CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

CLASSIFICATION OF FUNCTIONAL ELEMENTS OF GREEN INFRASTRUCTURE AS KEY INDICATORS OF SUSTAINABLE DEVELOPMENT IN RESIDENTIAL AREAS OF GREEN CITIES: EVIDENCE FROM OLSZTYN IN NORTHEAST POLAND

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A b s t r a c t

Residential green spaces are one of the key factors determining the quality of life for urban inhabitants, as well as an important element of the functional and spatial structure of cities. Their presence within the system of urban green and blue infrastructure contributes to improving microclimatic conditions, increasing water retention, and enhancing biodiversity, making them a vital aspect of sustainable urban development. Unfortunately, there is a lack of studies classifying green infrastructure elements in green cities, which motivated the authors to undertake this particular research topic. This study analyzes the types and forms of residential greenery from a functional and spatial perspective and assesses the degree of green space development based on three residential districts of Olsztyn: Jaroty, Pojezierze, and Kormoran. The specific objective of the research was to identify areas with development potential for green infrastructure within the studied residential neighborhoods and to provide corresponding recommendations. The research involved classifying greenery according to its functions, evaluating its accessibility, and assessing its integration with the built environment. Methods employed included spatial analysis, field surveys, observation, and both qualitative and quantitative evaluations of residential greenery. The results indicate a varied level of functional diversity and accessibility of green spaces across the studied neighborhoods. Based on the findings, recommendations were made to improve the management of green spaces, including the introduction of new green areas, supplementation of existing ones, and modification of their functions.

Keywords: functional structure, green space management, biodiversity, residential areas, spatial analysis

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1. INTRODUCTION

Contemporary cities face numerous challenges resulting from intensive urbanization, climate change, and spatial transformations. The "dense" development of residential areas (Veal and Piracha 2022, Nancy and Hafiz 2023), population growth (McGuirk and Argent 2011, Profiroin et. al. 2020, Braga 2024), and the expansion of transport infrastructure (Braçe 2018, Yannis and Chaziris 2022) are leading to a reduction in the amount of green space, which negatively affects residents' quality of life (Stanković 2024). In response to these challenges, urban spatial planning policies are increasingly embracing the concepts of green and blue infrastructure, which recognize the importance of green areas and water systems in improving urban functionality (Kimic and Ostrysz 2021, Czyża and Kowalczyk 2024, Zabel and Häusler 2024). Residential greenery constitutes a vital component of this infrastructure, playing a key role in creating a friendly and healthy living environment. The significance of residential green spaces for residents is multidimensional. First, they have a major impact on both physical and mental health. Research shows that the presence of green areas in the immediate vicinity of homes promotes physical activity, reduces stress, and improves overall well-being (Bertram and Rehdanz 2015, Krekel et al. 2016). Greenery also acts as an air filter, absorbing harmful substances and reducing noise levels an especially critical function in densely built-up urban areas (Aleksejeva et al. 2024). Secondly, green spaces serve an ecological function by supporting biodiversity and regulating the microclimate of neighborhoods (Fuller and Gaston 2009, McDonald et al. 2023). They mitigate the urban heat island effect and enhance rainwater retention (Hearth and Bai 2024). In the context of climate change adaptation, residential greenery becomes one of the key tools for mitigating the effects of extreme weather events, such as heatwaves or heavy rainfall (Almusaed 2011). Vegetation supports the natural water cycle, reduces the risk of flooding and stormwater system overloads, and contributes to cooling urban spaces during hot days. Furthermore, residential greenery plays an important role in shaping social bonds and fostering community integration (Akshay 2024). Parks, squares, and communal gardens provide spaces conducive to social interaction, recreation, and the organization of local community initiatives.

The literature review has revealed a lack of research addressing the presence and classification of green infrastructure (GI) elements within residential areas of "garden cities." Garden cities are specific urban units that, either wholly or partially, refer to a concept characterized by a significant share of green spaces. The representation of GI elements within such distinctive urban forms is both important and necessary from the perspective of the sustainable development of residential areas in garden cities. Achieving the main research objective will contribute to filling this gap in the current body of knowledge.

The primary aim of the study was to classify GI elements in garden cities and to identify them within the spatial structure of three residential estates differing in urban layout and construction technologies. The specific objective was to determine the areas with development potential for GI within residential neighborhoods using a methodological approach that considers residents' well-being, the functionality of existing GI elements, and the specific spatial characteristics of the estates. Based on this analysis, targeted recommendations were developed.

2. LITERATURE REVIEW

2.1. Green cities – The concept of garden cities

The concept of the garden city represents an attempt to combine the advantages of urban living with close proximity to nature. Its origins date back to the 19th century, when it was introduced and thoroughly described by Ebenezer Howard as a response to the sudden and uncontrolled expansion of cities (Tomczak and Szoszkiewicz 2023). In practice, the term "garden cities" is often used to describe cities, districts, or neighborhoods characterized by a high share of green spaces and designed with recreation and residents' health in mind (Swensen and Berg 2020).

In contrast, green cities represent a contemporary vision of urban environments that coexist harmoniously with nature, where natural elements are an integral part of the urban fabric (Breuste et al. 2020). Special attention is paid to biodiversity, ecosystem services, sustainable resource management, and the broader pursuit of sustainable development goals (Tappert et al. 2018; Ritesh and Mohammed 2021; Breuste 2022).

Both concepts emphasize the significant role of green spaces in urban infrastructure and their impact on enhancing residents' quality of life.

2.2 Residential Greenery in the Context of Urban Spatial Development

Residential greenery fulfills many important functions that affect both residents' quality of life and the functioning of urban ecosystems. Several key roles of greenery in residential areas can be distinguished, including ecological, social, aesthetic, and recreational functions. Urban greenery improves air quality, reduces the urban heat island effect, increases rainwater retention, and supports biodiversity by providing habitats for many plant and animal species. Vegetation helps regulate the microclimate by shading spaces, reducing surface heating, and improving air humidity.

Green areas also foster social integration by encouraging social interaction and the building of local communities. They serve as recreational and educational spaces and support mental health by offering environments conducive to relaxation. Greenery enhances the landscape value of neighborhoods, giving them a harmonious and welcoming character. It influences the perception of urban space, making it visually more attractive. Parks, squares, community gardens, and walking paths serve as places for rest and physical activity (Chiesura 2004; Tzoulas et al. 2007; Van den Bosch and Ode Sang 2017; Wolch et al. 2014).

Effective planning of residential greenery requires consideration of both residents' needs and environmental conditions. Several strategies exist for integrating greenery into residential spaces. These include planning multifunctional green areas, applying both traditional and new sustainable solutions, integrating greenery with buildings and infrastructure, adapting to climatic conditions and local needs, and engaging residents in the process. Residential green systems form an integral part of a city's ecological structure, contributing to improved quality of life, enhanced biodiversity, and better microclimate regulation (Taylor and Hochuli 2017). Contemporary academic literature widely analyzes the role of greenery in urban planning, emphasizing its ecosystem, health, and social functions (Akpinar 2016). Residential greenery is a component of urban green space and refers to the layout of green areas found within residential zones.

According to classifications used in urban planning and spatial design, the main types of green spaces within residential areas include:

- Managed green spaces, e.g., neighborhood parks, squares, private gardens;
- Unmanaged green spaces, e.g., natural vegetation enclaves, extensively used areas;
- Elements of green infrastructure, such as green roofs, vertical gardens, and buffer green belts.

Residential green systems are a crucial element of urban spatial planning, offering numerous ecological, social, and economic benefits. Their development should be prioritized in the context of increasing urbanization and climate change. Despite the many benefits of residential greenery, its development faces several challenges, such as limited space, competition with built infrastructure, and a lack of long-term green space management strategies. Future research should focus on identifying new methods for integrating greenery into the urban fabric and improving management strategies, including the use of GIS technology for optimizing green space planning and the large-scale implementation of Nature-based Solutions (NbS).

2.3. Impact of Residential Green Systems on Quality of Life in Cities

Studies indicate that access to green spaces near residential areas has a significant impact on quality of life (Van den Bosch Ode Sang 2017). Benefits include improvements in mental health, stress reduction, and increased physical activity among residents. Residential green systems significantly contribute to quality of life in cities by improving health, reducing pollution, regulating the microclimate, and strengthening social bonds. One of the key elements in the approach to sustainable development and enhancing residents' quality of life is biophilia, the concept of humans' natural tendency to connect with nature. This theory was popularized by American biologist Edward O. Wilson in the 1980s. He argued that over millions of years of evolution, humans adapted to natural environments, which made their mental and physical well-being strongly connected to interaction with nature (Beatley 2011; Jaszczak et al. 2020). In the context of residential greenery, this means designing residential spaces that promote integration with nature. Research indicates that the presence of vegetation near residential areas reduces stress, improves mood, and increases the sense of safety. Green spaces encourage physical activity, walking, and social interaction, which fosters human connections and improves quality of life (Bertram and Rehdanz 2015; McCormick 2017). Increasing urbanization necessitates the implementation of policies promoting the development of green spaces and efficient management strategies. Future research should focus on optimizing urban greenery design and assessing the long-term effects of its presence in residential neighborhoods.

2.4. Challenges in Planning and Establishing Residential Green Spaces in Cities

Residential green spaces play a key role in shaping urban spaces and significantly influence the quality of life of residents. Proper planning of green areas contributes to improving the microclimate, reducing noise, as well as fostering social integration and recreation (Kabisch et al. 2015; Kabisch et al. 2016; Jim and Chen 2009). However, this process encounters a number of challenges resulting from spatial, legal, and economic limitations. One of the biggest challenges in planning residential green spaces is the limited space available in densely built urban areas. Intensive urbanization leads to a reduction in the area designated for green spaces, with the priority being to maximize space for residential and commercial buildings (Wolch et al. 2014). Dense development often results in residential greenery being limited to small squares or passageways between buildings, which do not fully meet their intended function optimally (Palliwoda et al. 2020).

Planning green spaces in cities often faces legal and administrative obstacles. Ambiguous regulations concerning the standards for green space per resident and the lack of uniform guidelines in this matter lead to an uneven distribution of green areas across different districts (Haase et al. 2017). Furthermore, lengthy permit procedures and the need to adapt plans to local zoning regulations hinder

the swift implementation of new green space projects. Financing residential green spaces is another challenge. The costs of acquiring land, developing it, and maintaining these spaces are high, and municipal budgets often do not allocate sufficient funds for such investments (Lennon 2015). Private developers, who dominate the creation of modern neighborhoods, often view green spaces as an additional cost rather than as an integral element of urban planning.

As previously mentioned, residential green spaces play essential ecosystem functions, such as air filtration, water retention, and protection from excessive urban heat (Gill et al. 2007). However, a lack of environmental awareness and low community participation in the planning process can lead to the creation of green areas that do not meet residents' needs (Buijs et al. 2016). Moreover, in some cases, poor management of these spaces results in neglected greenery that is ill-suited for everyday use.

Therefore, planning residential green spaces in cities is a complex process that requires collaboration between urban planners, city authorities, and residents. Overcoming the challenges related to space, legal regulations, financing, and community engagement is crucial to ensuring the sustainable and functional development of cities. The introduction of new strategies, such as green roofs, pocket parks, or adaptive management of green areas, could contribute to improving the quality of life in urban environments (Aronson et al. 2017). Beyond planning, the subsequent maintenance of green spaces is crucial; integrated systems utilizing data from national databases can also facilitate effective urban green space management (Dawidowicz et al. 2022).

A sustainable strategy for managing urban green spaces is considered to involve both the preservation and maintenance of existing areas and the parallel development of new spaces characterized, among other features, by high biodiversity (Jim 2013). Contemporary models of green space management primarily encompass aspects such as public participation, expert involvement, and the establishment of long-term management plans (Battisti et al. 2023). To enhance the effectiveness of management processes, it is recommended to implement smart systems that optimize resource usage through the application of advanced technologies (Ababneh 2023). The adoption of a sustainable strategy can significantly reduce management costs while improving the performance and efficiency of green areas (Pantaloni et al. 2022). An alternative perspective on green space management emphasizes goal-oriented approaches, allowing for the prioritization of actions; however, the success of such an approach largely depends on the availability of data resources (Rambhai et al. 2024).

3. RESEARCH METHODOLOGY

3.1. Study area

Three residential districts within the city of Olsztyn were selected as the study area: Jaroty, Kormoran, and Pojezierze. Olsztyn is a provincial city and the capital of the Warmian-Masurian Voivodeship. It is located in northeastern Poland, specifically in the center of the region defined as the Olsztyn Lakeland, which forms part of the Masurian Lake District. The city is situated on the Łyna River, and its origins date back to 1353, when it was granted municipal rights (Kondracki, 1998). Each of these districts differs in terms of urban structure. The primary criteria for their selection among other neighborhoods in Olsztyn included a high degree of land development for residential and service purposes, as well as their spatial location within the city layout. Accordingly, Jaroty was chosen as a district characterized by a significant share of both multi-family and single-family housing; Kormoran as an area dominated by multi-family housing built primarily in the 1970s and 1980s; and Pojezierze, which features a predominance of single-family housing but also includes a substantial portion of industrial areas located in its eastern part. The location of these districts within the city boundaries is illustrated in Figure 1.
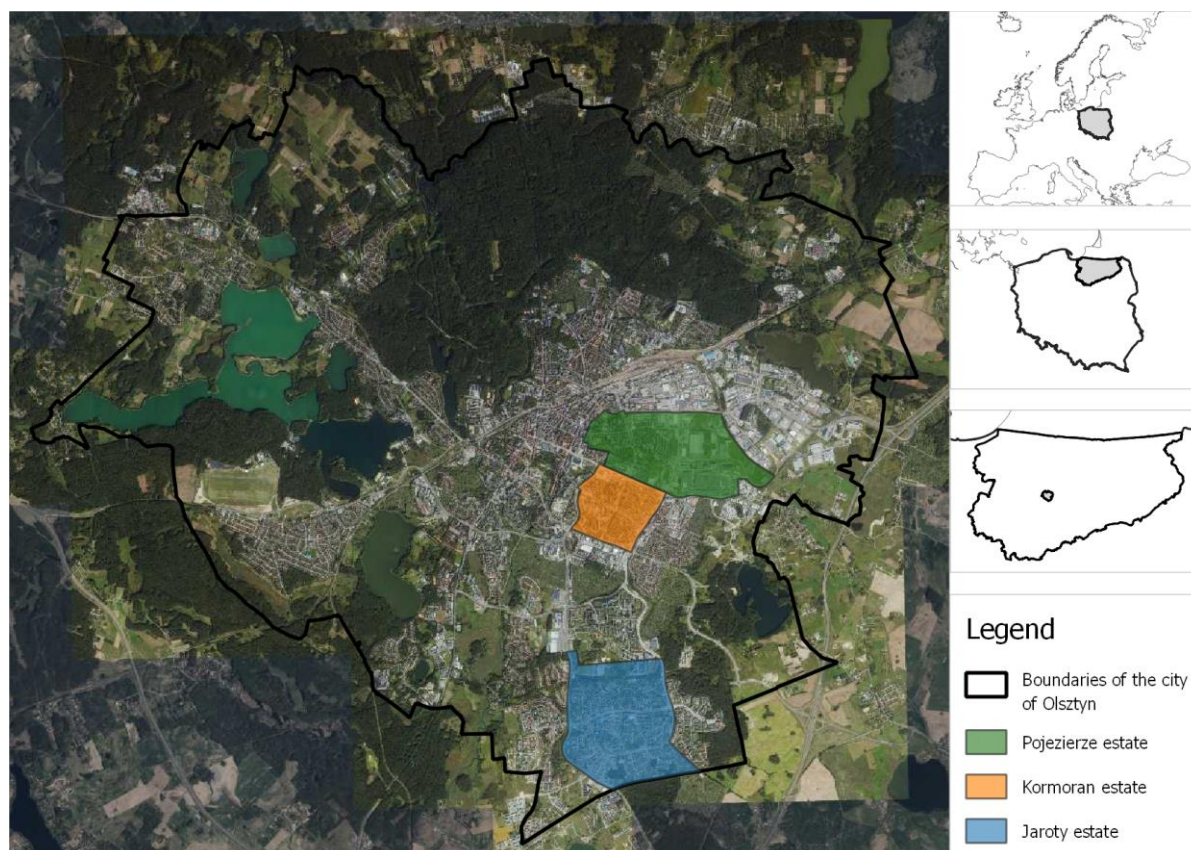
Fig. 1. Location of the analyzed housing estates within the city of Olsztyn

The study employed spatial analysis, field observations, and both qualitative and quantitative assessments of residential green spaces. The initial field analyses were conducted in November 2024. They allowed for the identification of specific areas for further investigation. The next stage involved determining the functions of green spaces in the selected areas. Field analyses and mapping were subsequently carried out during March and April 2025. A key stage of the research involved defining the classification of specific areas according to an adopted functional division of green spaces. This process was conducted using QGIS 3.22 software, where the QIS Support plugin was used to download a standard-resolution orthophotomap. The classification of land categories was carried out in three main stages. The first stage consisted of importing spatial data layers available through public geospatial data services. These included polygon layers representing land cover types as defined in the Topographic Object Database (BDOT). The land cover categories comprised: built-up areas, transportation infrastructure, forested or wooded areas, grass vegetation and agricultural land, paved surfaces, surface waters, permanent crops, and other undeveloped land. The second stage focused on a detailed analysis of green space functions through the digitization of the orthophotomap within district boundaries. Polygon layers were created based on a predefined classification system, which included the following categories: green spaces adjacent to multi-family housing (residential green areas near apartment blocks); green spaces adjacent to single-family housing (private gardens); public parks, greens, and squares; green areas associated with cultural, service, and commercial facilities; green areas around industrial sites; green strips along transportation corridors; allotment gardens; and unmanaged or

uncategorized green areas. During this stage, over 1,700 polygons were created, enabling further analyses. For all polygon layers both those imported from BDOT and those created during the analysis the surface area was calculated. The results were aggregated according to category and compared by calculating the percentage share occupied by each type of land cover or green space function. The third and final stage involved formulating recommendations regarding the condition and development of green spaces. This included assessing their accessibility, identifying the need for functional modifications, and proposing the creation or enhancement of a network of green corridors connecting individual green spaces to facilitate user movement.

4. RESULTS

Within the boundaries of the selected residential districts, land cover types as categorized in the BDOT exhibit considerable variation. In all categories and across all districts, built-up areas are dominant, ranging from 43% to 56% of total area. The distribution of other land cover types varies depending on the specific characteristics of each district and the nature of its built environment. In terms of overall land coverage, the proportion of green spaces is relatively consistent across all districts, ranging between 30% and 33% (see Table 1).

Table 1. Percentage share of land cover forms in the total area of the housing estates based on BDOT data

Estate	Built-up areas	Roads and transportation areas	Green spaces	Public squares	Surface waters	Other areas
Jaroty	57,60%	7,82%	30,49%	3,55%	0,34%	0,20%
Kormoran	43,02%	13,91%	31,59%	11,48%	0,00%	0,00%
Pojezierze	52,65%	3,60%	32,70%	8,03%	1,27%	1,75%

A detailed analysis of land use and specific land cover types was carried out based on the categorization of green space functions within the selected residential districts. The analysis revealed that the proportions of individual land cover types differ significantly from the results obtained using data from the BDOT. Most notably, a lower proportion of built-up areas and a substantially higher share of green spaces was observed. This discrepancy is attributed to the application of an alternative land classification system, in which only the surface area outlined by building footprints based on BDOT data was counted as built-up land. The remaining areas (previously categorized as built-up) were reassigned to more specific functional categories developed for the purposes of this study. These refined categories provide a more accurate representation of actual land use functions.

The calculated percentage share of different land cover types indicates that green spaces constitute the largest proportion of land use across the analyzed districts: 47% in Pojezierze, 49% in Kormoran, and as much as 61% in Jaroty (see Table 2). Variations were also evident in other functional categories, with the most pronounced differences observed in transportation-related areas ranging from 6% in

Pojezierze to 15–16% in the remaining districts. A notable share was also recorded in the hardened surface category, which includes areas designated for parking, paved squares, wide pedestrian routes, and minor roads. In this category, the lowest share was found in Jaroty (11.5%), while the remaining districts showed similar values (Kormoran – 22.5%, Pojezierze – 24%).

Table 2. Percentage share of land cover forms in the total area of the housing estates based on own analyses

Estate	Built-up areas	Roads and transportation areas	Green spaces	Paved areas	Surface waters
Jaroty	11,5%	15,4%	61,3%	11,5%	0,3%
Kormoran	11,9%	16,1%	49,4%	22,5%	0,0%
Pojezierze	21,4%	6,1%	47,0%	24,2%	1,3%

4.1. Analysis of Residential Districts in Olsztyn in Terms of Green Space Development and Green Space Functions

Eight categories of green space functions were identified as part of the analysis. The examined residential districts in Olsztyn differ in the proportion of green spaces within their total area, though this share is consistently high across all cases. However, these green areas serve various functions, including recreational, leisure, and decorative (representative) purposes. The adopted classification allows for the distinction of green spaces in direct proximity to residential areas, which are of particular importance from the perspective of residents due to their frequent use. Other categories include green areas associated with service or industrial facilities, green strips along transportation corridors, urban parks, as well as lawns and public squares of social significance.

A more detailed analysis further highlights the functional differences between districts. In Jaroty, nearly 36% of all green areas consist of greenery adjacent to multi-family housing, while unmanaged greenery accounts for approximately 29.5%, and private gardens represent nearly 15%. A different pattern emerges in Kormoran, where green spaces adjacent to multi-family housing make up about 55% of the total green area. The next most prominent category is greenery associated with service facilities (23%), followed by roadside greenery (12%). In contrast, Pojezierze presents yet another distribution pattern: here, green spaces associated with industrial facilities represent the largest share (approximately 26%), followed by greenery adjacent to multi-family housing (22.5%) and unmanaged green areas (around 19%) of the total green space (see Table 3).

Table 3. Percentage share of individual green space functions in their total area

Estate	Green spaces							
	Adjacent to multi-family housing	Adjacent to single-family housing	Parks and public squares	Adjacent to service facilities	Adjacent to industrial facilities	Close to the transportation areas	Allotment Gardens	Informal greenery and other
Jaroty	35,91%	14,84%	3,68%	6,70%	0,00%	9,29%	0,06%	29,53%
Kormoran	54,86%	0,00%	4,58%	23,33%	0,00%	12,40%	0,00%	4,82%
Pojezierze	22,55%	0,28%	10,69%	10,76%	26,42%	8,74%	1,84%	18,72%

The highest percentage values for each green space category were highlighted in Table 3. Among the types of green areas considered most desirable in terms of resident usability namely parks, greens, and public squares the results may be deemed unsatisfactory. Although Pojezierze shows a relatively high share for this category (approximately 10.7%), this figure is still insufficient to conclude that the area of the most attractive and accessible green spaces is adequate.

Therefore, recommendations were developed for the analyzed districts, emphasizing the need to enhance the accessibility of green areas, particularly those with the highest recreational and social value.

4.2. Analysis of Green Space Accessibility in Olsztyn from the Perspective of Residents

The accessibility of green areas in the immediate vicinity of one's place of residence is of considerable importance due to its significant impact on quality of life and overall well-being. Furthermore, not only the proximity of green spaces matters, but also their quality, social functions, and the opportunities they provide. The results of the conducted study indicate that the current supply of green areas capable of simultaneously meeting a wide range of needs is insufficient. This is due not only to their limited surface area (particularly in Jaroty and Kormoran), but more importantly to their restricted capacity and limited functional versatility. It is simply not feasible for all residents to make simultaneous use of a single, large recreational space.

The substantial share of unmanaged green areas located near residential buildings such as the spaces between multi-family housing units offers partial compensation for these deficits. However, such areas are generally not sufficiently adapted to perform multiple functions. Therefore, it is essential to enhance the usability of individual green spaces so they become diverse, high-quality green areas, located as close to residences as possible.

A potential solution to this issue is the creation of micro-park spaces situated within residential developments so-called "micro-interiors" which would be linked to larger recreational areas through green corridors.

4.2.1. Recommendations for Neighborhood Green Space Planning in Selected Districts of Olsztyn

Recommendation 1: Integrating Neighborhood Green Spaces with the Urban Ecosystem

The protection and planning of green areas particularly in the context of integrating neighborhood greenery with the broader urban ecosystem requires consideration of various aspects, including connections with existing ecological systems, improving residents' quality of life, and promoting sustainable development. For the districts of Jaroty, Kormoran, and Pojezierze in Olsztyn, which are situated within an urban framework, several key priorities should be addressed.

A beneficial approach involves planning green corridors that connect different types of green spaces (e.g., parks, neighborhood greenery, recreational areas) with larger natural zones such as wooded groves or waterside areas in Olsztyn. Such green linkages can help support biodiversity and enhance

Existing and proposed green pathways integrating residential areas with green spaces
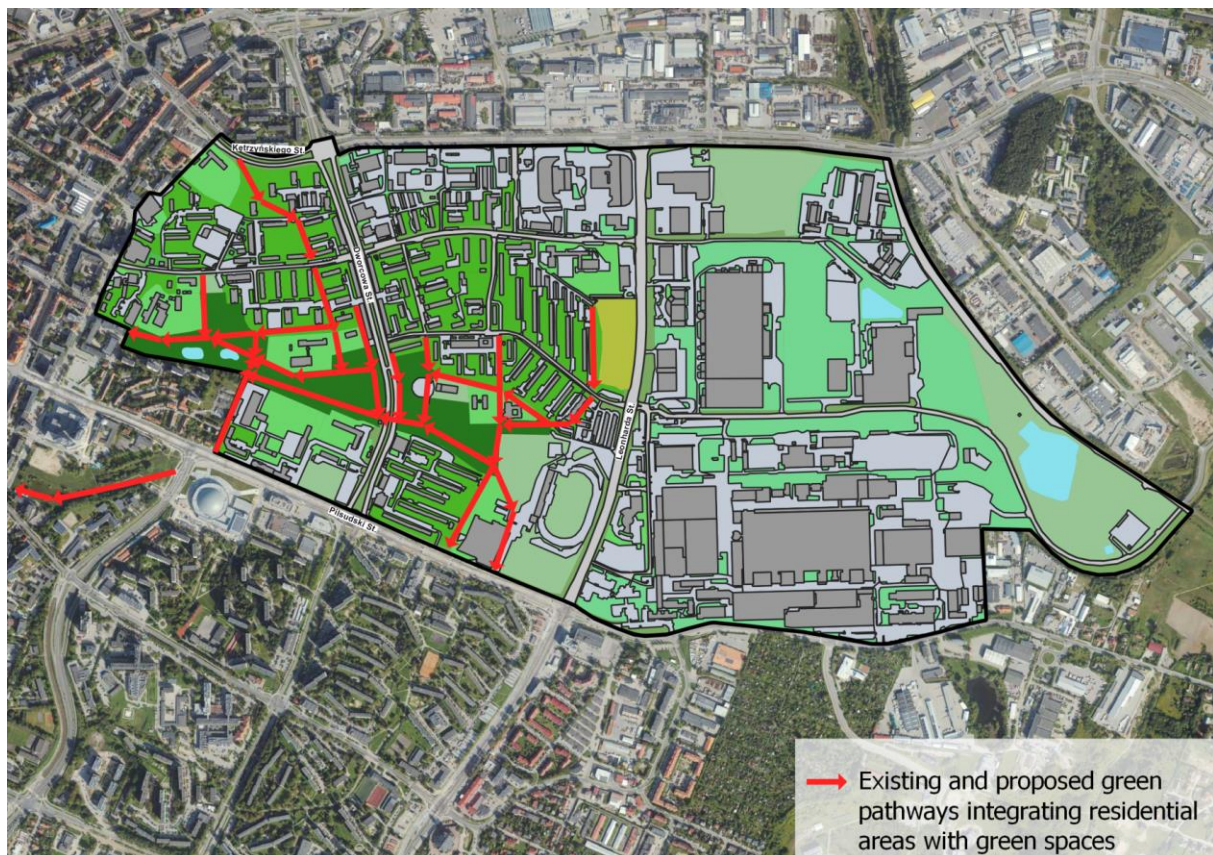
ecological continuity.

Fig. 2. Green corridors in the Pojezierze district

In the Pojezierze district specifically (Fig. 2), the primary recommendations for green corridors involve creating or improving pedestrian infrastructure that links existing neighborhood greenery. Additionally, the development of neighborhood-scale "micro-parks" is proposed, which would be connected to green areas located beyond the boundaries of the district.

The recommendations concerning green corridors in the Kormoran district (Fig. 3) primarily focus on establishing connections between the proposed neighborhood green areas, as well as linking them with green spaces located in adjacent districts.

Fig. 3. Green corridors in the Kormoran district

The green corridors recommended for the Jaroty district (Fig. 4) represent an extension of the existing central pedestrian and green axis, with proposed continuations both southward, reaching into adjacent forested areas, and eastward and westward, in order to establish connections between neighborhood green spaces and larger, unstructured green areas located beyond the district boundaries. Additionally, the creation of branching paths is proposed to enhance access to internal neighborhood green areas and ensure connectivity among smaller green spaces.
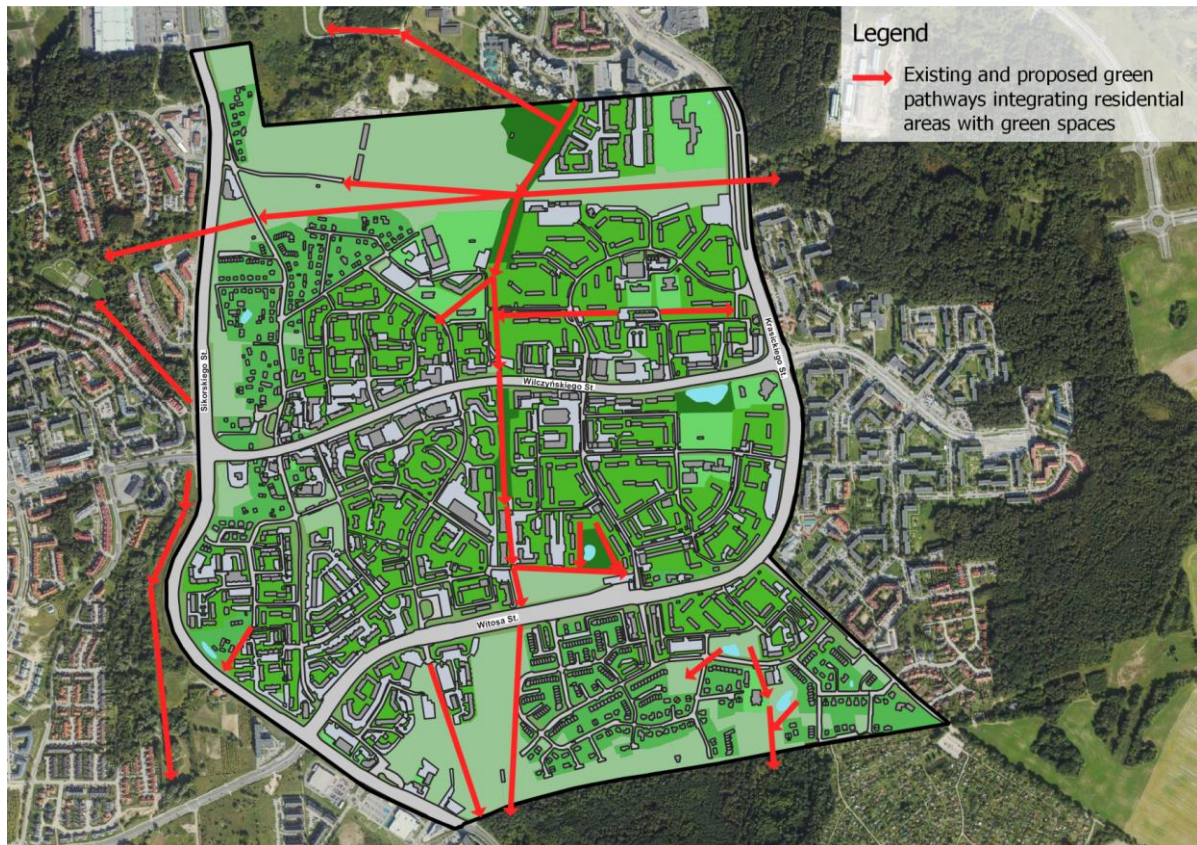
Fig. 4. Green corridors in the Jaroty district

Recommendation 2: Diverse Forms of Greenery Serving Multiple Functions

A variety of green space types such as parks, woodlots, squares, lawns, greenery between multi-family buildings, recreational green spaces, community gardens, pocket parks, areas for physical activity, and playgrounds contribute significantly to improving residents' quality of life and health. Increasing the amount of greenery in public, semi-public, and private spaces enhances environmental quality, which in turn positively affects public health. Dense green structures also act as noise buffers, supporting overall well-being.

Due to the high density of different land uses and surface types, as well as a clear spatial division between residential and industrial zones, the need for more diverse green space forms is particularly evident in certain areas (Fig. 5). The primary recommended intervention is the creation of a green buffer stri, composed of trees and shrub, along Leonharda Street and its intersection with Piłsudski Street, in order to spatially separate the industrial and residential zones. Another key recommendation is the enrichment of existing green forms within the boundaries of the park, especially in the less developed northern and eastern sections. Additionally, similar actions are proposed for two locations in the northern part of the district: near Kętrzyńskiego Street, to enhance landscape diversity and encourage more active use of the area, and near the retention reservoir, to open new opportunities for functional land use.
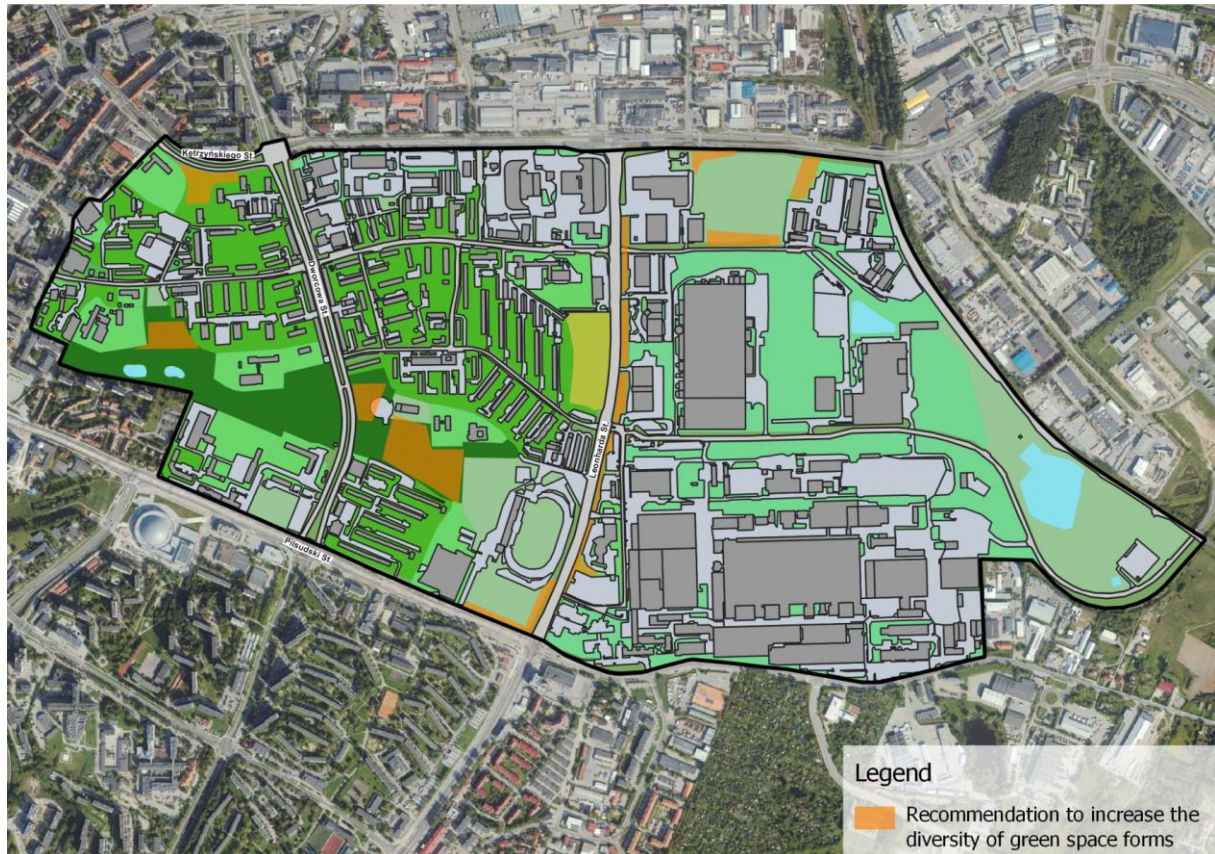
Fig. 5. Areas recommended for the diversification of green space forms in the Pojezierze district

In the case of the existing green spaces in the Kormoran district, minor interventions are proposed (Fig. 6). Some of the areas recommended for changes are located in the centers of building blocks. The goal of these changes would be to diversify the use of these spaces designated for residents by creating neighborhood micro-parks. It is also suggested to establish buffer zones that would separate residential areas from busy transportation arteries.

Fig. 6. Areas recommended for the diversification of green space forms in the Kormoran district

The recommendations for the Jaroty district (Fig. 7) primarily focus on the creation of a green corridor running through the interior of the neighborhood, along with its extensions in the central-eastern and southern areas. The objective is to enhance the attractiveness of the space. Additionally, it is recommended to plan recreational areas and to increase the ecological benefits arising from their function.
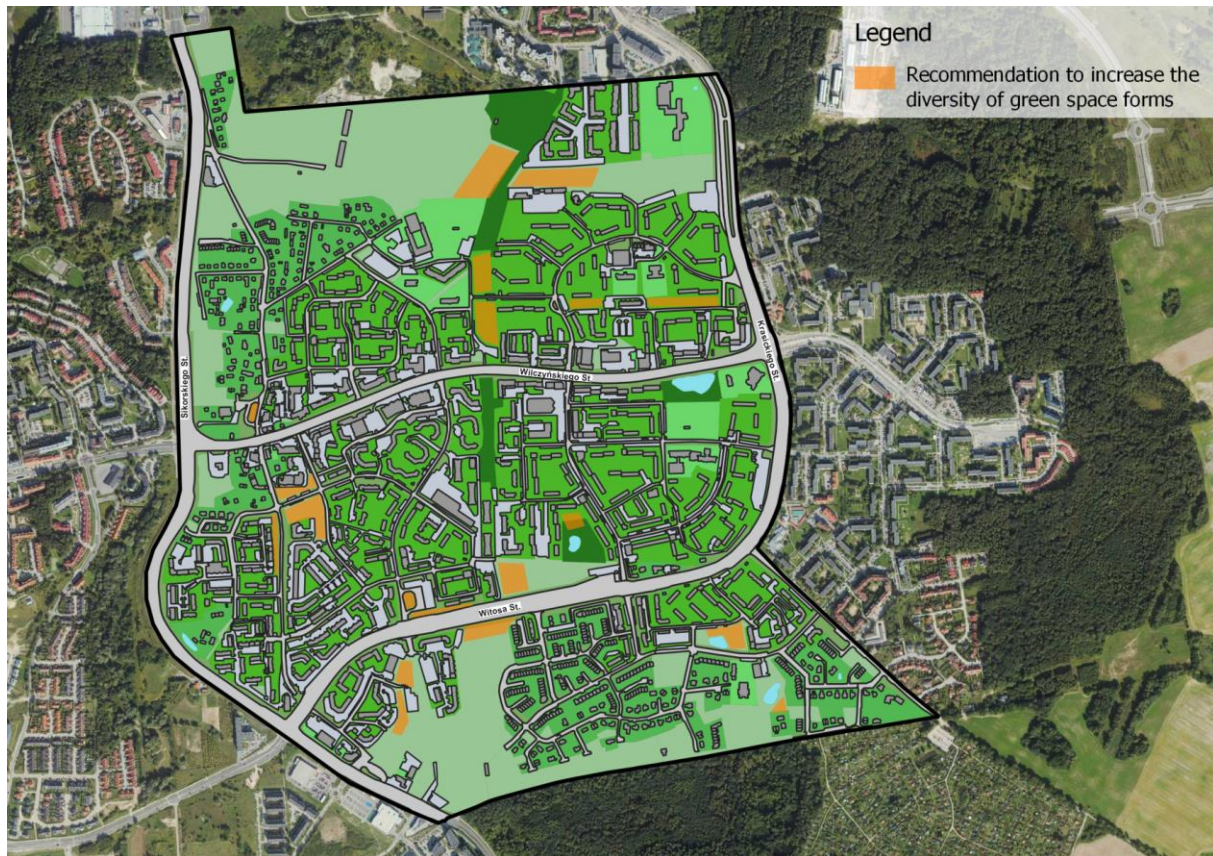
Fig. 7. Areas recommended for the diversification of green space forms in the Jaroty district

Recommendation 3. Accessibility to Neighborhood Green Spaces and Residents' Well-Being

It is crucial that green spaces are easily accessible to residents within a short walking distance. It is worth considering improving access to existing green areas by introducing new pedestrian and cycling paths that connect different parts of the neighborhoods. Creating new micro-parks, squares, and gardens in areas that are distant from the current green spaces may improve the equitable access of residents to nature.

To increase the accessibility of green spaces in the Pojezierze district and to alleviate the pressure on the city park located within its boundaries, which is currently intensively used by residents, it is proposed to enhance the quality of green areas with other functions available within the neighborhood. The areas for which actions are recommended are marked on Fig. 8. These are primarily the northern and eastern parts of the district, due to their lower level of development, resulting in fewer functions and less interest from users. The area in the southern part of the district, adjacent to the park, constitutes an important communication route leading deeper into the neighborhood, and increasing its functionality will allow for closer proximity to high-quality green spaces. The areas in the central and western parts

of the district are green spaces between residential buildings that require improvement in terms of development; enhancing these areas will offer an opportunity to decentralize the park's functions as the most heavily used area. The northeastern part of the district contains a retention basin, which is an area with significant potential for development into a green space with recreational and educational functions. Planning the necessary infrastructure would allow for a change in the function of this area, thus making it available to residents.
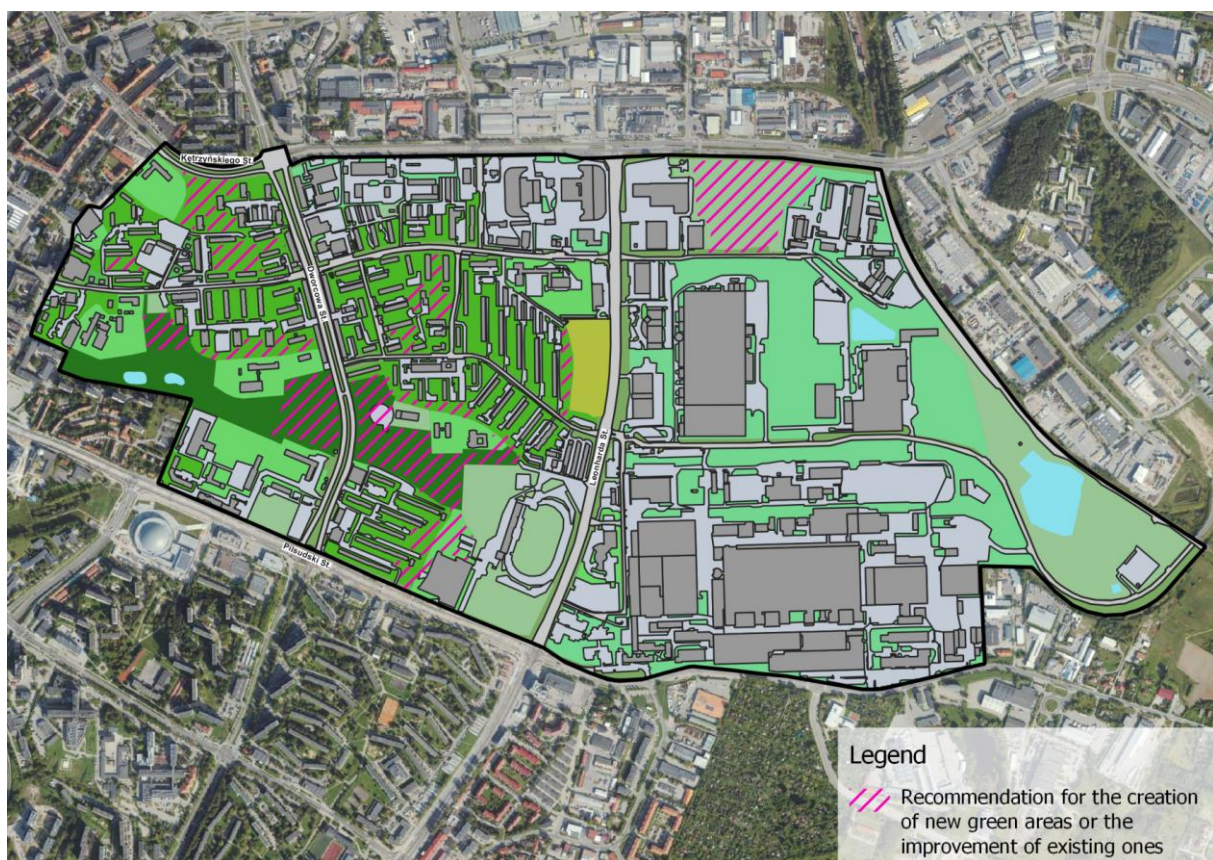

Fig. 8. Areas recommended for increasing the accessibility of green spaces in the Pojezierze district

Within the boundaries of the Kormoran neighborhood, there are not many areas designated as high-quality green spaces (parks, squares, green spaces). Therefore, as part of the recommendations aimed at increasing access to green spaces, changes have been proposed for the central part of each building block (Fig. 9). These actions will increase the potential for using these spaces for recreational purposes. The possibility of changing their function is facilitated by the large distances between buildings and the existing pedestrian paths. Additionally, changes are recommended for the area at the intersection of Pstrowskiego and Dworcowa streets, which could become a square near an important transportation hub.
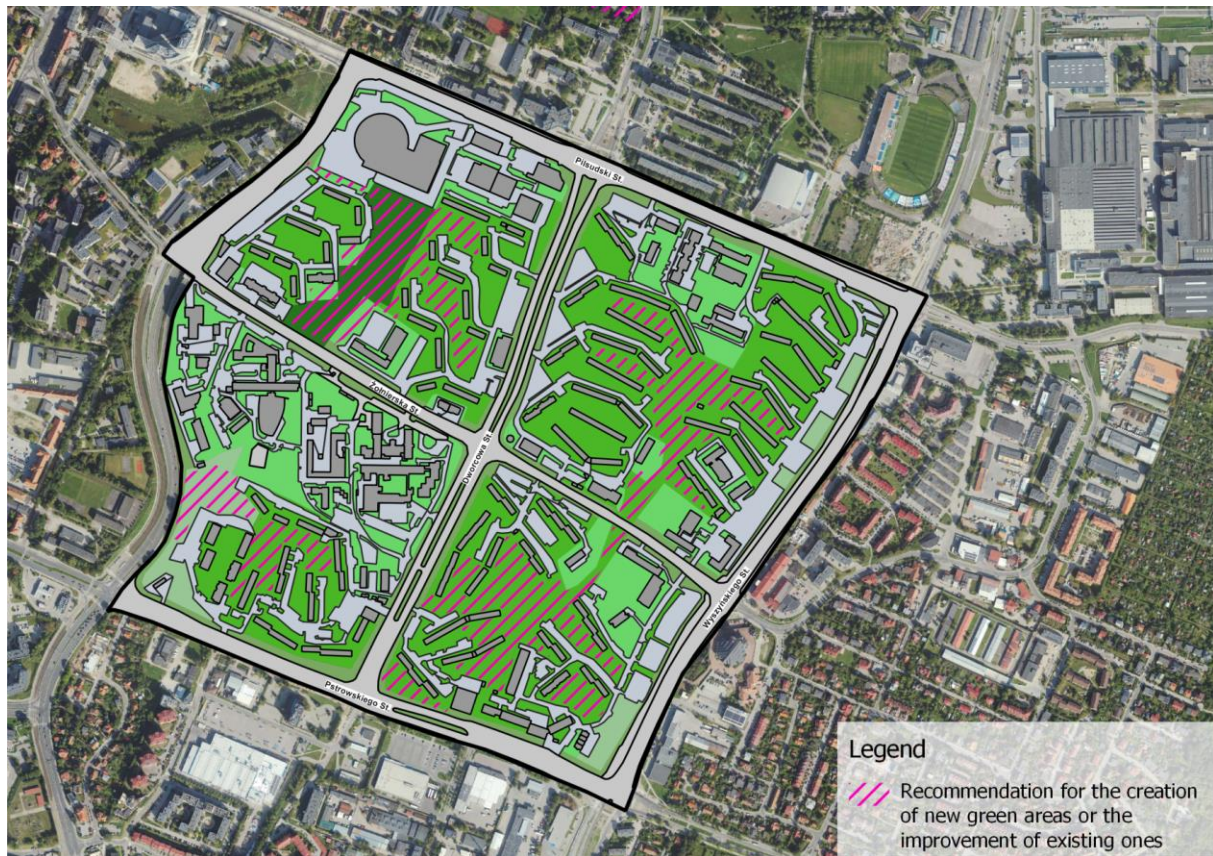
Fig. 9. Areas recommended for increasing the accessibility of green spaces in the Kormoran district

Recommendations for improving accessibility in the Jaroty neighborhood (Fig. 10), despite the large area of land proposed for changes, aim to create a unified park area stretching through the central part of the neighborhood and extending into the residential areas in its northern and southern parts. This would significantly improve accessibility, particularly due to the possibility of connecting this park system with areas located outside the boundaries of the neighborhood. It is also recommended to create micro-parks within individual parts of the neighborhood to further balance access to green spaces.
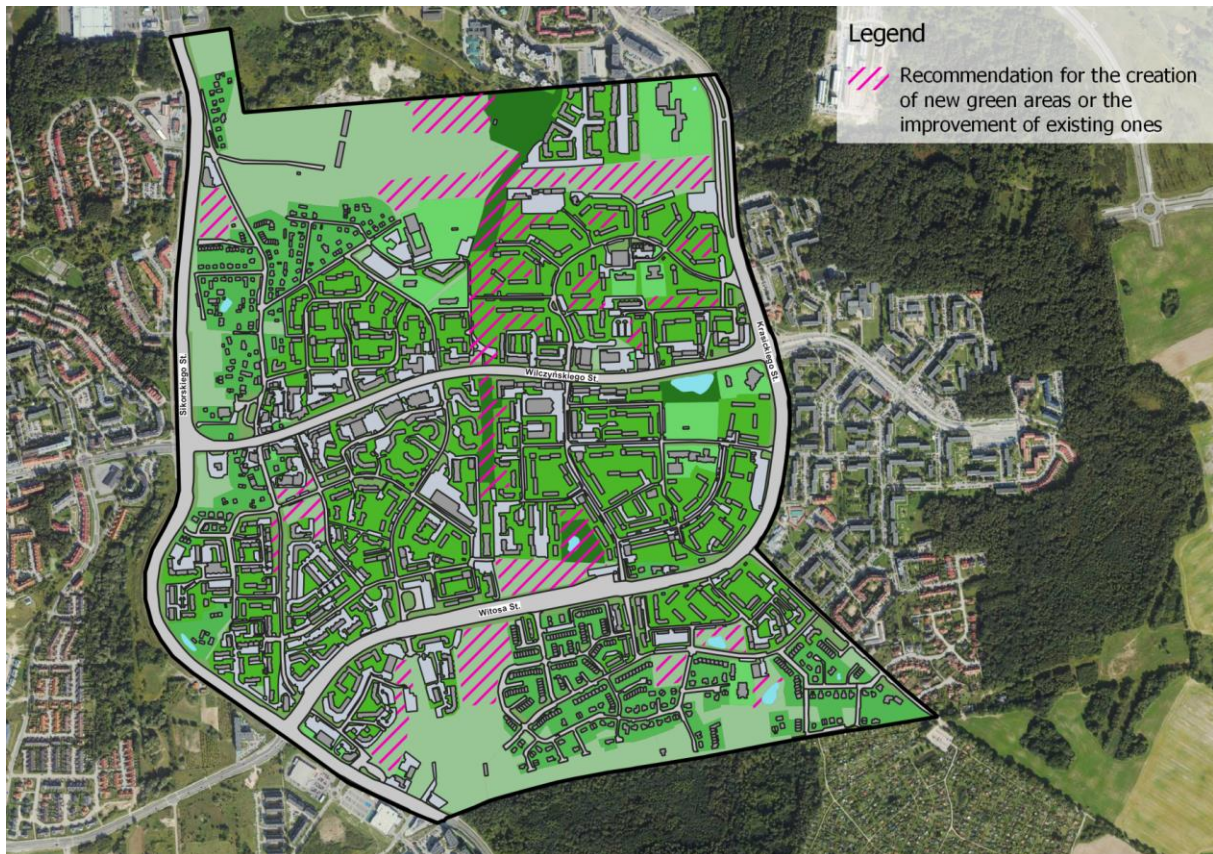
Fig. 10. Areas recommended for increasing the accessibility of green spaces in the Jaroty district

An additional analysis was conducted for all residential districts to determine the percentage share of areas recommended for intervention, and this was compared with the share of proposed changes located on land classified as having the function of informal greenery and others (Fig. 11). The analysis revealed that in the case of the Jaroty district, nearly 61% of all recommended areas for transformation involve greenery with an informal function. For the Pojezierze district, this share amounts to approximately 24%, while in the Kormoran district, it is 6.5%. These results highlight the significant spatial potential of informal greenery as a resource that can substantially enhance residents' access to green spaces.
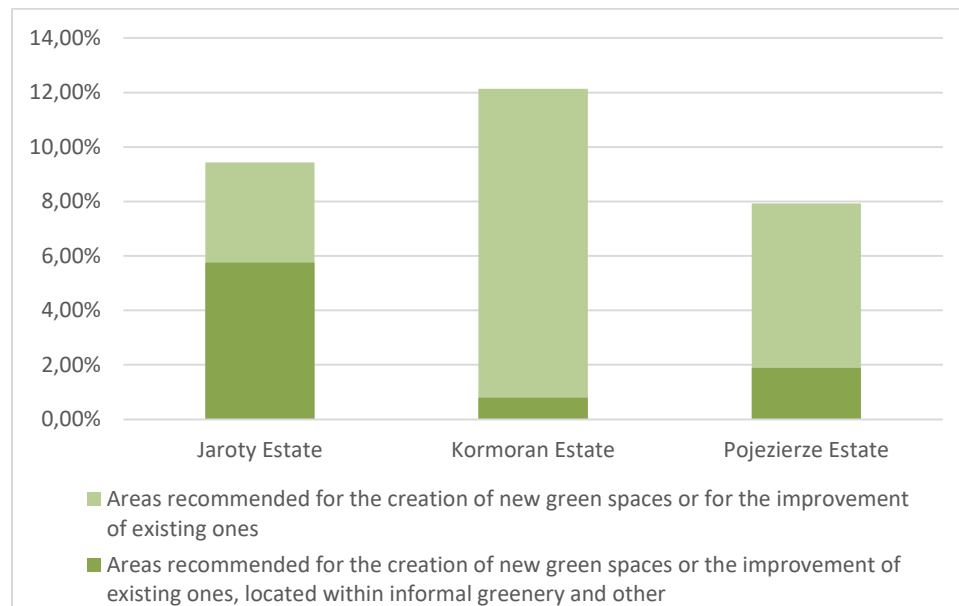
Fig. 11. The percentage share of areas recommended for the creation of new green spaces or for the improvement of existing ones in relation to the total area of the residential district, including the proportion corresponding to recommendation for areas with informal functions.

5. DISCUSSION AND CONCLUSIONS

The analysis of neighborhood green spaces in three Olsztyn districts (Jaroty, Kormoran, Pojezierze) revealed significant differentiation in both the forms of land coverage and the functions performed by urban green spaces. These differences arise not only from the varying character of the development but also from the quality of spatial planning and the adaptation of green spaces to the needs of the residents.

Similar findings were obtained in studies conducted in Kraków, where significant unevenness in the distribution of recreational green spaces was observed, and their functions were insufficiently tailored to the needs of local communities, despite the relatively high proportion of green areas in the total surface area (Studziżór and Kwiatek-Sołtys 2021; Kochel and Zieliński 2021). In Poznań, substantial discrepancies were also noted between the formal classification of green spaces and their actual use, especially in the context of green spaces designated for residential neighborhoods (Szumigała et al. 2023; Raszeja and Gałecka-Drozda 2020).

Although neighborhood green spaces in the studied areas represent a relatively high share of the total area (30–33% according to BDOT, 47–61% according to the author's classification), they still fail to ensure adequate accessibility or functional diversity. A key issue remains the lack of evenly distributed, functionally valuable green spaces, as well as their limited user capacity. An example is the Pojezierze district, where, despite the relatively high share of green spaces, their functionality (e.g., recreational or relaxation purposes) is limited due to the dominance of industrial and unorganized green areas.

Similar limitations were observed in studies conducted in Berlin, where, despite the large surface area of green spaces in the urban structure, their functionality and accessibility for residents of peripheral neighborhoods remained limited (Kabisch & Haase, 2014). In contrast, studies in Barcelona have shown that it is not only the quantity but primarily the quality and integration of green spaces with the public space system that determines their actual usability (Anguelovski et al., 2017).

The data also shows that significant discrepancies arise from the use of different land coverage classification methods. Spatial analysis based on BDOT does not fully capture the real functional structure of green spaces. Including detailed field observation and categorization based on the actual function of green spaces allows for a better understanding of their real significance and use. This is evidenced by the significantly larger share of green spaces around multi-family housing and unorganized areas in the author's classification, which in BDOT were largely considered part of the built-up land. Similar conclusions were presented in Warsaw studies, where the authors emphasized the need to introduce diverse criteria for evaluating green spaces, including their social and ecological functions, rather than relying solely on formal records in geodetic documentation (Oględzka, 2020; Staniszewska, 2022).

From the perspective of sustainable urban development, it is crucial not only to increase the surface area of green spaces but also to improve their quality, accessibility, and integration with the built environment. The introduction of micro-parks, green communication corridors, and diversification of green space uses (e.g., community gardens, activity zones) can significantly improve residents' quality of life and increase the ecological and social value of these spaces. In this context, the experiences of Scandinavian cities such as Copenhagen and Malmö, where the implementation of green infrastructure at the neighborhood level is an integral part of urban planning and community participation, are noteworthy (Beatley, 2011).

Conclusions

The conclusions drawn from the conducted research are presented in the six points outlined below:

1. Neighborhood green spaces play a crucial role in urban infrastructure, providing not only aesthetic functions but also social, ecological, and health-related benefits. In the studied neighborhoods, they form an essential part of the city's green infrastructure, although their potential is not fully utilized.
2. The application of a differentiated functional classification of green spaces allows for a more accurate determination of their role and usage, revealing the real character of green areas and identifying those requiring intervention.
3. There are significant differences in the structure and functions of green spaces between neighborhoods, indicating the need for an individualized approach to planning and modernizing green spaces in each neighborhood, considering its spatial, social, and functional specificity.
4. Accessibility to high-quality green spaces in close proximity to residential areas is critical for improving residents' well-being. Currently, the analyzed neighborhoods do not provide equal access to such areas, requiring planning and investment actions.
5. Recommended actions should include: creating green corridors linking different types of green spaces, developing micro-parks, increasing biodiversity, introducing buffer green zones, and reclaiming unused spaces.

6. Neighborhood green space planning should be an integral part of the city's development strategy, encompassing ecological, social, and health aspects, while striving for sustainable urban space management.

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