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Landscape Design of Zones with Large-Scale Warehouse and Industrial Development Located in Peri-Urban Areas Using Sectoral Analysis of Landscape Interior (SALI)—A Case Study of Wroclaw, Poland

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Abstract: Suburban areas are often used for large-scale developments such as hypermarkets, warehouses, and logistics zones, which lead to the fragmentation of natural areas and the visual degradation of the landscape. This study aimed to evaluate ways to reduce the negative impact of these developments by introducing green infrastructure (GI) elements. The analysis focused on warehouses in the inner ring of the planned green infrastructure system in the Wrocław Functional Area (GI WFA). This study involved three stages: (1) selecting a landscape-functional unit (LaFU) vulnerable to landscape degradation; (2) analyzing changes from the development of large-scale warehouses between 2004 and 2021; and (3) assessing the effect of new GI elements using the Sectoral Landscape Interior Analysis (SALI) method. Three models of GI implementation were proposed and evaluated both from a plan view and from a moving observer's perspective. The results showed that large-scale developments reduce biologically active areas and disrupt landscape harmony. Model III, which includes green roofs, trees, and semi-permeable surfaces, significantly increased greenery and reduced visual degradation. It is recommended to apply the model and its variations in other similar developments for the benefit of the natural environment and landscape.

Keywords: green infrastructure; landscape analysis; fragmentation of open areas; rural–urban fringe; large industrial real estate; warehouses

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1. Introduction

A specific area within peri-urban regions is the rural–urban fringe (RUF), a transitional zone between urban and rural landscapes. This zone is characterized by highly dynamic spatial changes and environmental processes. Most decision-makers and stakeholders influencing the RUF aim to repurpose agricultural land for residential, industrial, or commercial uses, thereby altering the land use pattern [1–5]. This transformation results in landscape fragmentation and inefficient utilization of natural resources. Conversely, there is growing recognition that the sustainable development of the RUF is essential for the optimal functioning of urban areas and the quality of life of their inhabitants. Consequently, two conflicting approaches to spatial and landscape planning and management emerge within RUF areas. One approach emphasizes the necessity of environmental protection and ecosystem conservation, while the other promotes the expansion of built environments, often manifesting as urban sprawl [6,7]. Therefore, it is imperative to balance development

with the protection and restoration of the environment and landscape [8]. Currently, various methodologies are being employed to quantify urban sprawl, including the sprawl index, multidimensional indicators using remote sensing, and analyses based on demographic or socio-economic data. These approaches confirm the previously mentioned negative processes in RUF areas, such as resource wastage, inefficient spatial configurations, and environmental pollution [9–11]. To mitigate the detrimental effects of excessive urbanization, the implementation of green belts (edge lands) and their integration into development plans and strategies for urban functional areas are recommended [2,12]. There is a pressing need for better integration of policy strands in environmental and spatial planning to fully harness the potential of ecosystem services [13,14]. The sustainable development of cities and peri-urban areas is further supported by establishing green infrastructure (GI) systems within their functional areas, linked to urban GI networks [15,16]. Land prices in areas surrounding cities are significantly lower than within city boundaries, encouraging the development of not only residential projects but also commercial, warehousing, and industrial facilities in the rural–urban fringe (RUF) zone. These developments require large land areas and strong transportation accessibility.

In recent years, there has been a significant increase in the warehousing industry within major metropolitan regions worldwide, driven by the growth of global supply chains and the rise in e-commerce consumption [17–20]. Large cities have experienced notable growth in logistics activities, with warehouses relocating from city centres to metropolitan areas, particularly the RUF. These areas attract investors due to their accessibility to transport networks and lower land costs.

Historically, parcel transport terminals were connected to railway networks, but recent changes in transportation methods have led to their relocation closer to highway systems. Over the past two to three decades, the logistics industry has undergone significant transformation. Technological advancements in logistics management and the rise in e-commerce have resulted in larger, more efficient warehousing facilities with greater throughput. Consequently, larger and more automated warehousing and distribution centres have moved to the urban periphery, where they can access large, affordable plots of land and have direct highway access and a lower-cost labour force [17,21–23].

The spatial patterns in the RUF, driven by the concentration of logistics centres, are consistent across various urban contexts. These facilities have become focal points in scientific discussions that address economic, social [18–20], and landscape considerations [24–27]. Landscape studies have examined various strategies for better integrating these facilities into their surroundings by considering materials, textures, and colours [28]. The need for comprehensive "green practices", incorporating diverse pro-environmental solutions in and around buildings, has also been emphasized [25,29,30]. However, relatively few studies compare the effectiveness of different forms of greenery as mitigation measures against the negative visual impact of large-scale warehouses on the landscape. Additionally, there is limited research on the extent of warehousing and distribution centre expansion within the RUF. In light of these considerations, the objective of this study is to analyze recent landscape changes in the rural–urban fringe (RUF) caused by the construction of large-scale warehouses and commercial facilities. The study aims to explore strategies for developing their surroundings that are most beneficial from both environmental and landscape perspectives. The research focuses on an area within the RUF of Wrocław, Poland, which forms a key part of the inner ring of the planned green infrastructure system in the Wrocław Functional Area (GI WFA).

2. Materials and Methods

2.1. Research Area

The city of Wrocław, situated in southwestern Poland, serves as the capital of the Lower Silesia Voivodship (Figure 1). It boasts a population of 674,312 [31].



Figure 1. Location of the study area. Source: author's elaboration.

In line with trends observed in most post-socialist cities, the phenomenon of urban sprawl around Wrocław intensified following the systemic transformations of the 1990s. This was primarily associated with the shift from a centrally planned economy to a market economy. Prior to the systemic transformations, the peri-urban zone did not exhibit dynamic urbanization processes, including urban sprawl, which were already present in other foreign cities, including post-socialist ones [32]. The transition to a market economy, coupled with the demographic and spatial development of the city, resulted in uncontrolled urban expansion, primarily residential, and the consequent fragmentation of natural areas. These processes have intensified in recent years, marked by an increase in the conversion of agricultural land to residential, commercial, and industrial uses. These changes are most prominently observed along arterial roads extending from the city, a characteristic feature of suburbanization [5,33]. An analysis conducted in 2014 of the conditions and spatial development plans for 25 municipalities within the Wrocław Functional Area (WFA) revealed significant agricultural lands proposed for conversion to residential, commercial, or industrial functions, particularly within the RUF zone. Consequently, in 2014, a project was initiated to optimize the green infrastructure (GI) layout in the WFA, part of a larger analytical framework aimed at preparing strategic documents for regional and local spatial policy [34]. The primary objective of the GI WFA project was to delineate a potential GI layout to serve as a foundation for identifying guidelines for future spatial development plans. The proposed GI system consists of three rings, with the first ring (R1) encompassing the RUF of Wrocław. The system is interconnected by wedges, five of which (D1a, D3, D4, D5, and D6) are based on rivers that flow into the Odra (D1 and D2), the principal river forming the axis of the entire system, referred to as the backbone O1, O1 (Figure 2).

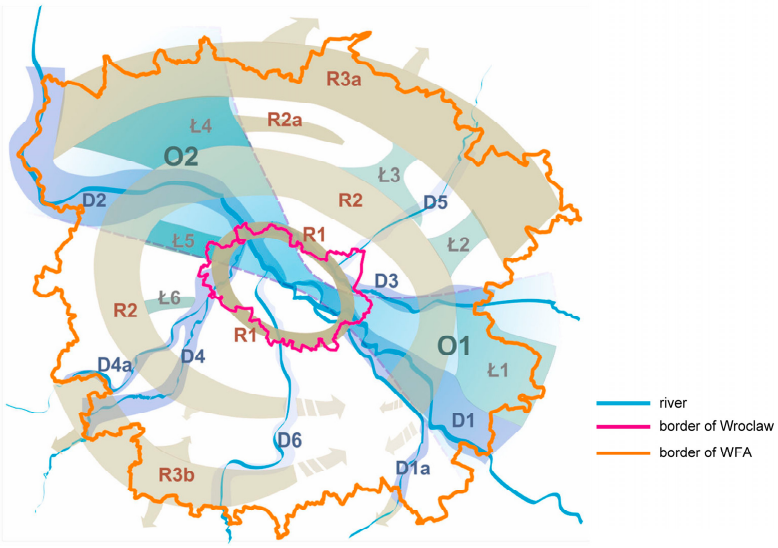


Figure 2. Proposed scheme of green infrastructure system in Wrocław Functional Area (WFA): O1, O2—main axis; R1, R2, R2a, R3a, and R3b—rings; Ł1–Ł6 and D1–D6—wedges [15] (Arrows—potential connections).

Beyond its protective and ecological functions, Ring 1 is intended for daily recreation, Ring 2 for one-day recreation, and Ring 3 for weekend recreation. In 2016, the subsequent stage of this project, titled "Detailing and Developing Implementation Principles for the Optimal Green Infrastructure Layout in the Wrocław Functional Area", was undertaken [35]. This phase aimed to classify and analyze the system's components, enabling the identification of areas at risk of degradation and those necessitating immediate intervention as essential supplements for the functioning of the entire GI system [15]. The guidelines and conclusions from this study have been incorporated into the spatial development plan for the Lower Silesian Voivodship, the current binding strategic planning document defining the spatial development policy of the regional government [36].

2.2. Methods

The research was conducted in three phases. The first phase involved the selection of an area within the RUF zone of Wrocław for detailed examination in subsequent phases. Currently, Wrocław experiences similar phenomena to those observed globally, driven by significant urban population growth and spatial expansion, and influenced by various factors including landowners' preferences and decision-making at both the parcel and higher administrative levels [3]. Along the arterial roads leading out of the city, particularly near highways, large-scale commercial centres are being rapidly developed, with an intensified construction of logistics centres in recent years. These developments often result in continuous expanses that conflict with the green infrastructure (GI) system of the Wrocław Functional Area (WFA), particularly within the R1 ring located in the RUF zone of Wrocław. The logistics centres' loading facilities are large volumetric structures (12–18 metres in height), which, along with parking areas and service roads, occupy the majority of the parcel. According to local land use plans, only up to 10% of the parcel area is permitted to remain biologically active.

The selection of the research area was based on the division of the green infrastructure (GI) system in the Wrocław Functional Area (WFA) into functional landscape units (LaFUs), with an analysis conducted in 2016 as presented in [35]. This study involved the classification of LaFUs and the evaluation of their rank and significance, determining the importance of individual GI units identified in previous phase analyses for the construction, shaping, and functioning of the proposed system elements. The study also identified threats to the

system's functionality and the necessity for protective measures [35]. Further, all 42 units comprising the first ring of the GI system were analyzed using data from the Urban Atlas. The surface area of built-up land in category industrial, commercial, public, military, and private units was compared for the years 2006, 2012, and 2018. This comparison facilitated the identification of areas with the most significant increases in built-up land. By correlating these areas with LaFUs that had the highest degree of obligatoriness for protective measures, one of the most degradation-prone LaFUs was selected for a detailed study. In the second phase of the study, transformations of built-up areas within the selected functional landscape unit (LaFU) were analyzed between 2004 and 2021 using QGIS 3.28 software. The chosen 17-year timeframe allows for illustrating land use changes over the past two decades. Data for 2021 pertaining to built-up areas, including large-scale warehouses and residenti al buildings, were sourced from the publicly accessible Polish topographic objects database BDOT10k. To depict the land use status of the study area in 2004, an orthophotomap from that year was utilized. Comparison of data from the BDOT10k database and the orthophotomap facilitated the identification of buildings constructed after 2004, enabling a comparison with their spatial footprint in 2021. This methodological approach was driven by the absence of archival data in the BDOT10k database and the inadequacy of other data sources, such as the Urban Atlas, for such detailed analyses. These sources also lack the contemporary data necessary for comprehensive change assessments at this scale. Furthermore, to ascertain trends, the collected data were juxtaposed with future projections outlined in municipal planning documents within the analyzed LaFU. These documents provide insights into the anticipated locations of new large-scale logistics centres and warehouses.

In the third phase of the analysis, the focus was on the area currently occupied by existing large-scale warehouses within the studied functional landscape unit (LaFU). This stage aimed to evaluate the potential implementation of various green infrastructure elements to mitigate their adverse impact on the landscape. To achieve this, the current state was compared with three proposed land use models. Initially, the baseline scenario reflected the conditions as of 2021. The land use consisted primarily of non-biologically active surfaces across the entire area, lacking vegetation such as shrubs or trees. Green areas were defined as non-hardened, biologically active surfaces with the potential for planting, generally characterized by minimal green cover. Communication areas, including parking lots, were predominantly paved. Subsequently, three hypothetical land use models were considered:

- Model I introduced green roofs on all buildings and semi-permeable surfaces on parking lots. Climbing plants were selectively applied on buildings in areas that do not interfere with their operational functionality and daylighting, avoiding conflicts with entrances, exits, or windows. Half of the area covered by green roofs and semi-permeable surfaces on parking lots was included in the total biologically active surface area studied.
- Model II implemented tall vegetation (trees) in all feasible locations within the study area. Site selection for tree planting considered a 5 m distance from building facades and a 3 m buffer from road edges.
- Model III combined green roofs and climbing plants on all buildings, semi-permeable surfaces on parking lots, and tree planting in all viable locations within the study area. This model integrated aspects from both previous models. Similarly to Model I, half of the total area covered by green roofs and semi-permeable surfaces on parking lots contributed to the overall biologically active surface area.

The study was conducted using a dual approach: cartographic analysis for quantifying land cover percentages and a three-dimensional assessment from a pedestrian perspective

to evaluate the proportion of greenery within views. For the three-dimensional analyses, the Sectoral Analysis of Landscape Interiors (SALI) method was employed [37], designed to assess visual landscapes from a human observer's standpoint. The analysis focused on the interior environment along the road leading from Psary to Trzebnica, flanked by logistics centres featuring warehouses (loading bays) on both sides. According to Polish landscape research methodology, the road interior is conceptualized as a landscape interior—a physiognomic setting where individuals view the landscape [38–41]. This notion can be correlated with the enclosure concept in landscape theory, applicable to urban as well as open landscape systems [42,43]. The SALI method integrates quantitative analysis, which calculates the proportional distribution of different landscape components within the studied area, and qualitative analysis, which provides supplementary insights into its character, value, and condition. This study primarily focused on the quantitative aspect to compare the share of green elements within the landscape interior, omitting qualitative assessments of its quality. Initially, panoramic photographs were captured at specific locations within the landscape interiors (360 degrees). These panoramas were divided into two halves, extracting frames of 180 degrees each, and forming matrices for subsequent analyses. These frames encompassed views along the road in both directions. The field of view for a stationary observer's head typically spans 120 degrees [44,45], a standard in SALI analyses. However, in this study, it was expanded to 180 degrees to analyze the complete panoramic photograph. The matrix framework was essential to standardize the size and proportion of images above and below the horizon, facilitating comparisons across different perspectives. The matrix size was determined by overlaying a grid with a fixed ratio of 12 units vertically and 48 units horizontally (96 units horizontally for a full 360-degree panoramic photo), encompassing the horizon and providing a schematic outline of all visible components within the photographs. Photographs were cropped so that the horizon aligned at a 5:7 ratio from the bottom of the frame, a technique akin to the golden ratio, aimed at evoking a sense of visual harmony [46,47]. In the quantitative analysis, the percentage contribution of individual elements within the cropped matrices was computed using a conventional method with a pre-applied grid. This approach incorporated the concept of "transparency" to estimate surface areas, particularly where elements partially occlude those situated behind them. The introduction of three transparency levels was necessary: high—assuming the analyzed element obscures up to 25% of the elements behind it; medium—up to 50%; and low—up to 75%. This consideration was essential because the matrices delineated elements such as leafless deciduous tree canopies or mesh fences. At this stage, calculations are approximate and involve aggregating the areas of each interior element across 384 grid cells on the matrix:

$$X_i = \sum_{n=1}^{384} (\%a_n + \%b_n) \text{ total area of the studied element}$$

where

i represents the constituent element of the street interior;
n denotes the grid cell number;
a represents the area of the analyzed grid cell entirely covered by the element;
%b is the sum of transparent areas where the element is visible;
X indicates the total area of the specific element in the analyzed view [36].
The analyzed elements of the landscape interior encompassed the following:

- buildings, including warehouses,
- greenery, subdivided into:
- high greenery;
- medium greenery;

- low greenery;
- climbers;
- small architecture;
- paved areas;
- pavement;
- vault.

3. Results

3.1. Selection of LaFU for Detailed Studies

In the first part of the analysis, Ring 1 of the WFA was examined. Within its scope are 42 LaFU units, out of which 9 have the highest degree of obligatoriness in undertaking protective measures (Figure 3).

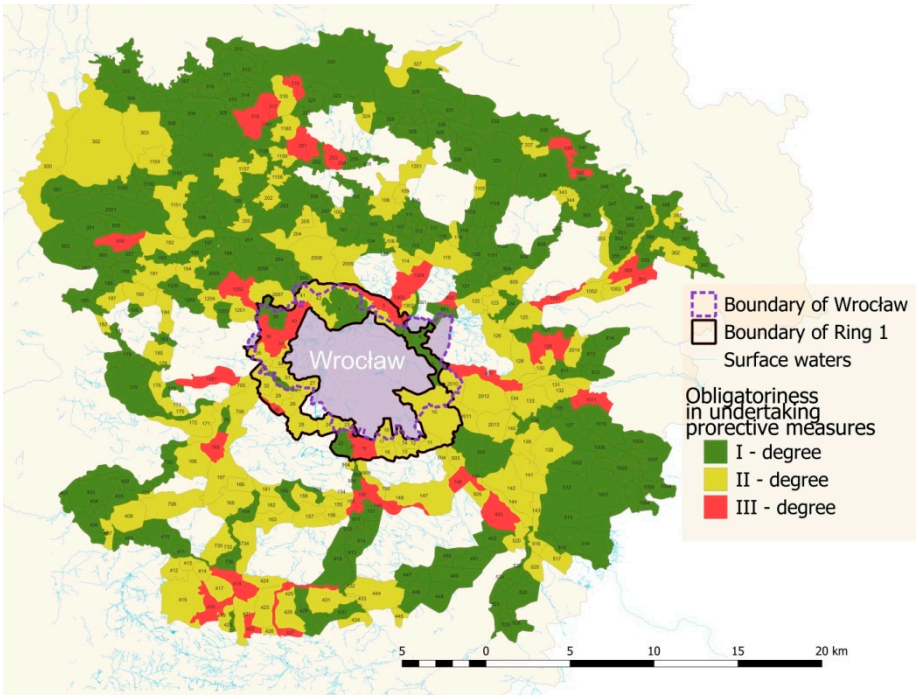


Figure 3. Map showing the division of landscape-functional units (LaFUs) in the GI WFA system, according to the degree of obligatoriness in undertaking protective measures in Ring 1 [35].

Within Ring 1 of the GI WFA, the areas designated in the Urban Atlas as industrial, commercial, public, military, and private units occupied the following proportions in the respective years:

- year 2006—665.53 ha;
- year 2012—677.85 ha;
- year 2018—722.76 ha.

This represents a 9 percent increase in the area of these zones. The greatest concentrations and increases are noted in the southern segment of the ring, particularly in its western fragment and northern section (Figure 4). Ultimately, for detailed analysis, an LaFU unit located in the northern segment of Ring 1 of the GI WFA was chosen. This unit is among the nine with the highest degree of obligatoriness in undertaking protective measures and is also under threat of significant degradation due to the construction pressure from logistics centres.

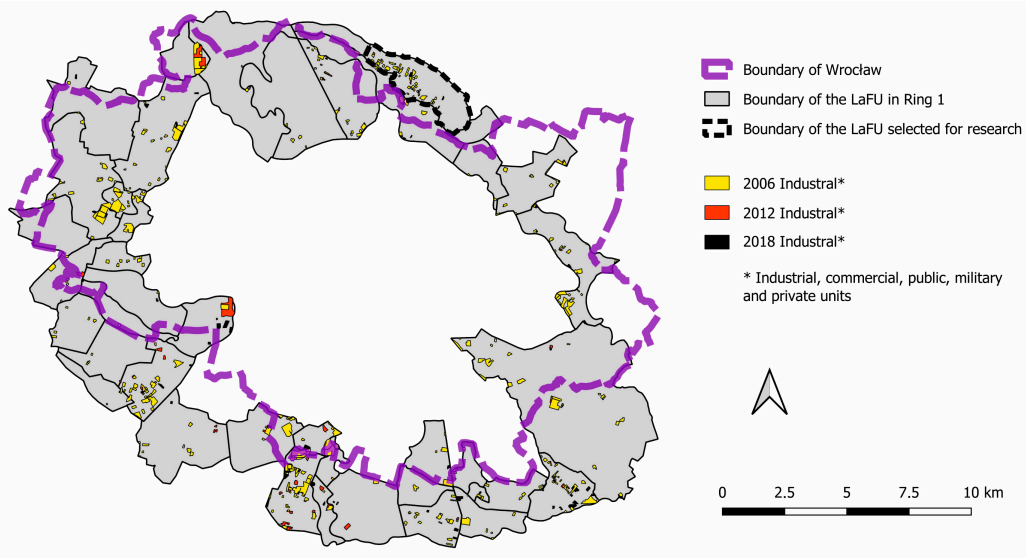


Figure 4. Growth of industrial, commercial, public, military, and private units within Ring 1 of the GI WFA from 2006 to 2012 to 2018. Source: author's elaboration.

3.2. Changes in Land Use in the Study Area

The selected unit encompasses three villages: Szymanów, Psary, and Krzyżanowice, which belong to the Wisznia Mała municipality. In the first stage of the research, changes in the land use of the selected LaFU area were analyzed. The total area of the study region was 608.83 hectares. Between 2004 and 2021, there was a significant increase in built-up areas. The area occupied by residential and farm buildings increased by 5.62 hectares, but most notably, a complex of large-scale industrial and service buildings was established, which expanded the area they occupy by 11.1 hectares. As a result, the built-up area increased by approximately 100% (Figure 5, Table 1).

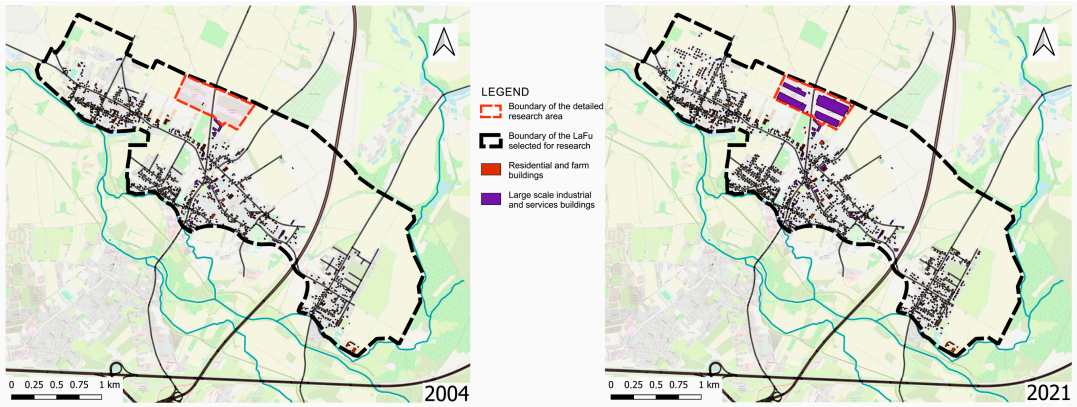


Figure 5. Analysis of changes in the area occupied by the buildings in selected La FUs from 2004 to 2021—stage 2 (own study based on topographic objects database BDOT10k, accessed 7 August 2024).

Table 1. Areas under analysis in the years 2004 and 2021. Source: author's elaboration.

	Surface [ha]	
	2004	**2021**
Residential and farm buildings	13.65	19.27
Large-scale industrial and services buildings	2.42	13.52
Total	16.07	32.79

The assessment of the current expansion of areas designated for development is insufficient to determine the trends that will shape the future of this region. Consequently, an analysis of the provisions and diagrams in planning documents related to future activities in this domain was conducted. In August 2022, a new study on the conditions and directions of spatial development (SUiKZP) for Psary Północ, encompassing the selected study area, was approved [47]. Regrettably, this study does not incorporate the recommendations for the protection of the GI WFA system as outlined in the 2020 Lower Silesian Voivodeship plan. The majority of the LaFU area under investigation is designated for economic activity, which implies the potential construction of logistics centres with large-scale warehouses and extensive areas allocated for roads and parking. The local plans allocate only 15% of the area to biologically active space [47]. In February 2023, a meeting of the residents of Psary, located within the area covered by the new SUiKZP, was convened, resulting in resolutions addressed to the municipal authorities as a form of protest against the successive decisions of the Wisznia Mała municipality, which include further proposed modifications. Specifically, on one of the plots designated for economic activity, there is a proposal to increase the building height from 12 m to 18 m, the percentage of the plot allocated for construction from 50% to 70% of the total area, and the biologically active area from 15% to a mere 10% of the total plot area. Additionally, the proposed site is situated on an elevation approximately 10 m above the level of the Psary village, which would result in a prominent vertical feature in the landscape.

The analysis of the expansion of plots designated for service-oriented development has indicated that, within the study of conditions (the baseline document describing the current state), the area allocated for such purposes within the analyzed LaFU currently comprises 26.51 hectares. However, the projected target area is expected to increase to 176.84 hectares, reflecting a planned sixfold expansion of land designated for service activities. The term "services" encompasses areas intended for both existing and planned service and economic activities (Figure 6).

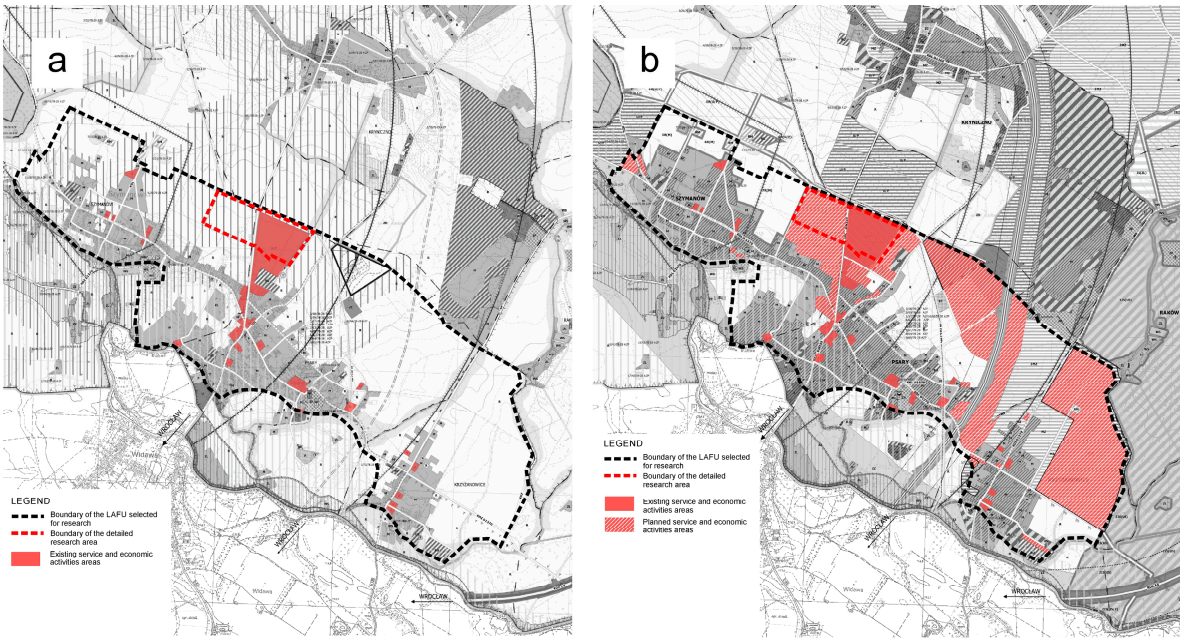


Figure 6. The selected LaFU for research within the context of the study of conditions and directions for spatial development (SUiKZP) for Psary Północ-scheme: (**a**) conditions and (**b**) directions for spatial development [47].

3.3. Analysis of Model Solutions for the Development of Plots with Large-Scale Buildings

It is important to note that, as demonstrated, plots designated for the construction of large-scale buildings typically allocate only approximately 10–15% of their area to biologically active surfaces. Consequently, in the third stage of the research, an analysis was conducted to identify measures that could mitigate the negative impact of such developments on the landscape. To this end, plots with existing large-scale buildings were selected for further analysis (Figure 5). The study area also includes a wide road corridor encompassing the road itself, shoulders, a bicycle path, drainage ditches, and biologically active surfaces behind it. This corridor is situated between two plots with large-scale buildings. The total area of the study region was 24.15 hectares.

3.3.1. Map Analyses

The first part of the analysis focused on various changes in three models of land use, as depicted on maps, with reference to the baseline conditions from 2021. This study also considered the surface areas of roofs.

2021 Baseline

In the baseline year of 2021, when the large-scale buildings were constructed, the green area covered 4.98 hectares, accounting for approximately 20% of the analyzed area, while the area occupied by buildings constituted 42% of the land.

MODEL I

In this model, green roofs were implemented on all large-scale buildings, climbing plants were introduced on the walls of the buildings, and semi-permeable surfaces were used in parking areas. According to Polish law, half of the area covered by these semi-permeable surfaces can be counted as biologically active. As a result, the biologically active area increased by 5.37 hectares compared to the baseline, with roof surfaces allowing for the introduction of low vegetation on an additional 5.08 hectares and the parking areas contributing 0.29 hectares. This effectively doubled the biologically active area to nearly half of the analyzed area (47%), thereby significantly reducing the overall negative impact of the area on the landscape. In this analysis, the climbing plants did not affect the total biologically active area.

MODEL II

This model determined that the area suitable for introducing tall vegetation amounted to 3.91 hectares, representing 78.5% of the current green area. Two types of tall plantings were proposed: small and large trees, depending on the width of the available green space. The small tree proposed was the birch species *Betula pendula* “Fastigiata”, which can reach a height of 10–15 m and a width of 3–4 m, with a planting distance of 6 m. The large tree proposed was the lime species *Tilia euchlora*, which can grow to 15–20 m in height and 10–12 m in width. The study area could accommodate 146 large trees and 280 small trees, totalling 296 trees. In this model, the biologically active area remains unchanged from the baseline (2021), at 18.99 hectares.

MODEL III

This proposal combines the greenery introduction strategies from the previous MODELS I and II. The paved area remains the same as in MODEL I, at 8.25 hectares; however, the structure of the green areas changes due to the proposed planting of 296 trees (Figure 7, Table 2).

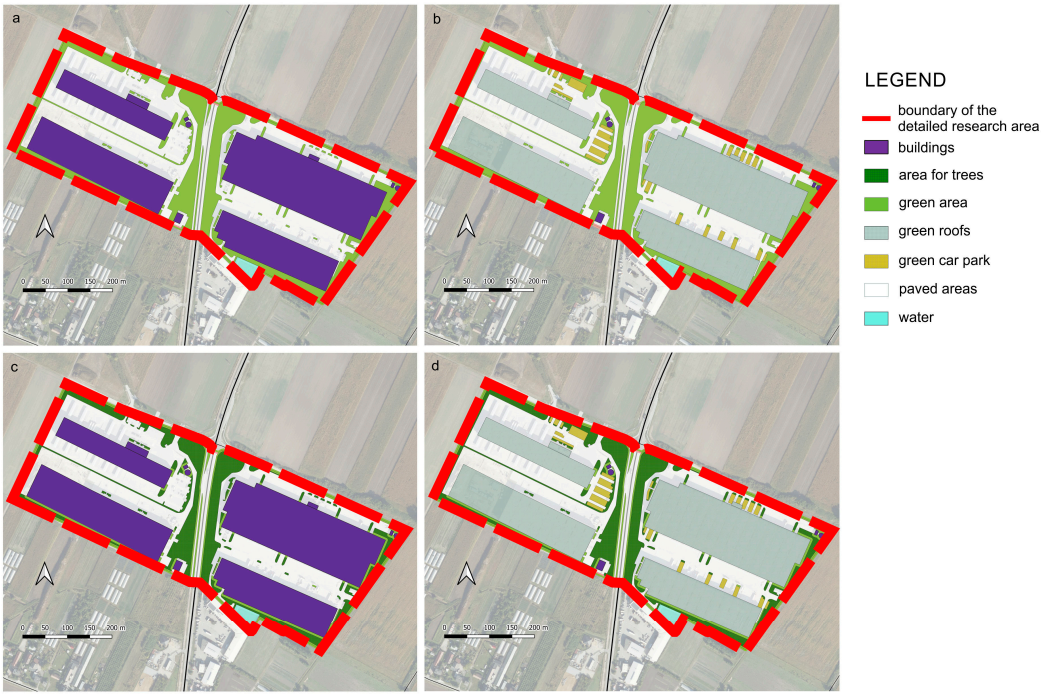


Figure 7. Model changes in land development type: (**a**) 2021 baseline; (**b**) MODEL I—introducing green roofs and semi-permeable surfaces on parking plots; (**c**) MODEL II—introducing high greenery (trees); (**d**) MODEL III—introducing trees, green roofs, and semi-permeable surfaces. Source: author's elaboration.

Table 2. Comparison of land development types in the selected study area: baseline (2021) and proposals for Models I, II, and III (MI, M II, M III). Source: author's elaboration.

No.	The Form of Land Development and Building Roofs	Surface [ha]			
		2021	**M I**	**M II**	**M III**
1	Area occupied by buildings	10.16	0	10.16	0
2	Area occupied by buildings with green roofs	0	10.16	0	10.16
3	Green area	4.98	4.98	1.07	1.07
4	Water	0.18	0.18	0.18	0.18
5	Paved area	8.83	8.25	8.83	8.25
6	Green car park	0	0.58	0	0.58
7	The area for trees	0	0	3.91	3.91
	Surface (1 + 2 + 3 . . . + 7)	24.15	24.15	24.15	24.15
Total biologically active surfaces $1/2 \times 2 + 3 + 4 + 1/2 \times 6 + 7$		5.16	11.25	5.16	11.25

3.3.2. Analysis of the View of the Complex of Buildings with the Use of the SALI Method

In the second part of this research stage, the impact of the solutions proposed in the three models on the view from point 0 was analyzed. The analysis focused on a vantage point from which the buildings are visible and occupy the largest portion of the initially analyzed sequence of views located along the access road, taken every 100 m. The analysis included a full 360-degree panoramic photograph taken from this point, divided into two segments of 180 degrees each (Figure 8).

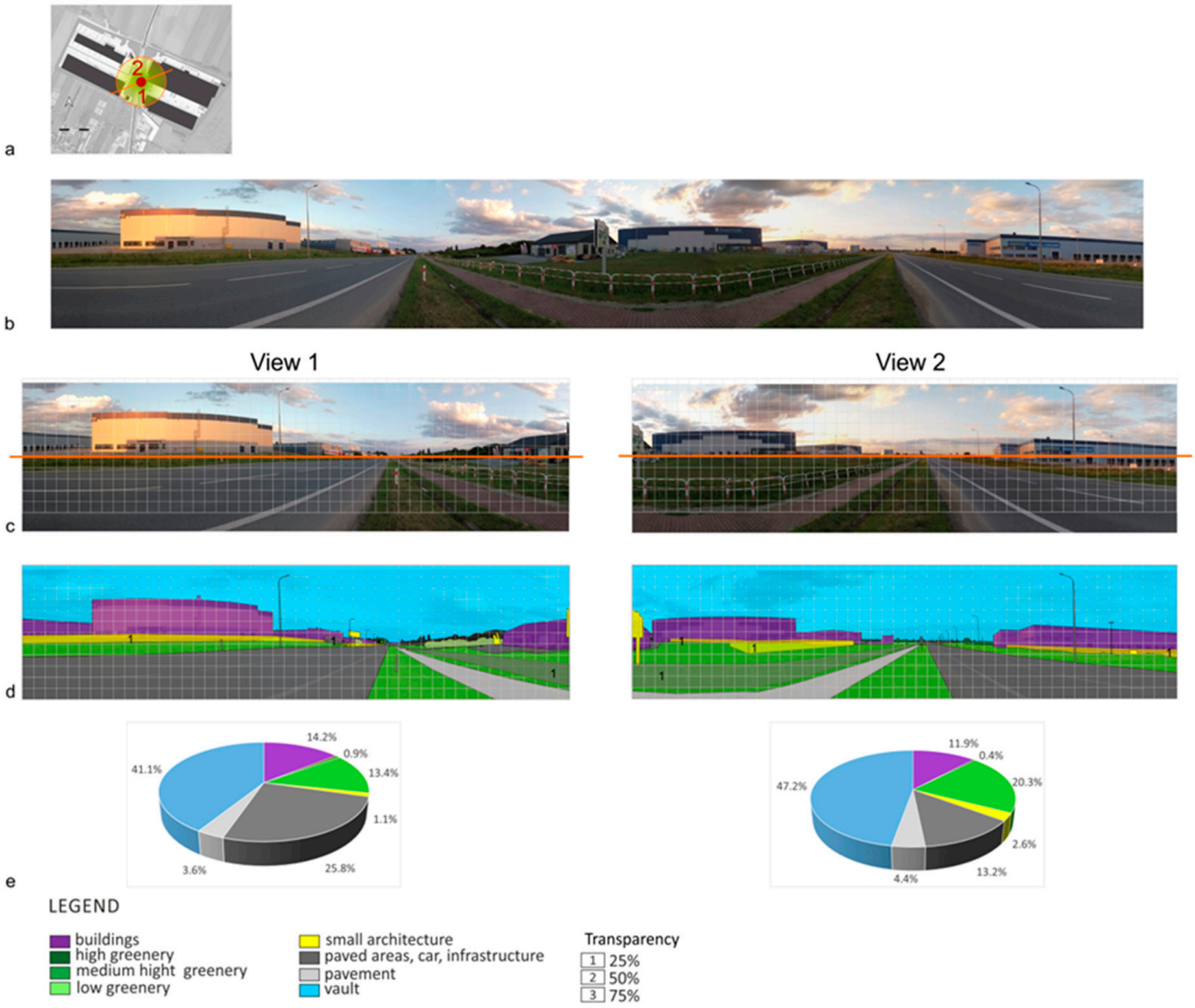


Figure 8. Analysis of the view in 2021: (**a**) location of the observation point, (**b**) 360-degree panoramic photo, (**c**) two selected 180-degree photos/views with an overlaid grid, (**d**) quantitative analysis, and (**e**) percentage breakdown of the contribution of individual forms in the analyzed views. Source: author's elaboration.

MODEL I

The introduction of vegetation on horizontal surfaces did not significantly impact the percentage of low greenery within the views observed from the perspective of a person moving along the street. However, analysis utilizing the SALI method revealed a notable effect from the presence of climbing plants on the walls of the halls. Consequently, the percentage representation of hall buildings within the observed views decreased by 8.1% in View 1 and by 6.11% in View 2 (Figure 9, Table 3).

MODEL II

Analyzing the SALI results, it was found that the introduction of tall greenery reduced the coverage of large-scale buildings to only 2.41% of View 1 and 2.37% of View 2. Conversely, the percentage of tall greenery significantly increased, reaching 31% in View 1 and rising to 34.7% in View 2 in the proposed model (Figure 10, Table 3).

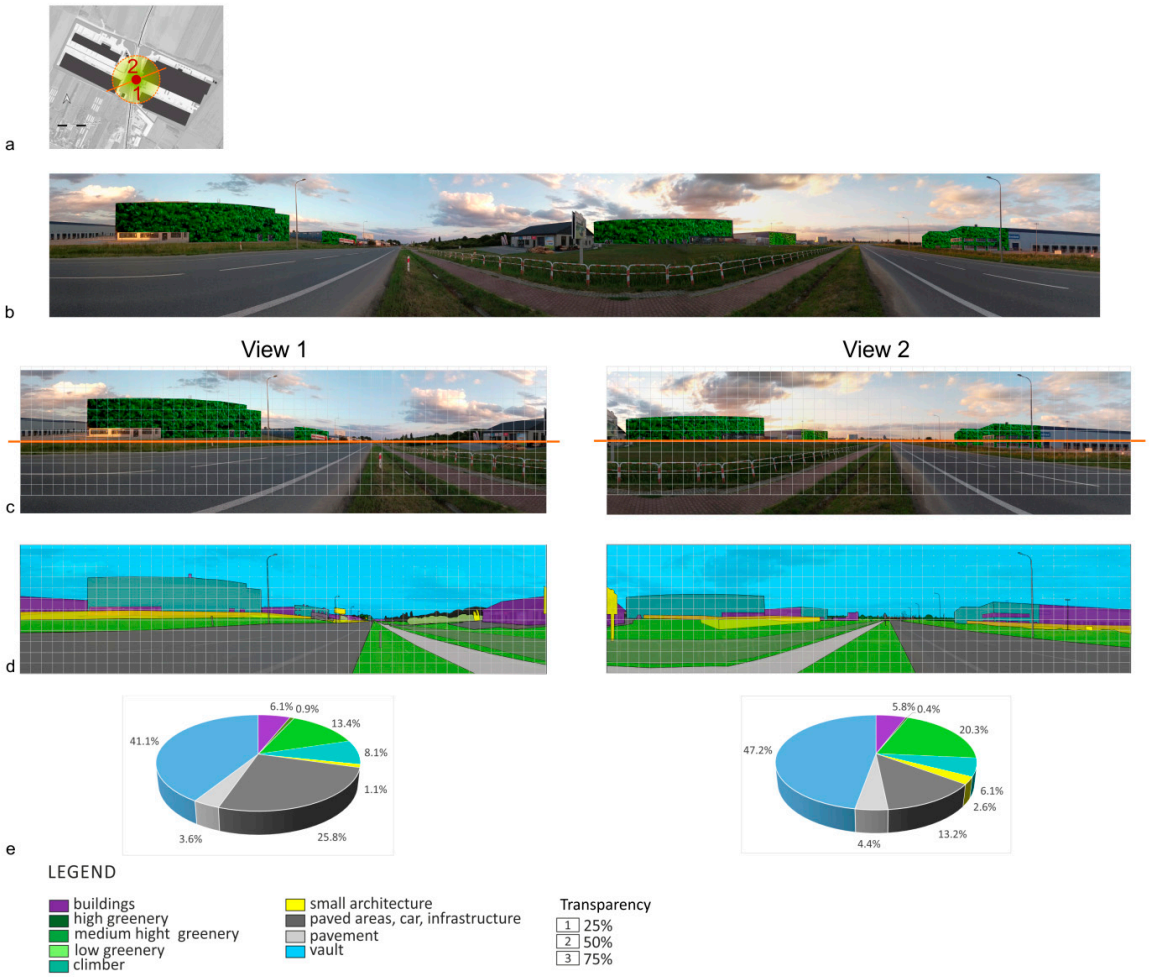


Figure 9. View analysis, Model I: (**a**) location of the observation point, (**b**) 360-degree panoramic photo, (**c**) two selected 180-degree photos with overlay grid, (**d**) quantitative analysis, and (**e**) percentage breakdown of individual forms in the analyzed views. Source: author's elaboration.

Table 3. Percentage breakdown of individual elements in Views 1 and 2 and the entire 360-degree panoramic view from point 0, according to data obtained using the SALI method. Source: author's elaboration.

		Buildings	High Greenery	Medium Greenery	Low Greenery	Climber	Small Architecture	Paved Areas	Pavement	Vault	All Forms of Greenery
		%	%	%	%	%	%	%	%	%	%
2021	view 1	14.2	0	0.85	13.35	0	1.13	25.8	3.59	41.3	14.2
	view 2	11.9	0.37	0	20.35	0	2.59	13.22	4.37	47.22	20.72
	360°	13.05	0.19	0.42	16.85	0	1.86	19.51	3.98	44.26	17.46
MODEL I	view 1	6.05	0	0.85	13.35	8.1	1.13	25.8	3.59	41.13	22.3
	view 2	5.77	0.37	0	20.35	6.11	2.59	13.22	4.37	47.22	26.83
	360°	5.91	0.19	0.42	16.85	7.15	1.86	19.51	3.98	44.18	24.57
MODEL II	view 1	3.46	31.8	0.65	13.35	0	1	25.8	3.59	21.07	45.8
	view 2	3.47	34.7	0	20.35	0	2.59	13.22	4.37	21.30	55.05
	360°	3.46	33.25	0.33	16.85	0	1.79	19.51	3.98	21.19	50.43
MODEL III	view 1	2.41	31.8	0.65	13.35	1.05	1	25.8	3.59	21.7	46.85
	view 2	2.4	34.7	0	20.35	1.1	2.59	13.22	4.37	21.30	56.15
	360°	2.41	33.25	0.33	16.85	1.08	1.79	19.51	3.98	21.19	51.5

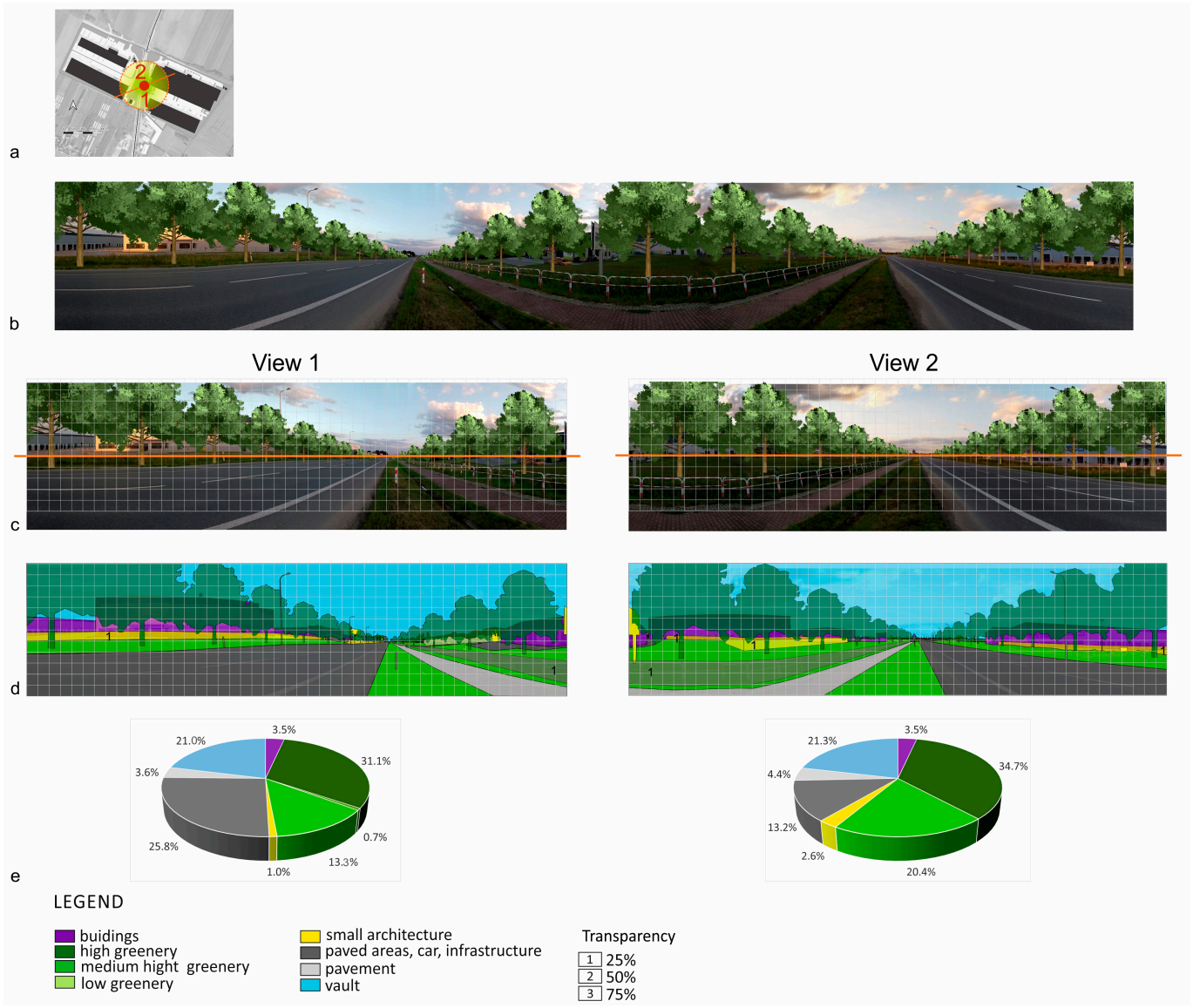


Figure 10. View analysis, Model II: (**a**) location of the observation point, (**b**) 360-degree panoramic photo, (**c**) two selected 180-degree photos with overlay grid, (**d**) quantitative analysis, and (**e**) percentage breakdown of individual forms in the analyzed views. Source: author's elaboration.

MODEL III

The introduction of both tall greenery and green roofs and climbing plants has led to a significant increase in vegetation within the views. In View 1, the total visible greenery coverage increased to approximately 46.85%, and in View 2, it increased to 56.15%. It was assumed that deciduous species were introduced; thus, during the leafed period, climbing plants were partially obscured by the tree canopies in the foreground. Their significance was expected to increase during the leafless period. Similarly, as in MODEL I, the introduction of semi-permeable surfaces in parking areas had no effect on the percentage share of low greenery in either view (Figure 11, Table 3).

The comparison of research findings from both sections of the third stage analyses reveals that MODEL II, which is less favourable in two-dimensional map analyses, demonstrates improved performance in the SALI of both views. While MODEL I indicates a substantial increase in green areas according to map analyses, only half of these areas can be considered biologically active. The SALI of MODEL I reveals no change in the percentage share of all forms of greenery across both views. MODEL III emerges as the

most advantageous solution in both analyses, exhibiting significant increases in greenery and biologically active areas. Specifically, in View 1, there is an approximate increase of 33%, while in View 2, the increase is approximately 35% (Table 3).

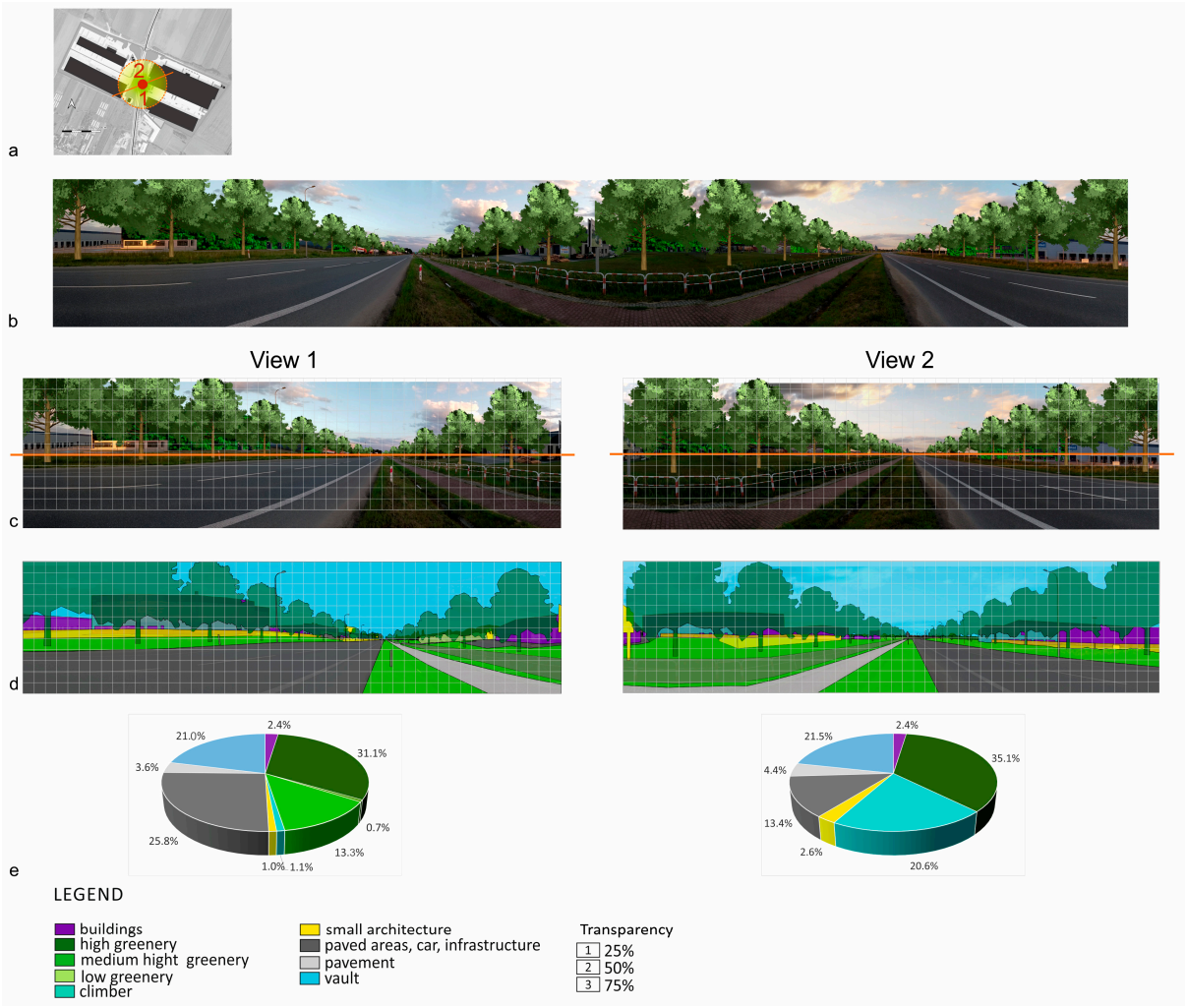


Figure 11. View analysis, Model III: (**a**) location of the observation point, (**b**) 360-degree panoramic photo, (**c**) two selected 180-degree photos with overlay grid, (**d**) quantitative analysis, and (**e**) percentage breakdown of individual forms in the analyzed views. Source: author's elaboration.

4. Discussion

In the spring of 2024, an analysis was conducted to compare the land use actions in the studied area with the three proposed MODELS. It was observed that there were minimal tree plantings on the plot with halls on the western side of the access road, while the eastern part of the plot with halls remains devoid of trees. Similarly, no tree plantings were observed within the road right-of-way. On the western side of the road, there is a row of five cherry plums (Figure 12a), and in the corner, there is another row of seven cherry plums and two linden trees (Figure 12b). Additionally, perpendicular to the road, along another wall, 32 linden trees were planted (Figure 12c). However, there are no plantings along the opposite hall or on the other side of the road (Figure 12d). MODELS II and III indicate that the area has the potential for planting 146 large trees and 280 small trees. If we consider the cherry plum as a small tree, the 12 cherry plums planted represent only 4% of the area's potential, while the 34 linden trees account for 23% of the utilized potential. The entire area lacks parking with permeable surfaces and climbing plants. It should be noted that green roofs and living walls require specific structures, which would need to be

considered during the implementation phase of the investment; therefore, these types of greenery were not feasible in this case.



Figure 12. The plot with warehouses in the western part of the study area: (**a**) a row of 5 cherry plum trees, (**b**) plantings in the corner consisting of 7 cherry plum trees and 2 linden trees, (**c**) 32 visible linden trees, and (**d**) no plantings. Source: author's photos 2024.

To mitigate the negative visual impact of large-scale structures on the landscape, colour modification is often employed, particularly when the application of green screens is not feasible. Consequently, green or brown colours are used on electric traction poles, as well as on whimsically painted high chimneys and large factory buildings. While these proposed methods are effective in reducing the visual impact of large structures on the landscape, they primarily serve a cosmetic purpose and do not address their environmental impact. The camouflage of these landscape-unfriendly structures is further supported by the introduction of greenery, which reduces the negative perception of skylines and close-up views [24,28,48]. These examples, along with the studies conducted in this article, demonstrate the positive effects of such measures on the landscape.

Using the SALI method, the percentage share of individual elements in the analyzed images is estimated by applying a grid of squares over a fixed frame with constant proportions and composition relative to the horizon. The introduction of the concept of transparency allows for the estimation of the percentage share of elements that are partially obscured. The results, correlated with land cover analyses on maps, clearly illustrate differences in the percentage of greenery in both dimensions. The significance of this approach aligns with studies conducted using GSV images and the analysis of the green view index or measurements of tree cover density [49,50].

The issue with warehouses extends beyond just the large volumes of individual structures; it also involves the extensive areas occupied by these facilities. Near major

cities, there is a significantly increasing number of logistics facilities, often concentrated in specific areas, leading to what is known as "logistics sprawl". This phenomenon is on the rise, as documented by [51]. Our studies conducted in 2006, 2012, and 2018 within the inner ring of Wrocław's first GI WFA confirm this trend, showing a significant percentage increase in areas classified in the Urban Atlas as industrial, commercial, public, military, and private units. Moreover, as demonstrated by the case study of the selected LaFU, this trend has not halted, with future plans indicating further expansion of areas designated for economic activities, predicting a sixfold increase compared to 2021. Interestingly, this phenomenon does not always occur near large cities. An example is Katowice, Poland, where the opposite trend, termed "logistics anti-sprawl", has been observed [52]. This differs from the majority of cities in Central and Eastern Europe (CEECs). The authors attribute this to factors such as the period of socialist development in the region and the polycentric nature of the conurbation.

In the context of ongoing climate change, it is imperative that spatial planning policies are more effectively integrated with the potential of ecosystem services [13,14]. Moreover, strategic land use management in peri-urban areas can mitigate the urban heat island (UHI) effect. Decision-support systems have been developed to facilitate the appropriate landscape management of the rural–urban fringe (RUF), particularly by illustrating the effects of landowner interactions on landscape patterns [11]. Empirical studies suggest that a preference exists for residing in rural villages rather than suburbs, leading to initiatives in Switzerland aimed at promoting urban redensification and curbing urban sprawl [53]. Given that warehouse zones frequently abut residential areas, the creation of expansive warehouse spaces devoid of greenery is inconsistent with the rural village concept. The models presented in this study, which enhance biologically active surfaces and increase the proportion of greenery within visual landscapes, are well positioned to meet both the policy objectives for climate change mitigation and adaptation, as well as the needs of RUF residents. Additionally, incorporating peri-urban farmlands into these strategies can protect the areas surrounding cities from uncontrolled expansion and significant alterations in land use patterns and contribute to the development of urban and peri-urban green infrastructure, particularly concerning ecological connectivity. It is essential to adopt strategies that enhance the economic viability of farms within the RUF, thereby elevating agricultural land values. This approach not only fosters agricultural development but also contributes to the reduction in urban sprawl [1,10,15,54–57].

Further investigation is warranted to assess whether the most rapidly expanding warehouse zones in Wrocław are situated similarly to those in four major metropolitan areas in California—Los Angeles, San Francisco, San Diego, and Sacramento—where warehouses are predominantly located in proximity to low- and medium-income minority neighbourhoods [19]. Alternatively, the pattern observed in the Belo Horizonte Metropolitan Area, Brazil, where warehouses are situated near high-income neighbourhoods [17], should be examined. Importantly, research conducted in the Paris metropolitan area indicates that the concentration of warehouses significantly increases CO_2 emissions, primarily due to the associated rise in vehicular traffic [21]. Thus, it is essential not only to consider aesthetic interventions, such as colour schemes on building facades but also to integrate green spaces and biologically active surfaces to mitigate the deleterious effects on the landscape and to reduce the negative environmental and local climatic impacts. While quantifying the economic value of landscape qualities, including the incorporation of green infrastructure, remains challenging, Mell et al. [58] found that 75% of respondents in Manchester were willing to invest in green infrastructure. In the future, it will be critical to engage and incentivize investors to adopt sustainable solutions as proposed in these models, emphasizing the potential environmental and economic benefits associated with such investments.

5. Conclusions

The findings of the study reveal a notable upward trend in the establishment of logistics and commercial centres within the examined RUF area, as well as substantial opportunities for the greening of both the associated land and the buildings themselves. Such measures have the potential to mitigate the adverse impacts on the landscape, local climate, and natural environment. Conducting land cover analyses not solely based on site plans but also from the observer's vantage point enables a more precise assessment of the effects of changes within a given area on the landscape.

The incorporation of greenery, as illustrated in Model I, which involves the installation of green roofs and the use of permeable parking surfaces, is advantageous for enhancing biologically active areas and improving the connectivity of green infrastructure (GI). However, this approach exerts only a limited influence on the landscape as perceived by a human observer. Conversely, the additional tree plantings proposed in Model III around the perimeters of logistics and commercial centre buildings provide a straightforward and effective strategy for both visually integrating the buildings into the landscape and significantly increasing the extent of biologically active surfaces.

The solutions implemented in MODEL I and MODEL III involve the use of green infrastructure elements in areas that are currently most often devoid of them. This is particularly important when large-scale facilities of this type are located within urban and peri-urban green infrastructure systems, as is the case with the GI system in the Wrocław Functional Area (WFA). These facilities may disrupt the continuity of such systems and fragment natural areas. The solutions applied in the models are not ideal, but they demonstrate the potential to mitigate the negative phenomena occurring in the RUF.

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