	C3	3
	E	3
	F	5
	G	15
8	C2	5
9	K	7
12	C4	4

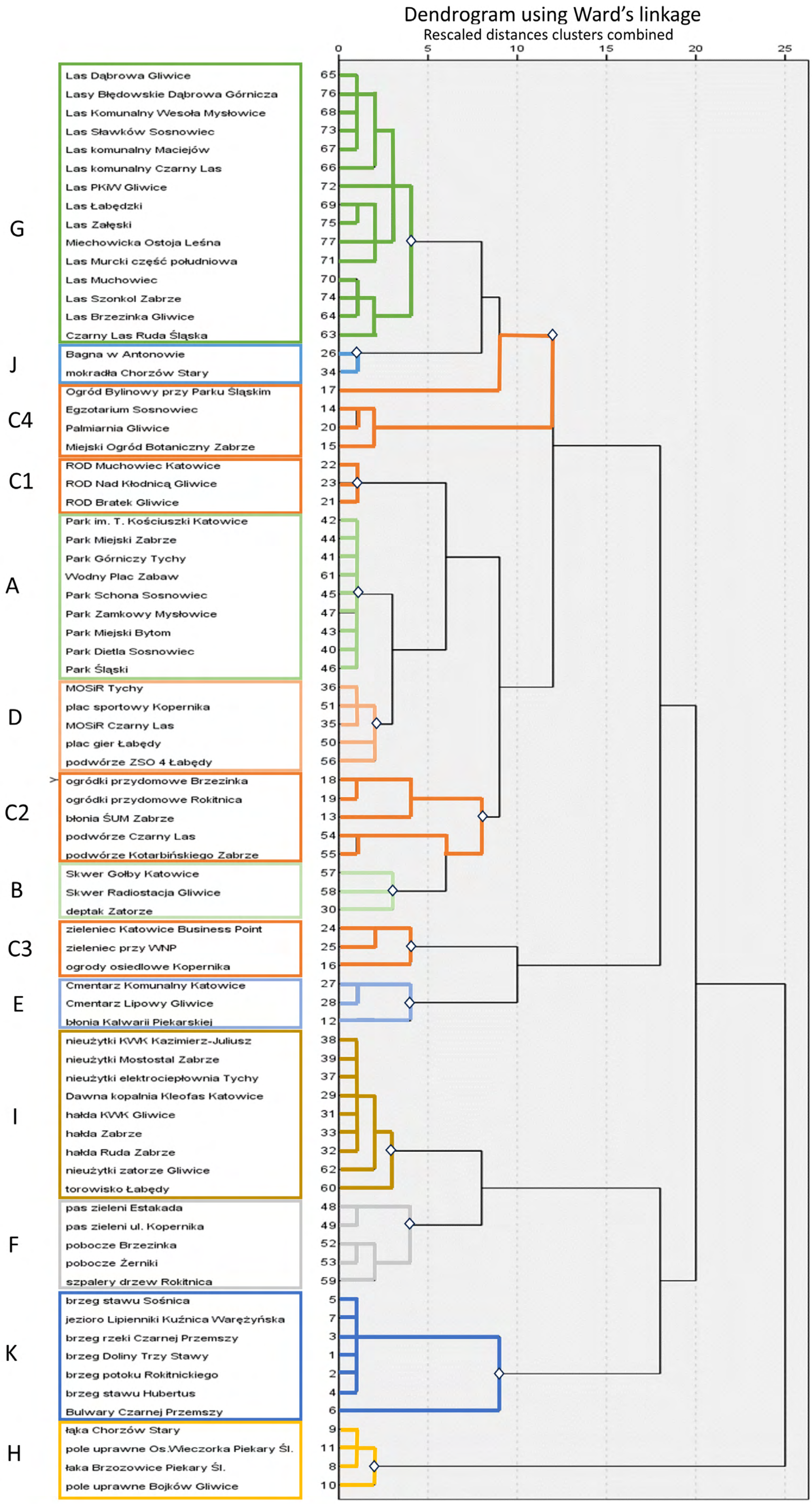

Figure 3. Dendrogram of the hierarchical cluster analysis (own elaboration).

However, a closer examination of the dendrogram reveals the presence of several objects which deviate noticeably from the structure of their assigned clusters. A particularly evident example is object no. 6 in cluster K. Its substantial vertical separation from the remaining objects of the cluster suggests a low degree of similarity and strongly impacts the homogeneity of the entire group. A similar effect is observed for object no. 17 in cluster C4, which is positioned on a long branch within its cluster, indicating limited affinity with the remaining elements. These cases illustrate that while the overall classification maintains separability and completeness, a few elements exhibit ambiguous affiliations.

The results of the post-clustering statistical analysis using the Kruskal–Wallis ANOVA test reveal variability in parameters among the individual clusters and indicate which variables differentiate the clusters most strongly. The distribution of variables across clusters is visualized using boxplots in Fig. S1 (governance, management, and operations parameters), Fig. S2 (morphological parameters), and Fig. S3 (functional parameters). The p-values indicate that the variables differ significantly between clusters ($p < 0,001$). Overall, the most differentiating variables are: associated structure (H=73,87), aesthetical value (H=71,19), and social function (H=70,13). For the only continuous variable (size), the moderate F value ($F = 1,94$) indicates that its variation does not translate into differences between clusters; the influence of the other parameters outweighs that of this variable.

Some variables also show greater variability within certain clusters than within others. For example, most clusters exhibit high internal variability in terms of health and cultural function. An opposite tendency is observed for formality and social function; for these parameters, only four clusters show internal variation.

A cross-analysis of the boxplots and Table 4 also provides insight into the relationship between the RCD value and the variability of parameters within a given cluster. This relationship can be observed, for example, in cluster A, where low parameter variability corresponds to a low RCD value and high cluster homogeneity. An opposite pattern is observed in cluster C2, where numerous outlying parameter values increase cluster heterogeneity.

3.2 Creation of urban green space typology

Identifying 14 clusters—a primary step in the analysis—enabled the development of a hierarchical urban green space typology. The initial clusters, originally labelled with letters, were re-assigned descriptive names. These working names were chosen to be self-evident and to reflect the general character of each given urban green space type. The resulting typology is presented in Table 5.

Table 5. Urban green space typology based on hierarchical clustering. Source: own elaboration

Group	Type	Clusters
Group A: Managed UGS	1. Parks	A
	2. Squares	B
	3. Gardens	C1, C2, C3, C4
	4. Sport & recreational areas	D
	5. Cementeries	E
	6. Infrastructural greenery	F
Group B: Unmanaged UGS	7. Forests	G
	8. Agricultural areas	H
	9. Brownfields & industrial areas	I
	10. Wetlands	J
	11. Waterside greenery	K

Due to the low degree of homogeneity in clusters C2, C3 and C4, the authors merged them with cluster C1 to form a single urban green space type named "gardens".

To construct the typology hierarchically—that is, with clusters nested within higher-level units—the clusters were grouped into two categories based on the origins of the urban green spaces. The first category comprises types that are man-made and regularly maintained, such as parks, squares, gardens, sports and recreational areas, cemeteries and infrastructural greenery. These are referred to as managed urban green spaces. The second category, termed un-managed urban green spaces, includes all other types: forests, agricultural areas, brownfields & industrial areas, wetlands and waterside greenery.

The spatial distribution of the urban green spaces identified in the study is shown in Figure 4, and the proportion of each type is illustrated in Figure 5.

The percentage share of the particular urban green space types is uneven, and only two types – forests and agricultural areas – occupy as much as two third (67,5 %) while the remaining nine occupy a minority (32,5 %) of the total green space area (76 016 ha).

It can also be observed that, contrary to forests and agricultural areas, many types are concentrated in central urban cores. These are primarily managed types such as parks, gardens, and infrastructural greenery. They show simultaneously a highly scattered spatial structure. On the other hand, some un-managed types, like wetlands, waterside areas, and brownfields, demonstrate a high spatial irregularity, concentrating only in certain spots.

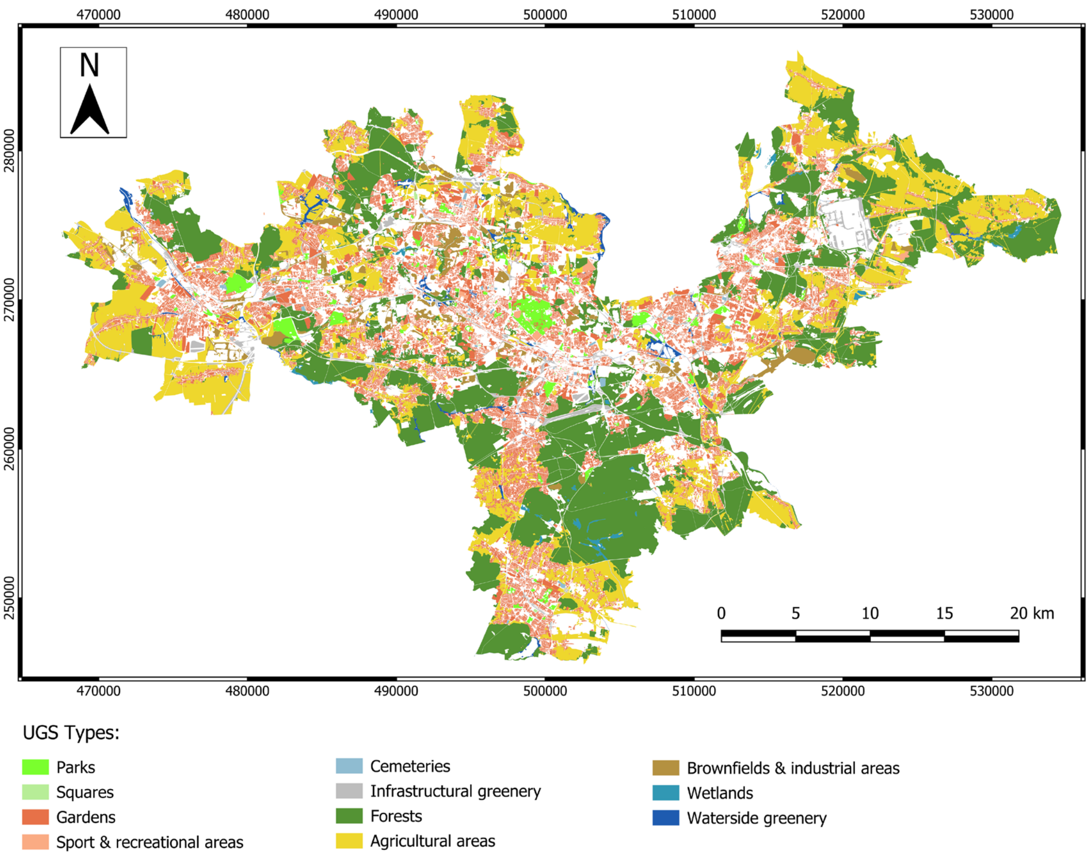

Figure 4. The spatial distribution of the urban green spaces in the study area (own elaboration).

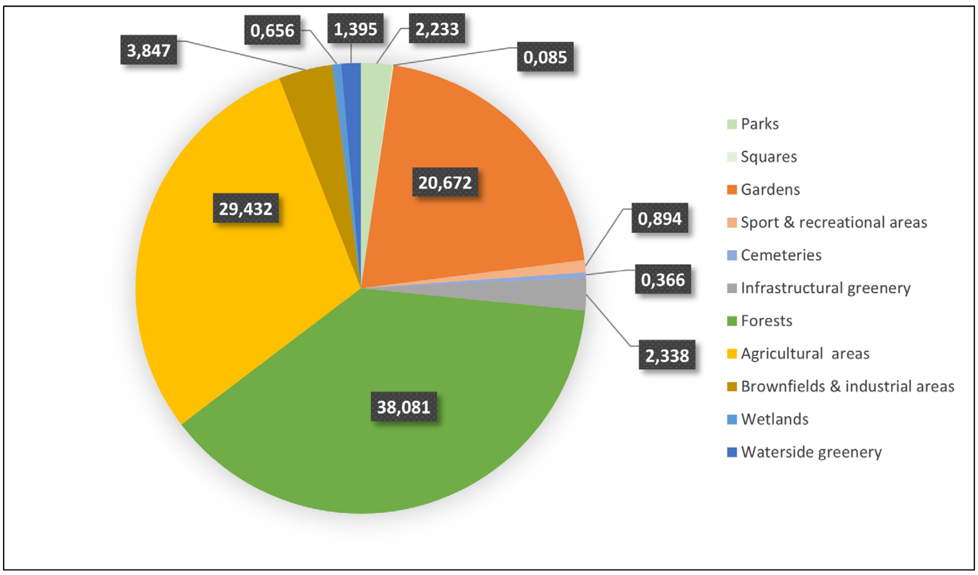

Figure 5. Percentage share of the following types of urban greenspaces (own elaboration).

4 Discussion

4.1 Overall result of hierarchical clustering and degree of heterogeneity among clusters

Researchers and urban planners have become increasingly focused on the quality of urban landscapes, which has led to greater emphasis on the role of urban green spaces in recent decades (Wu et al., 2023). However, detailed research on urban green spaces, both qualitative and quantitative, often necessitates the development of a typology. Beyond general typologies, region-specific typologies tailored to particular environmental and geographic conditions are crucial. The need for a comprehensive typology, one that encompasses all vegetation areas and is specifically adapted to the case study, is widely recognized by researchers (Jerome et al., 2019, Ignatieva and Mofrad, 2023). However, typologies have been typically based on a variety of classification parameters. As noted by Bartesaghi Koc et al. (2017), the most common parameters include size, location, management and function. The typology in this study also adopts a multi-criteria approach, which, while complex, allows for a more accurate representation of the diversity in urban green spaces. While the inclusion of multiple criteria complicates the clustering process, it enhances the ability to classify urban green spaces in a manner that better reflects their actual conditions. This process is facilitated through statistical clustering methods.

Statistical clustering not only enables researchers to prioritize types of green spaces but also serves as an advantage for those conducting GIS analyses based on green space inventories (Zinia and McShane 2021; Biernacka et al., 2023). In this study, urban green spaces are divided into two primary categories: managed and un-managed. This division is largely driven by the clustering results, where most of the clusters are positioned adjacent to each other on the dendrogram (8 of 9 clusters). Within the managed green spaces group, six types were identified, while the un-managed group contained five types. This method of classifying urban green spaces into two main groups is also found in several studies (Zwierzchowska, 2008; Engemann et al., 2024), though some studies adopt a division between formal and informal types (Ruppreht and Byrne, 2014, Feltynowski, 2023).

The cluster analysis results indicate that while most clusters reflect the same morphological form of urban green space, not all do. This finding is in line with Khodadad et al. (2023), who note that the vast majority of studies on urban green spaces use morphological form as a criterion. However, in that study, not all types of urban green spaces align with the same morphological form. For instance, gardens were grouped into four separate clusters, but the heterogeneity within these clusters remains high (Table 4). An alternative approach might involve designating one type for each of the four clusters. However, this would be controversial, and likely unsatisfactory, as it would not yield clear distinctions between the clusters. While some studies integrate gardens into a single category (Czerwieniec and Lewińska, 2006; Zwierzchowska, 2008), many researchers differentiate gardens, even when using arbitrary classification criteria. Some categorize gardens into just two (Bell et al., 2007) or three types (Feltynowski, 2023), while others divide them into as many as six (Neuenschwander et al., 2014) or even seven categories (Biernacka, 2023). The heterogeneous nature of gardens present in urban landscapes is further reflected in existing typologies, with some studies suggesting that certain garden types are more akin to city parks, at least in terms of management (Jones et al., 2022). This heterogeneous nature, coupled with the clustering algorithm's inability to clearly separate gardens, as evidenced by the lower rescaled cluster distance, underscores the need for more a nuanced approach.

Therefore, authors propose the introduction of subtypes for urban green areas, as presented in Table 6. This expanded typology divides the 11 types of urban green spaces into 28 distinct subtypes, with a particular focus on urban gardens.

This typology is constructed using a statistical approach for the first two hierarchical levels, while the third level is primarily informed by an extensive literature review and ground-based surveys. In essence, the statistical analysis is directly applicable only to gardens. Although some degree of arbitrariness exists, the authors contend that the concept captures the complexity and physiognomical diversity of vari-

Table 6. The detailed urban green space typology based on hierarchical clustering, an extensive literature review and ground-based surveys. Source: own elaboration.

Group	Type	Sub-type
Group A: Managed UGS	1. Parks	large-sized parks (>20 ha)
		medium-sized parks (5-20 ha)
		small-sized parks (<5 ha)
	2. Squares	
	3. Gardens	garden allotments
		backyard gardens
		gardens near residential housing
		gardens near commercial and public institutions
		churchyards
		botanical gardens and palm gardens
	4. Sport & recreational areas	school yards
		playgrounds and sport fields
	5. Cementeries	
	6. Infrastructural greenery	tree lines
		roadsides, roundabounts and green islets
		railway tracks
Group B: Unmanaged UGS	7. Forests	large-sized forests (>1000 ha)
		medium-sized forests (100-1000 ha)
		small-sized forests (<100 ha)
	8. Agricultural areas	fields
		meadows and pastures
		orchads
	9. Brownfields & industrial areas	barren land inside post-industrial areas
		barren land inside industrial areas
		spoil heaps
	10. Wetlands	
	11. Waterside greenery	greenery along water bodies
		greenery along water courses

ous urban green space types (e.g., agricultural areas, infrastructural greenery). In certain cases—such as cemeteries and wetlands— sub-types are unnecessary because these areas are sufficiently homogenous.

4.2 Usefulness of the adopted method

Ward's clustering method is a well-established approach for creating various typologies. Its usefulness in this case stems primarily from the high flexibility of this method, adjustability and the ease of results interpretation. However, the quality of the results is also influenced by the databases used. While the applied research procedure successfully produced a typology, there are certain limitations to its use.

First, identifying objects using the DBoT10k database allowed for the detection of more objects and their features compared to more generalized databases such as Urban Atlas and Corine Land Cover. However, some elements smaller than 10 square meters were only observable during field research. This was particularly true for infrastructural greenery, as the study area contained numerous small-scale structures such as green roofs, green walls and other minor landscape transformations (Pancewicz et al., 2021). These elements are too small to be captured within the DBOT10k scale. While they could be included in the constructed typology, their overall presence in the urban landscape was negligible, leading to their exclusion.

Moreover, the hierarchical cluster analysis algorithm, widely used in social studies (Smith, 2018), can also be applied to environmental studies. However, its application in urban green space (UGS) studies remains rare (Vidal et al., 2022). The resulting dendrogram illustrated the relationships among 77 objects—a moderate sample size. While future studies could include more objects, this might hinder result visualization without significantly altering the constructed typology.

Kimpton (2017) recognized Ward's method as effective for both continuous and binary variables. Nevertheless, some objects inevitably deviate from their assigned cluster. This was evident in the case of object no. 6 in cluster K, which affected the rescaled cluster merging distance, and object no. 17 in cluster C4, which displayed a similar effect. This differentiation in the internal consistency of individual clusters prompted a supplementary analysis of which parameters were the most influential in deriving the clusters. A statistical exploration of this issue, even though superficial, confirms that the resulting typology is not arbitrary but statistically supported by consistent patterns in the raw data.

The above observations suggest also that while many UGS types fit within a single category, they may still differ in terms of functionality, morphology or management. Acknowledging these nuances and accounting for them in research enhances result quality and helps minimize errors.

4.3 The role of a comprehensive typology of urban green areas in spatial planning

Many authors emphasize the practical implications of UGS research (Feltynowski, 2023) for urban planners and decision-makers. There is a broad consensus among natural science experts on the necessity of applying an inclusive definition of UGS, regardless of its formal status (Feltynowski, 2023; Rupprecht and Byrne, 2014). Local authorities are responsible for maximizing the potential of urban green areas to support citizens' well-being (Zhao et al., 2024). This is especially crucial in human-modified landscapes, where the demand for ecosystem services is highest (Pukowiec-Kurda, 2022).

Urban green areas are not only vital ecosystems that provide habitats for plants and animals, but they also offer essential services to humans, known as ecosystem services. These services contribute to the well-being of urban residents, influencing their quality of life and even their health (Jay and Schraml, 2009).

In modern cities, green spaces play a crucial role in mitigating pollution, reducing congestion, and counteracting the overstimulation of residents. Effective spatial planning requires a holistic approach—one that views urban green areas not just as ecological and structural components of the landscape, but also as key social and environmental assets.

Developing a comprehensive typology of urban green areas is essential for capturing the full diversity of urban ecosystems and the services they provide. As Ahern (2016) notes, such typologies promote sustainable urban development and enhance ecological connectivity. They also help recognize overlooked spaces, such as allotment gardens and cemeteries, which urban landscape ecologists and policymakers may neglect in their analyses.

5 Conclusions

This study used hierarchical clustering to develop a typology of urban green spaces, using the Silesian Metropolis—a post-industrial, highly urbanized agglomeration—as a case study. The hierarchical cluster analysis identified 14 clusters, resulting in 11 UGS types divided into two groups. The typology captures the diversity of UGS, including both man-made and semi-natural forms.

The authors evaluated the clustering algorithm used, highlighting its strengths and limitations. Several key aspects emerged:

I. The clusters vary in homogeneity, as reflected by the rescaled cluster distance values.

II. Gardens are the most heterogeneous type due to their diverse morphological form.

III. The constructed UGS typology primarily relates to the land cover and land use.

IV. Using the DBoT10k database as a data source allows for an analysis of the spatial distribution of UGS types. However, infrastructural greenery is likely underestimated.

V. While the adopted method is effective for typology development, its results depend heavily on the chosen criteria.

The applied method met the conditions of separability and completeness without imposing a predefined number of clusters, demonstrating its high utility.

However, the difficulty in defining a single cluster for gardens suggests the need for further refinement at a more detailed level.

The study addresses a significant research gap concerning UGS typologies in post-industrial metropolitan areas, particularly in Central Europe. It also lays the groundwork for more advanced spatial analyses, including quantitative assessments across individual municipalities within the Silesian Metropolis. Nonetheless, the typology should remain adaptable to accommodate emerging forms of UGS, such as community gardens, which are increasingly integrated into urban greenery systems in line with trends observed in Western Europe.

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Declaration of Competing Interest

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

References

Ahern, J.F. (2016). Novel Urban Ecosystems: Concepts, Definitions and a Strategy to Support Urban Sustainability and Resilience. Landscape Architecture Frontiers, 66, 10-21.

Bartesaghi Koc, C., Osmond, P., & Peters, A. (2017). Towards a comprehensive green infrastructure typology: A systematic review of approaches, methods and typologies. Urban Ecosystems, 20, 15–35. https://doi.org/10.1007/s11252-016-0578-5

Bell, S., Montarzino, A., & Travlou, P. (2007). Mapping research priorities for green and public urban space in the UK. Urban Forestry & Urban Greening, 6(2), 103–115. https://doi.org/10.1016/j.ufug.2007.03.005

Belmeziti, A., Cherqui, F., & Kaufmann, B. (2018). Improving the multi-functionality of urban green spaces: Relations between components of green spaces and urban services. Sustainable Cities and Society, 43,1-10. https://doi.org/10.1016/j.scs.2018.07.014

Benton-Short, L., Keely, M., & Rowland, J. (2021). Green infrastructure, green space, and sustainable urbanism: geography's important role. In D.H Kaplan & V.K. Turner (Eds.), Geographic Perspectives on Urban Sustainability (pp. 330-351). Routledge. https://doi.org/10.4324/9781003130185

Biernacka, M., & Kronenberg, J. (2019). Urban Green Space Availability, Accessibility and Attractiveness, and the delivery of Ecosystem Services. Cities and the Environment (CATE), 12(1). Retrieved September 21, 2024, from: https://digitalcommons.lmu.edu/cate/vol12/iss1/5

Biernacka, M., Kronenberg, J., Łaszkiewicz, E., Czembrowski, P., Parsa, V.A., & Sikorska, D. (2023). Beyond urban parks: Mapping informal green spaces in an urban–peri-urban gradient. Land Use Policy, 131(106746). https://doi.org/10.1016/j.landusepol.2023.106746

Boulton, C., Dedekorkut-Howes, A., M Holden, M., & Byrne, J. (2020). Under pressure: Factors shaping urban greenspace provision in a mid-sized city. Cities, 106, 102816. https://doi.org/10.1016/j.cities.2020.102816

Buckland, M., Pojani, D. (2022). Green space accessibility in Europe: a comparative study of five major cities. European Planning Studies, 31(1), 146–167. https://doi.org/10.1080/09654313.2022.2088230

Cheng, Z., Li, X., & Zhang, Q. (2023). Can new-type urbanization promote the green intensive use of land?. Journal of Environmental Management 342, 118150. https://doi.org/10.1016/j.jenvman.2023.118150

Chmielewska, M., Lamparska, M., Pytel, S., & Jurek, K. (2016). Zagłębiowskie osiedla patronackie: Projekt szlaku turystycznego. Stowarzyszenie na Rzecz Ochrony Dziedzictwa Przyrodniczego i Kulturowego "Moje Miasto", Będzin.

Cvejić R., Eler, K., Pintar, M., Železnikar, S., Haase, D., Kabisch, N., & Strohbach, M. (2015). A typology of urban green spaces, ecosystem services provisioning services and demands. Report of the GREEN SURGE project. Retrieved September 21, 2024, from: https://assets.centralparknyc.org/pdfs/institute/p2p-upelp/1.004_Greensurge_A+Typology+of+Urban+Green+Spaces.pdf

Czarnecki, W. (1968). Planowanie miast i osiedli: Krajobraz i tereny zielone (T. III). Wydawnictwo PWN, Warszawa, p.706.

Czerwieniec, M., & Lewińska, J. (2000). Zieleń w mieście. Instytut Gospodarki Przestrzennej i Komunalnej, Kraków.

Dymek, D., Wilkaniec, A., Bednorz, L., Szczepańska, M. & (2021). Significance of allotment gardens in urban greenspace systems and their classification for spatial planning purposes: A case study of Poznań, Poland. Sustainability (Switzerland) 13(19), 11044. https://doi.org/10.3390/su131911044

Engemann, K., Breed, C., Brom, P., & Pasgaard, M. (2024). Transdisciplinary approaches assessing unmanaged urban green spaces reveal benefits for biodiversity and people.

Socio-Ecological Practice Research, 6(2), 155–175. https://doi.org/10.1007/s42532-024-00184-y

Feltynowski, M., & Kronenberg, J. 2020. Urban Green Spaces—An Underestimated Resource in Third-Tier Towns in Poland. Land, 9(11), 453. https://doi.org/10.3390/land9110453

Feltynowski, M. (2023). Urban green spaces in land-use policy – types of data, sources of data and staff – the case of Poland. Land Use Policy, 127, 106570. https://doi.org/10.1016/j.landusepol.2023.106570

Giannico, V., Spano, G., Elia, M., D'Este, M., Sanesi, G., & Lafortezza, R. (2021). Green spaces, quality of life, and citizen perception in European cities. Environmental Research, 196, 110922. https://doi.org/10.1016/j.envres.2021.110922

Giedych, R. (2003). Problemy identyfikacji systemu terenów rekreacyjnych miast na przykładzie terenów zieleni Warszawy. Problemy Ekologii Krajobrazu 11, 277–283.

Guo, G., Zhou, X., Wu, Z., Xiao, R., & Chen, Y. (2016). Characterizing the impact of urban morphology heterogeneity on land surface temperature in Guangzhou, China. Environmental Modelling & Software, 84, 427–439. https://doi.org/10.1016/j.envsoft.2016.06.021

Guo, G., Wu, Z., Cao, Z. Chen, Y., & Zheng Z. (2021). Location of greenspace matters: a new approach to investigating the effect of the greenspace spatial pattern on urban heat environment. Landscape Ecology, 36, 1533–1548. https://doi.org/10.1007/s10980-021-01230-w

Haq, S. M. A. (2011). Urban green spaces and an integrative approach to sustainable environment. Journal of Environmental Protection, 2, 601–608. https://doi.org/10.4236/jep.2011.25069

Henderson, C.J., Gilby, B.L., Schlacher, T.A., Connolly, R.M., Sheaves, M., Maxwell, P.S., Flint, N., Borland, H.P., Martin, T.S.H., Gorissen, B., & Olds, A.D. (2020). Landscape transformation alters functional diversity in coastal seascapes. Ecography, 43, 138-148. https://doi.org/10.1111/ecog.04504

Hu, R., Luo, J. M., Li, Y., Wang, L., Ma, J., Henriques, D., & Coetzee, W. (2020). Qualitative study of green resort attributes - A case of the crosswaters resort in China. Cogent Social Sciences, 6(1), 1742525. https://doi.org/10.1080/23311886.2020.1742525

Hunter, A. J., & Luck, G. W. (2015). Defining and measuring the social-ecological quality of urban greenspace: A semi-systematic review. Urban Ecosystems, 18(4), 1139–1163. https://doi.org/10.1007/s11252-015-0456-6

Ignatieva, M., & Mofrad, F. (2023). Understanding urban green spaces typology's contribution to comprehensive green infrastructure planning: A study of Canberra, the national capital of Australia. Land, 12(5), 950. https://doi.org/10.3390/land12050950

Islam, M. R., Talukdar, S., Rihan M., & Rahman A. (2024). Evaluating cooling effect of blue-green infrastructure on urban thermal environment in a metropolitan city: Using geospatial and machine learning techniques. Sustainable Cities and Society, 113, 105666. https://doi.org/10.1016/j.scs.2024.105666

Jay, M., & Schraml, U. (2009). Understanding the role of urban forests for migrants–uses, perception and integrative potential. Urban Forestry & Urban Greening, 8(4), 283-294. https://doi.org/10.1016/j.ufug.2009.07.003

Jerome, G., Sinnett, D., Burgess, S., Calvert, T., & Mortlock, R. (2019). A framework for assessing the quality of green infrastructure in the built environment in the UK. Urban Forestry and Urban Greening, 40, 174–182. https://doi.org/10.1016/j.ufug.2019.04.001

Jones, L., Anderson, S., Læssøe, J., Banzhaf, E., Jensen, A., Bird, D.N., Miller, J., Hutchins, M.G., Yang, J., Garrett, J., Taylor, T., Wheeler, B.W., Lovell, R., Fletcher, D., Qu, Y., Vieno, M., & Zandersen, M. (2022). A typology for urban Green Infrastructure to guide multifunctional planning of nature-based solutions. Nature-Based Solutions, 2,100041. https://doi.org/10.1016/j.nbsj.2022.100041

Kaczyńska, M. (2020). The church garden as an element improving the quality of city life – A case study in Warsaw. Urban Forestry & Urban Greening, 54, 126765. https://doi.org/10.1016/j.ufug.2020.126765

Khodadad, M., Aguilar-Barajas, I., & Khan, A. Z. (2023). Green infrastructure for urban flood resilience: A review of recent literature on bibliometrics, methodologies, and typologies. Water, 15(3), 523. https://doi.org/10.3390/w15030523

Kimpton, A. (2017). A spatial analytic approach for classifying greenspace and comparing greenspace social equity. Applied Geography, 82, 129–142. https://doi.org/10.1016/j.apgeog.2017.03.016

Koroso, N.H., & Zevenbergen, J.A. (2024). Urban land management under rapid urbanization: Exploring the link between urban land policies and urban land use efficiency in Ethiopia. Cities, 153, 105269. https://doi.org/10.1016/j.cities.2024.105269

Kronenberg, J., Haase, A., Łaszkiewicz, E., Antal, A., Baravikova, A., Biernacka, M., Dushkova D., Filčak, R., Haase, D., Ignatieva, M., Khmara, Y., Niţă, M.R., & Onose, D.A. (2020). Environmental justice in the context of urban green space availability, accessibility, and attractiveness in postsocialist cities. Cities, 106, 102862. https://doi.org/10.1016/j.cities.2020.102862

Kruja, S., Braçe, O., Garrido Cumbrera, M., & Kokthi, E. (2024). Exploring the mediating role of physical activity in the relationship between green space exposure and well-being: Results from the AUGS Survey. Landscape Online, 99, 1126. https://doi.org/10.3097/lo.2024.1126

leBrasseur R. (2022). Linking human wellbeing and urban greenspaces: Applying the SoftGIS tool for analyzing human wellbeing interaction in Helsinki, Finland. Frontiers in Environmental Science, 10, 950894. https://doi.org/10.3389/fenvs.2022.950894

Lis, M. (2001). Górny Śląsk: zarys dziejów do połowy XX wieku. Wydawnictwo Uniwersytetu Opolskiego, Opole.

Maes, M.J.A. (2021). Connecting science with policy for sustainable development of urban ecosystems [Doctoral dissertation, University College of London]. UCL Discovery. https://discovery.ucl.ac.uk/id/eprint/10138575/

Mabon, L., & Shih, W-Y. (2021). Urban greenspace as a climate change adaptation strategy for subtropical Asian cities: A comparative study across cities in three countries. Global Environmental Change, 68, 102248. https://doi.org/10.1016/j.gloenvcha.2021.102248

Mundher, R., Abu Bakar, S., Maulan, S., Mohd Yusof, M.J., Al-Sharaa, A., Aziz, A., & Gao, H. (2022). Aesthetic Quality Assessment of Landscapes as a Model for Urban Forest Areas: A Systematic Literature Review. Forests, 13, 991. https://doi.org/10.3390/f13070991

Myga-Piątek, U., Żemła-Siesicka, A., Pukowiec-Kurda, K., Sobala, M., & Nita, J. (2021). Is there urban landscape in metropolitan areas? An unobvious answer based on Corine Land Cover analyses. Land, 10(1), 51. https://doi.org/10.3390/land10010051

Head Office of Geodesy and Cartography. (2024). National Geoportal. Retrieved July 4, 2024, from https://www.geoportal.gov.pl/

Neuenschwander, N., Hayek, U.W., & Grêt-Regamey, A. (2014). Integrating an urban green space typology into procedural 3D visualization for collaborative planning. Computers Environment and Urban Systems, 48, 99–110. https://doi.org/10.1016/j.compenvurbsys.2014.07.010

Nordh, H., Evensen, K. H., & Skår, M. (2017). A peaceful place in the city—A qualitative study of restorative components of the cemetery. Landscape and Urban Planning, 167, 108–117. https://doi.org/1016/j.landurbplan.2017.06.004

Pałubska, K. (2012). Method for Assessing Recreational Usability of Complex Cultural Landscape Structures in Highly Urbanized Environments. Architektura Krajobrazu, 3, 22–36.

Pancewicz, A., Tadla, N., Janikowska, W., & Wawrzonowska, K. (2021). Wpływ działań rewitalizacyjnych na zmianę wizerunku oraz jakość życia w miastach rdzenia Górnośląsko-Zagłębiowskiej Metropolii. Builder, 285(4), 39–41. https://doi.org/10.5604/01.3001.0014.7832

Panduro, T.E., & Lausted Veie, K. (2013). Classification and valuation of urban green spaces—A hedonic house price valuation. Landscape and Urban Planning, 120, 119-128. https://doi.org/10.1016/j.landurbplan.2013.08.009

Pueffel, C., Haase, D., & Priess, J. A. (2018). Mapping ecosystem services on brownfields in Leipzig, Germany. Ecosystem Services, 30, 73–85. https://doi.org/10.1016/j.ecoser.2018.01.011

Pukowiec-Kurda, K., & Vavrouchová, H. (2020). Land cover change and landscapes transformations (2000–2018) in the rural municipalities of the Upper Silesia-Zagłębie metropolis. Sustainability, 12(23), 9911. https://doi.org/10.3390/su12239911

Pukowiec-Kurda, K., 2022. The urban ecosystem services index as a new indicator for sustainable urban planning and human well-being in cities. Ecological Indicators 144, 109532. https://doi.org/10.1016/j.ecolind.2022.109532

Pytel, S., Sitek, S., Chmielewska, M., Zuzańska-Żyśko, E., Runge, A., & Markiewicz-Patkowska, J. (2021). Transformation Directions of Brownfields: The Case of the Górnośląsko-Zagłębiowska Metropolis. Sustainability, 13(4), 2075. https://doi.org/10.3390/su13042075

Ritchie, H., Samborska, V., Roser, M. (2024). Urbanization. Retrieved August 7, 2024, from https://ourworldindata.org/urbanization

Romero-Duque, L.P., Trilleras, J.M., Castellarini, F., & Quijas, S. (2020). Ecosystem services in urban ecological infrastructure of Latin America and the Caribbean: How do they contribute to urban planning? Science of The Total Environment, 728,138780 https://doi.org/10.1016/j.scitotenv.2020.138780

Rupprecht, C.D.D., & Byrne, J.A., (2014). Informal urban greenspace: A typology and trilingual systematic review of its role for urban residents and trends in the literature. Urban Forestry & Urban Greening, 13(4), 597-611. https://doi.org/10.1016/j.ufug.2014.09.002

Schuster-Olbrich, J.P., Marquet, O., Miralles-Guasch, C., & Arce, L.F. (2024). Spatial patterns and drivers of urban expansion: An exploratory spatial analysis of the Metropolitan Region of Santiago, Chile, from 1997 to 2013. Cities, 153, 105305. https://doi.org/10.1016/j.cities.2024.105305

Šiftová, J. (2021). Shaping the urban home garden: Socio-ecological forces in the management of private green spaces. Land Use Policy, 111, 105784. https://doi.org/10.1016/j.landusepol.2021.105784

Sikorska, D., Łaszkiewicz, E., Krauze, K., & Sikorski, P. (2020). The role of informal green spaces in reducing inequalities in urban green space availability to children and seniors. Environmental Science & Policy, 108, 144-154. https://doi.org/10.1016/j.envsci.2020.03.007

Sun, L., Chen, J., Li, Q., & Huang, D. (2020). Dramatic uneven urbanization of large cities throughout the world in recent decades. Nature Communications, 11, 5366. https://doi.org/10.1038/s41467-020-19158-1

Smith, M. (2018). Statistical Analysis Handbook. The Winchelsea Press, Drumlin Security Ltd, Edinburgh.

Statistics Poland. (2024). Local Data Bank. Retrieved August 7, 2024, from https://bdl.stat.gov.pl/BDL/start

Head Office of Geodesy and Cartography. (2024). PZGiK Portal. 2024. Database of Topographic Objects. Retrieved July 7, 2024, from https://pzgik.wodgik.katowice.pl/bdot10k

Sztubecka, M., Maciejko, A., & Skiba, M. (2022). The Landscape of the Spa Parks Creation through Components Influencing Environmental Perception Using Multi-Criteria Analysis. Sustainability, 14(9), 5657. https://doi.org/10.3390/su14095657

United Nations. (2017). World Urbanization Prospects: The 2018 Revision. Retrieved August 7, 2024, from https://population.un.org/wpp/

Vidal, D.G., Dias, R.C., Patoilo Teixeira, C., Oliveira Fernandes, C., Filho, W.L., Barros, N., & Maia R.L. (2022). Clustering public urban green spaces through ecosystem services potential: A typology proposal for place-based interventions. Environmental Science & Policy, 132, 262-272. https://doi.org/10.1016/j.envsci.2022.03.002

Wali, B., Frank, L.D., Chapman, J., & Fox, E.H. (2024). Role of walkability, bike infrastructure, and greenspace in combatting chronic diseases: A heterogeneous ecological analysis in the United States. Sustainable Cities and Society, 113, 105550. https://doi.org/10.1016/j.scs.2024.105550

Ward, J. H. (1963). Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, 58(301), 236–244. https://doi.org/10.1080/01621459.1963.10500845

Wassenberg, C. L., Goldenberg, M. A., & Soule, K. E. (2015). Benefits of botanical garden visitation: A means-end study. Urban Forestry and Urban Greening, 14(1), 148–155. https://doi.org/10.1016/j.ufug.2015.01.002

Weerasuriya, R., Henderson-Wilson, C., & Townsend, M. (2019). A systematic review of access to green spaces in healthcare facilities. Urban Forestry & Urban Greening, 40, 125–132. https://doi.org/10.1016/j.ufug.2018.06.019

Włodarczyk-Marciniak, R., Sikorska, D., Krauze, K. (2020). Residents' awareness of the role of informal green spaces in a post-industrial city, with a focus on regulating services and urban adaptation potential. Sustainable Cities and Society, 59,102236. https://doi.org/10.1016/j.scs.2020.102236

Wu, S., Chen, B., Webster, C., Xu, B., & Gong, P. (2023). Improved human greenspace exposure equality during 21st century urbanization. Nature Communications, 14(1), 6460. https://doi.org/10.1038/s41467-023-41620-z

Yang, G., Yu, Z., Jørgensen, G., & Vejre, H. (2020). How can urban blue-green space be planned for climate adaption in high-latitude cities? A seasonal perspective. Sustainable Cities and Society, 53, 101932. https://doi.org/10.1016/j.scs.2019.101932

Young, R., Zanders, J., Lieberknecht, K., & Fassman-Beck, E. (2014). A comprehensive typology for mainstreaming urban green infrastructure. Journal of Hydrology, 519, 2571–2583. https://doi.org/10.1016/j.jhydrol.2014.05.048

Zinia, N.J., & McShane, P. (2021). Urban ecosystems and ecosystem services in megacity Dhaka: mapping and inventory analysis. Urban Ecosystems, 24(5), 915–928. https://doi.org/10.1007/s11252-020-01076-1

Zhao, Y., van den Berg, P. E. W., Ossokina, I. V., & Arentze, T. A. (2024). How do urban parks, neighborhood open spaces, and private gardens relate to individuals' subjective well-being: Results of a structural equation model. Sustainable Cities and Society, 101, 105094. https://doi.org/10.1016/j.scs.2023.105094

Zuzańska-Żyśko, E. (2012). Funkcje metropolitalne w Górnośląskim Obszarze Metropolitalnym. Studia Regionalne i Lokalne, 13(48), 39–61.

Zwierzchowska I. (2008). Zróżnicowanie stopnia fragmentacji terenów zieleni w miastach Wielkopolski. Problemy Ekologii Krajobrazu 22, 79-88.