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Green Infrastructure as an Effective Tool for Urban Adaptation—Solutions from a Big City in a Postindustrial Region

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Abstract: Adaptation to climate change is becoming one of the main paradigms for how cities function and develop. The significant role of green infrastructure (GI) as a tool for cities to adapt to climate change is increasingly emphasized among practitioners of spatial planning and in the research literature. Thus, despite the local impact, green infrastructure planning necessitates the creation of a holistic and integrated city management system. The aim of the article is to identify the effects generated by projects implemented in the field of green infrastructure in big cities of post-industrial regions and to formulate determinants and barriers limiting the strengthening of cities' adaptive capacity to climate change. In the methodological dimension, the article is based on the desk-research method (analysis of project documentation and specialist literature), logical reasoning and the case study method, enriched with a series of interviews and observation of the study area to present the selected projects implemented as part of green infrastructure. Solutions based on nature, green infrastructure and the adaptation of ecosystems are of strategic importance for the challenges of reducing the negative effects of urban heat islands and the risk of flooding, rational space management, regeneration of degraded urban spaces, the coexistence of urban and green space and, consequently, increasing housing, as well as cultural and recreation areas. This is especially true of post-industrial regions, such as the Katowice Conurbation in Poland, to which the examples presented here refer.

Keywords: adaptation; climate resilience; green infrastructures; urban resilience

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1. Introduction

The need to adapt to climate change is emphasized in the Strategy of the European Union [1,2]. Increasing the resilience of European Member States is to take place through "[achieving] coordination and coherence at the various levels of planning and management through national adaptation strategies" [2]. As a response, the Polish government published the "Strategic Adaptation Plan for Sectors and Areas Sensitive to Climate Change in Poland until 2020, with a perspective until 2030" (SPA 2020) [3]. At the regional and local level, strategic documents are being developed to define the directions of activities adapting cities to climate change.

The constant pressure of changes and the need to transform cities, caused by dynamic processes within urban structures and the impact of the environment, necessitates new abilities. Some urban centers quickly and effectively adapt to new challenges, but in others, the dynamics of the environment lead to regression or stagnation [4]. Adaptation is an auxiliary concept in planning activities and in directing the process of better managing the current conditions and those expected to change while limiting the negative effects [5]. This allows the desired balance and durability of the city's functional structure to be achieved. Thus, the adaptive capacity of cities is manifested by responding to disturbances and absorbing unpredictable disturbances without a significant change in the structure

and functions, or by effectively creating new ecosystem structures in a short time after the disturbance occurs. The harmonious development of the urban environment can be achieved by introducing greenery as a new infrastructure that better shapes the space in the city [6] and allows for a gentler adaptation to climate change.

Green infrastructure should be understood as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" [7]. An urban planning process focused on the inclusion of green spaces can contribute to the provision of ecosystem services and to benefits for the local community while also improving the quality of the environment and adapting cities with green infrastructure to climate change [8].

The Sustainable Development Goals adopted by the United Nations under the Agenda 2030 set new expectations for the future, focusing on sustainability, fairness and inclusiveness [9]. Hence, one of the key and multidimensional challenges of Upper Silesia is a just transition involving the transformation of the economy toward a low- and zero-emission economy, while reducing the social costs associated with the pro-environmental shaping of urban development. Changes in the energy sector toward a low-emission economy (energy transformation) will entail consequences on the labor market and in the structures of mining, conventional energy and related industries in the production chains. This can bring about negative social effects and, in coal regions, even changes in cultural identity [10]. The need to restructure the raw materials and energy sector, which still generates huge amounts of air pollution and greenhouse gases, is dictated by climate change and its global consequences [11].

Reorienting the development paths [12,13] of this region requires the search for new development concepts and technological changes conducive to sustainable socioeconomic transformation, as well as efforts to respect elements of the natural environment [14]. An important dilemma in defining new development paths in post-mining regions is posed by the need to revitalize [15,16] and transform the existing functions performed by post-industrial areas [16–19]. The emergence of problems related to designating new functions for post-mining areas generates the need to change local and regional land-use strategies [20] and to seek a balance between social and economic needs [21,22]. Therefore, research is being conducted on post-industrial cities in terms of opportunities and threats affecting the possibility of changing development conditions [23,24].

This study aims to fill research gaps by attempting to integrate the term 'adaptation' with its practical implementation in the form of green infrastructure in the context of spatial planning in post-industrial regions. With the help of selected projects, the effects generated by projects implemented in the field of green infrastructure in large cities of a post-industrial region were identified determinants, and barriers limiting the strengthening of the adaptive capacity of cities adapting to climate change were formulated. The research was carried out within the Katowice Conurbation in southern Poland, which is one of the largest (post-)industrial regions in Europe. This research is particularly important due to the spatial and functional specificity of the region and the ongoing process of system transformation. Therefore, the research question arises: Can small-scale and dispersed projects involving green infrastructure increase the effectiveness of the adaptive capacity of post-industrial regions?

2. Literature Review—Green Infrastructure in Spatial Planning

The European Commission recognizes green infrastructure as a strategic tool for the protection of biodiversity and ecosystem services and as an important solution for adapting and mitigating the effects of climate change [7,25,26]. In addition, nature-based solutions, green infrastructure and ecosystem adaptation are of strategic importance for the challenges of climate change and the resilience of cities, including society itself [27]. They provide benefits in terms of adapting areas in order to minimize the effects of climate change,

regulating the hydrological network, water management and the impact on land value. In addition, these solutions contribute to reducing soil erosion, filtering pollutants, food production, increasing recreational areas and improving the health of the population [28], as well as protecting biodiversity or restoring degraded biodiversity [29,30]. The negative effects of extreme climatic phenomena and natural disasters (floods, forest fires, avalanches) can be reduced using functional floodplains, riparian forests, protective forests in mountain areas or barrier beaches [7]. In cities, it is recommended to implement green infrastructure in the form of protected areas and other natural areas, restorative habitats, ecological corridors, green bridges, flower meadows or green roofs and walls [31], reducing both the outflow of rainwater [32] and heat island effect [33,34]. As a consequence, urban heat islands [35,36] have a negative impact on the comfort of living and healthy ecosystems (human health), generating problems related to energy management in the city [36] and natural wind flow [37,38].

The role of green infrastructure as a tool for adapting urban areas to climate change was emphasized by Gill et al. [39], who considered it a crucial policy instrument in urban planning at all levels. Irga et al. analyzed the popularity of targeted policy instruments aimed at implementing green infrastructure in Australia in the form of green roofs and green walls [40]. In the literature on the subject, attention has been paid to the aspects of planning and the successful implementation of green infrastructure, which is determined by the availability of planning tools [40], the interest shown by particular parties, the institution implementing the project, participants and coordination of the listed factors. Matthews et al. emphasized that the implementation of green infrastructure as a tool for adapting to climate change depends on the available areas for greening, the morphology of the area and the characteristics of individual species, but above all, on management and community involvement in the decision-making process [41].

Salata drew attention to the inconsistency of concepts describing adaptation, which are most often hidden under scientific terms referring to vulnerability, adaptability and resilience. She attempted to identify, classify and define the main determinants based on scientific and political documents dealing with the issues of practical adaptation regarding green infrastructure planning [5]. She outlined the key strengths and weaknesses of building urban resilience [42], which improves cities' capacities to cope with contemporary challenges [43]. In addition, she emphasized that GI is one of the most appropriate and effective ways to improve the microclimate and counteract the urban heat island effect [44,45].

Adapting cities to climate change and mitigating climate change has become, on the one hand, an important part of policy, and on the other, an indispensable strategic action at all levels of spatial planning and management [44,46–49]. In addition, spatial planning in the field of adapting to climate change should be promoted on a local and regional scale, inducing a synergy effect, for example, in the field of biodiversity protection [50]. Hurlimann and March [51] presented six reasons why spatial planning can address adaptation, while Wilson [52] focused on the role of local development plans in the UK as a means of promoting adaptation to climate change. Such an approach is crucial in adapting cities and creating their resilience to climate change [7,52–55].

A number of factors facilitating and hindering the successful implementation of green infrastructure projects can be found in the literature. Taking into account the possibilities in the field of design, management of organizational structures, obtaining funds or involving beneficiaries in the implementation of green infrastructure, it can be stated that there is no universal recipe ensuring the successful implementation of a project [55]. Structural/operational barriers characterize the group's functioning, organizational structures and procedures in accordance with the existing regulations, principles and directions of long-term policies. They may force the introduction of changes in project management during its implementation due to the difficulties arising from the determination of property ownership [56] or the ineffectiveness of the system's response procedures to bottom-up opinions. Regulatory and legislative barriers are characteristic of the policy tools (obsolete

or limited) at the disposal of organizations at many administrative levels. These barriers are caused by inconsistent and frequently changing relevant legal regulations, which, in turn, leads to a lack of connections between strategic and planning documents [56] or cumbersome administrative procedures related to the required documentation or applications for investment co-financing. The influence of cultural and behavioral barriers stems from customs, values, beliefs, interests and personal relationships between decision-makers [56]. They are related to the low level of awareness and social acceptance resulting from the different priorities and concerns of landowners and the potential negative impact on adjacent areas [57]. The above types of barriers appear in the context of each investment, i.e., the environment in which the organization operates, and the values and priorities represented by a given society [58]. When long-term processes of environmental change come into contact with short terms of office, it usually results in populist political decisions and expectations of spectacular results. There are also barriers due to the use of human, technical and financial resources that hinder the integration of a new initiative with the development strategy developed by a given administrative unit [59]. The fragmentation in how green infrastructure projects are implemented and the lack of continuity in financing result in an inability to create a common vision of development that seeks to create a system of natural, recreational and landscape connections. It should be noted that particular groups of barriers may occur at any stage of the implementation of green infrastructure projects or may constitute an obstacle preventing the implementation of projects.

The concept of green infrastructure has become one of the most efficient and effective planning tools for mitigating and adapting to climate change [5]. This tool increases the resilience of cities and reduces their vulnerability to the effects of climate change, thus enabling sustainable development. In order to obtain the most effective benefits from the use of green infrastructure, activities in the field of urban planning and management should be integrated [60,61]. The physical and organizational aspect of spatial planning should integrate socioecological interactions, changing the approach to a more ecosystem-based one.

However, it should be take into consideration that setting new paths for the development of post-industrial cities in the Katowice Conurbation is dictated primarily by the possibility of re-development of the post-mining areas studied, on the one hand, in the natural aspect, by preserving biodiversity and strengthening ecosystem services [62–66], and on the other hand, in terms of social transformation, economic and spatial development of the city and even the region [65,67]. Over the last 30 years, the image of Silesian Voivodeship and the Katowice Conurbation located within it has changed from one of a region dominated by heavy industry (especially hard coal mining) to that of a region with a diverse structure of industrial sectors and services, including metropolitan services and functions [68,69].

The development of post-industrial areas in the central part of the Silesian Voivodeship using the principles of green infrastructure has, so far, been carried out in the following areas: leisure and recreation (revitalization and afforestation, allotment gardens), education (education paths), nature (flower meadows, planting native plants, retention of rainwater), tourist (walking paths, bicycle routes) and investment (pocket parks, green balconies and roofs) [10,70–73]. Therefore, strengthening the resilience of cities to the effects of climate change induces a change in the approach to issues related to planning green areas and sustainable land use, migration and unemployment, social inclusion and exclusion, the commercial and residential real estate market and the scale of post-industrial areas and wastelands.

3. Data and Methods

The main aim of the article is to integrate the term 'adaptation' with its practical implementation in the form of green infrastructure in the context of spatial planning. The inspiration for formulating such a goal came from an article by K.D. Salata and A. Yiannakou [5], which emphasizes the ambiguity of the scientific terminology regarding adaptation to counteract climate change and its practical implementation in spatial planning.

The lack of a clear concept complicates city management, in particular, decision-making and implementation of functional solutions. The thematic analysis of key concepts related to green infrastructure and the adaptation and adaptability of cities allowed us to explore various contexts and interpretations. to be This phase made it possible to compile their individual determinants and attributes (phase 1).

In the next step of the research, projects in the field of green infrastructure implemented in the Silesian Voivodeship were analyzed. Projects were selected for further analysis, the principles of which were in line with the implementation of projects aimed at bolstering adaptability to climate change in urban areas. Using logical reasoning, two projects (Figure 1) promoting transnational cooperation were selected, under which sets of rules for the implementation of green infrastructure for the development of environmentally and resident-friendly post-industrial areas were created (phase 2 and phase 3). Two projects were sought for in-depth analysis, one for green (terrestrial) infrastructure and the other for blue (water) infrastructure. In addition, these had to be implemented in at least three partner countries in order to identify the scale of the project and spatial dispersion, and to enable the comparison of potential problems at each stage of the project implementation. It was also important that the assumptions for implementing green infrastructure projects take into account the variety of forms and their multifunctionality. Based on the analysis of the substantive and technical design documentation, the REURIS (Revitalization of Urban River Spaces) project was selected as the first which, as a pioneer in Central Europe, emphasized transnational cooperation aimed at creating a set of rules for the revitalization and practical implementation of riverside spaces in people-friendly cities [73]. The project consisted of a study part, social consultations and pilot activities. The project involved eight partners representing six regions in three countries: Poland (Katowice, Bydgoszcz), Czech Republic (Pilzn, Brno) and Germany (Stuttgart, Leipzig) [74]. The partners of the project, implemented between 2008 and 2012, emphasized that the scope of environmental and spatial information for the purposes of revitalization of urban rivers and riverside spaces has not yet been defined, nor have the rules for obtaining and processing such data been written down. Moreover, the procedures for cooperation with experts and the local community have not been developed, nor has the public planning of revitalization activities. Thus, it was the first attempt at transnational cooperation consisting in creating a set of principles for the revitalization of riverside spaces and illustrating these principles through practical implementation [75]. For the first time in a Polish city, the creation of public space was combined with the partial naturalization of the river valley.

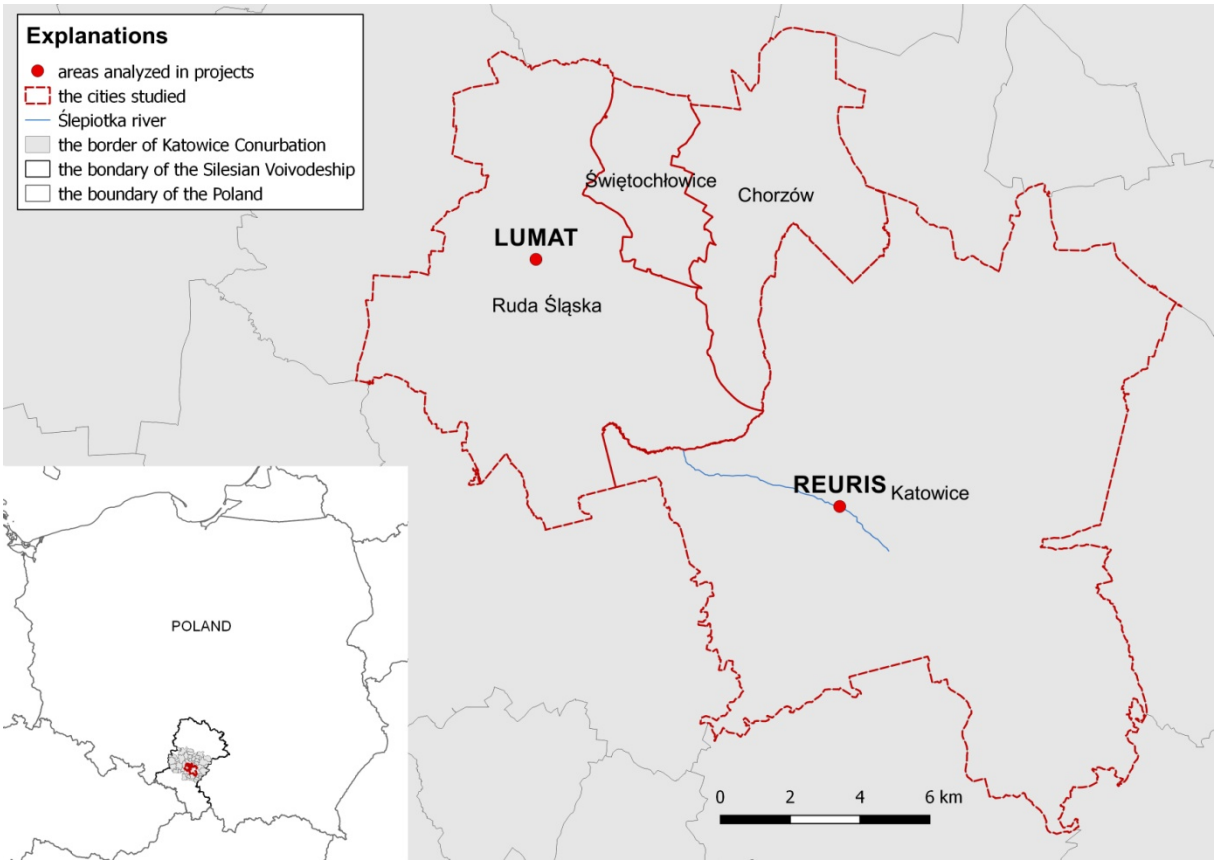

Figure 1. Location of projects against the background of cities. Source: own study using the Topographic Objects Database [76].

The second project selected in this phase of research was the LUMAT (Implementation of Sustainable Land Use in Integrated Environmental Management of Functional Urban Areas) project implemented under the Interreg Central Europe programme. It involved 13 entities from 7 countries (Poland, Slovakia, the Czech Republic, Germany, Slovenia, Italy and Austria). The aim of the LUMAT project was to strengthen integrated environmental management in functional urban areas through sustainable land management and by developing ecosystem services [77]. In Poland, the LUMAT project was implemented within the Functional Urban Area (FUA) of Ruda Śląska, which is comprised of three cities: Chorzów, Ruda Śląska and Świętochłowice. The FUA area is located in the Silesian Metropolitan Area, which includes 14 cities. The aim of the LUMAT project was to strengthen the system of green and blue infrastructure (BGI) in FUA Chorzów, Ruda Śląska and Świętochłowice [78]. Although a common goal was set, its implementation concerned tasks of a different scale. Areas were designated in three cities: in Ruda Śląska, actions were taken in 8 areas; in Chorzów, in 6 areas; and in Świętochłowice, in 3 areas [79]. The dispersion of the areas of strengthening the BGI system within the LUMAT project made the authors decide to carry out the research undertaken in Ruda Śląska.

The analysis of the specialist literature and project documentation was augmented by a series of interviews with project coordinators, residents of housing estates and observations during field research, which allowed the effectiveness of projects in the field of strengthening the adaptive capacity of the city (districts where the project was implemented) to be identified in the context of climate change (phase 4). The interviews were conducted during information meetings and random meetings with the users of the analyzed space during field research. The interviews were conducted among 100 respondents in spring (May) 2016 and autumn (November) 2022. Due to activities dedicated to particular age groups by partners of the projects implemented in Katowice and Ruda Śląska, the following age

ranges were adopted in the survey: people under 26 ('students'), people between 27 and 59 ('people of working age') and people aged over 60 ('persons of retirement age') (Table 1).

Table 1. Age structure of people participating in the study.

Project	REURIS	LUMAT
Number of respondents	100	100
Sex	Share [%]	
Woman	59	63
Man	41	37
Age	Share [%]	
<26	21	27
27–59	36	32
>60	43	41

Source: own study.

The types of cover and use of the study areas were investigated using modern digital tools. Due to the area of the surveyed area (approximately 5 ha) and the accuracy of the metadata, information collected as part of the Urban Atlas—2018 Copernicus land monitoring service was used [80].

Determining the effects of the solutions implemented in the field of green infrastructure made it possible to attempt to formulate general recommendations for fostering institutional cooperation, therefore promoting cooperation between stakeholders to build the adaptive capacity of the city (society, economy and environment) adapting to climate change (phase 5).

4. The Case Study Projects

Adaptation and resilience are not new concepts, although they may be relatively new in the field of spatial and urban planning. Despite their diverse uses, these concepts remain fuzzy and inconsistently applied [81–83]. According to some authors, resilience seems to be gradually replacing the concepts of adaptation and sustainable development, and cities preparing for the effects of climate change use resilience rather than adaptation strategies to deal with these effects [81,83]. Different theoretical and empirical approaches emphasize particular elements of urban development; therefore, the links between them are still difficult to determine [84,85]. The lack of consensus on how to describe and measure a city's adaptability and resilience is reflected in various goals and objectives [84]. However, some common areas and key indicators of urban adaptation have been proposed, as it is essential to adapt to and mitigate climate change [83].

The links between the concepts of vulnerability, resilience and adaptability of cities overlap because how they are interpreted depends to a large extent on subjective factors, i.e., the academic background of the authors [43]. The city's vulnerability and resilience are linked by adaptability, and the key determinants identified as increasing adaptability simultaneously increase resilience and reduce vulnerability. All these determinants include forms of social, human, economic, natural and physical/built capital, as well as the management and planning system [5,44,56,57,59,60,86].

Spatial planning can increase a city's resilience and adaptability while reducing its vulnerability. It can achieve this by regulating land development and using urbanized areas as well as green areas and open spaces, thus affecting the adaptability of the city and, consequently, its durability [47,87–89]. It is emphasized that the ecosystem approach to planning, especially using green infrastructure, can contribute to strengthening resilience and adaptability by promoting diversity, connectivity and flexibility, along with encouraging learning, multi-level decision-making and the co-creation of a multifunctional system of connections [54,88,89].

With regard to these ideas, the determinants of adaptive capacity in the Silesian Voivodeship cities examined here were established using a detailed analysis of scientific and strategic documents carried out by Salata and Yiannakou [5]. When making the selection, an analysis was performed based on identifying green infrastructure planning indicators that have an impact on strengthening the adaptive capacity of cities. The analysis of the REURIS and LUMAT projects implemented in Katowice and Ruda Śląska made it possible to establish the effects of the seven key determinants.

The first group of effects related to economic capital includes improving safety and communication, as well as increasing the attractiveness of areas for residents and investors while increasing the market value of land, which was achieved by cleaning up municipal waste and regulating water management. The effects in terms of human capital concerned increased ecological awareness among inhabitants in terms of perceiving land and soil as an environmental resource. This was achieved through a series of training courses on ecological topics aimed at the local citizens. The effects classified as natural capital concerned projects consisting in increasing the green areas in the city and restoring native vegetation, thus increasing biodiversity and limiting the mobility of heavy metals in the soil. Park and recreational spaces referring to the cultural heritage were created, and natural habitats were recreated. In addition, the hydrotechnical condition of the river was improved, thus increasing river water retention, accumulating excess rainwater and reducing the urban heat island effect. As part of the physical/built capital, recreational areas were tidied up along with walking, cycling and educational and scientific paths introduced into them. In addition, a green-blue river valley corridor was recreated in part of the urbanized district. Public participation was included in the decision-making process, which strengthened identification with the territory and commitment to the success of the project. These activities contributed to the development of social capital for all interest groups. The projects also contributed to the development of a decision support system regarding the development of urban spaces, to developing methods and principles of spatial management, to establishing formal links between partners and to the creation of structures managing the implementation of action plans, which ultimately led to the restoration of natural, landscape and functional values in cities.

4.1. REURIS Project

The REURIS (Revitalization of Urban River Spaces) project emphasized the practical implementation of a set of rules for the renaturalization of riverside spaces in people-friendly cities [73]. It consisted of a study part, social consultations and pilot activities [90]. As part of the project, approximately 4.1 ha of the Ślepiotka valley located in Katowice (Ochojec district) was developed in the immediate vicinity of intensive residential and industrial developments, as well as the transport network. The area was heavily degraded, with a large part of it being used for the illegal dumping of waste, where natural vegetation was replaced by invasive species.

Interviews were conducted with 100 respondents, who included representatives of the institutions involved, experts, local residents and people running local activities in the vicinity of the study area. Women accounted for 59% of the respondents, and men for 41%. Overall, 43% of them were people over 60, 36% were people of working age (27–59) and 21% were students. As many as 87% of those surveyed had not used the area in question before this revitalization. The reasons most frequently indicated were unattractiveness resulting from the illegal dumping of waste and earth masses, the smell released from a nearby sewer, burning vegetation, and acts of vandalism, which contributed to the area being defined as dangerous. However, after the investment was completed, as many as 83% of respondents began to use the area of the Ślepiotka river valley, mainly residents of the Ochojec and Panewniki districts. To a small extent (4%), these were people living in other districts of the city of Katowice who used the nearby public transport stop. The following argument was given for this use: an increase in aesthetic values, which consisted in removing waste, restoring a flower meadow, setting up an orchard of traditional varieties

of trees and shrubs, introducing a green amphitheater and educational paths, walking paths and a paddock for dogs. Residents participating in information meetings, workshops and field visits with guides identified themselves with the implemented project. Even after the project was completed, they showed initiative by monitoring the site, reporting vandalism and requesting improvements. However, despite the increase in awareness and positive opinions regarding the individual stages of the project, in which the organizers made great efforts to ensure that the project management process was carried out in line with the principle of participation, two main barriers were indicated. These concerned economic capital and the planning and management system, as the organizers did not provide financial resources to maintain the project after its completion. In addition, the structures allowing investment to continue were not bolstered, as only a pilot project was implemented on a 350 m section of the Ślepiotka River.

4.2. LUMAT Project

The aim of the LUMAT (Implementation of Sustainable Land Use in Integrated Environmental Management of Functional Urban Areas) project was to strengthen integrated environmental management in functional urban areas through sustainable land management and the development of ecosystem services [76]. As part of the project, an action plan was implemented to strengthen and develop the green infrastructure system in the urban functional areas of Chorzów, Ruda Śląska and Świętochłowice. The main assumptions of the project related to land management in cities, treating them as a valuable and spatially limited resource. The problems in these cities stemmed mainly from strong urbanization and industrialization, uncontrolled urban sprawl, surface sealing and the excessive growth of degraded areas. The sealing of soils (which, as a consequence, weakens the city's capacity to adapt to climate change) was counteracted by introducing compensatory plantings in degraded areas, which was supposed to counterbalance the location of projects in non-urban areas. The pilot project carried out in the area of a post-zinc heap [91] with an area of 6.5 ha, located in Ruda Śląska, is an example of the reuse of post-industrial areas (with polluted soil and social problems).

These interviews involved 100 respondents, who included representatives of the institutions involved, experts, local residents and people running local activities in the vicinity of the study area. Women accounted for 63% of the respondents, and men for 37%. Overall, 41% of respondents were over the age of 60, 32% were people of working age (27–59) and 27% were in education. Among those surveyed, 64% did not use the area in question, often attributing to it a lack of utility functions. The area was described as unsafe and contaminated by previous industrial activity. After the completion of the project, 71% of respondents answered that they use the newly developed space. The main reasons were improved safety, the creation of a recreational and leisure space with educational paths, as well as the pedestrian and bicycle paths. The main barriers related to human and technological capital were indicated, which related to acts of vandalism and the effectiveness of the implemented remediation and phytostabilization solutions.

5. Results

5.1. General Arrangements

Adaptive capacity is one of the determinants of vulnerability and resilience and is defined by many researchers as the ability of system actors to influence and manage resilience [86,92]. The adaptive capacity of cities depends mainly on all types of capital, the management and planning system and the technologies used. Human capital becomes important, especially skills related to the ability to learn and use knowledge and experience. In addition, social capital is important, i.e., bottom-up initiatives, impacts on the creation of a network of new institutional connections and interactions between various groups of the local community. The framework of adaptive capacity of cities is closed by multi-level planning and management systems that enable the co-decision and cooperation of society and institutions [5].

Salata distinguished seven determinants affecting the implementation of green infrastructure as a way to strengthen the adaptive capacity of cities. She drew attention to the inconsistency of concepts describing adaptation, which are most often hidden under scientific terms referring to vulnerability, adaptability and resilience. She attempted to identify, classify and define the main determinants based on scientific and political documents dealing with the issues of practical adaptation regarding green infrastructure planning. These determinants included capital (economic, human, natural, physical, social), the governance and planning system and technology [5]. The first determinant is economic capital, which is the basic factor in planning GI as public investment. Appropriate resources should be secured, including financial resources at the stage of creation and management, as well as maintenance after the investment is completed. On the other hand, economic capital as a determinant of the city's adaptability relates mainly to financial resources and the economic situation, as well as to the wealth and economic well-being of residents calculated as income per capita on the one hand, and to the marginalization and economic poverty on the other. Economic capital is also understood as the economic capacity to bear investment risk or the use of financial incentives.

The second determinant of GI planning is human capital, which is defined as knowledge, information, the learning process and well-being. The city's adaptive capacity determined on the basis of human capital refers to formal and informal education, learning, acquiring knowledge and experience, the city's demographic situation and personal characteristics used to introduce innovations. The third determinant is natural capital, which is important in GI planning. It refers to natural resources and their protection and ecosystem services. Attention is drawn to undertaking holistic and integrated projects that influence adaptation through the quantity, availability and diversity of natural resources. The fourth determinant is the physical/built capital that makes it possible to integrate gray and green infrastructure by introducing cycleways or green roofs. The fifth determinant of GI planning concerns social capital relating to cooperation, creating multidisciplinary teams, stakeholder diversity, building interactions between people and between people and nature, as well as participation, co-creation and co-determination. Like adaptive capacity, this element is based on building social, institutional and communication networks. As part of social capital, the opportunities for the flow of ideas, resources, information and knowledge become significant.

The sixth determinant addresses the issues of GI governance and planning on many levels. It concerns comprehensive, integrated, multi-scale projects based on cooperation and partnership. GI projects should be in line with the strategic and long-term goals and directions of the city's development and should also be rooted in legal regulations and solid scientific approaches. Moreover, the adaptation of cities depends on the governance structure of institutions and interactions at all levels of the planning system, as well as their ability to create and implement. The decisions made by the management and planning system affect future generations and strengthen or weaken the adaptive capacity of the city. The last determinant of GI planning and the adaptability of cities comprises the technologies and innovative solutions that are implemented.

Adaptability is also considered in interdisciplinary fields relating primarily to:

- accessibility (to various types of capital, resources, infrastructure, social, institutional networks, information, opportunities, financial instruments, education);
- the desirability of the initiatives undertaken;
- diversity (biological, economic, cultural);
- flexibility;
- space specificity;
- hazard specificity;
- persistence;
- self-organization [5].

In the cross-sectional domain, determinants describing persistence and desirability are important. Persistence combines adaptation with the development of the city in accordance

with the development path chosen and the maintenance of key structures and functions of the ecosystem [83]. Desirability means the ability of the system to move to more complex, desirable states after a disturbance and to respond to and absorb the disturbance by maintaining or transforming the overall structure, functions and properties. Desirability integrates the determinants of persistence and transformability [86].

In response to the growing problems related to air pollution in cities, an unfavorable functional structure for urban spaces, difficult water management and increased pressure on the environment by the population living in cities, solutions in the field of green and blue infrastructure are implemented at all levels of the management and planning system. In the cities of the Katowice Conurbation, Urban Adaptation Plans (MPA) are being developed, implementing the indications of the "Strategic Adaptation Plan for Sectors and Areas Sensitive to Climate Change in Poland until 2020, and with a perspective until 2030" (SPA 2020) [93]. However, the implementation of green infrastructure projects in the cities of the Silesian Voivodship has encountered difficulties related to reclamation activities conducted incorrectly in the past, which now determine the huge costs of removing ground contamination [94,95]. There are also problems with determining the ownership of plots, as well as abandonment and neglect of the land [70], a lack of funds for implementing and maintaining the project [96] and a low level of awareness and social involvement in the planning process, especially in small towns. Examples of policies related to the implementation of green infrastructure principles in the Silesian Voivodeship include the REURIS project implemented in Katowice and the LUMAT project implemented in Ruda Śląska. Based on Urban Atlas data from 2018 [80], the forms of cover and use of the study area were examined. This was then used to determine the forms of green infrastructure in the area of the REURIS project, establishing that 91.9% (3.77 ha) of the area was covered by forest. In the case of the LUMAT project, green areas covered 77.2% (5.02 ha) of the area under study (Table 2).

Table 2. Land-use structure within the analyzed projects.

Land Use	Share (%)	Area (ha)	Code (Urban Atlas)
REURIS	**100**	**4.1**	
Continuous urban fabric	8.1	0.33	11100 11210 12220
Forests	91.9	3.77	31000
LUMAT	**100**	**6.5**	
Continuous urban fabric	22.8	1.48	11100
Arable land (annual crops)	21.7	1.41	21000
Pastures	44.2	2.87	23000
Forests	11.3	0.74	31000

Source: own research based on [80].

5.2. Effects of GI Implementation in the Area Being Researched

Shaping a space friendly to both residents and the environment under the REURIS and LUMAT projects involved protecting and restoring degraded and abandoned areas of natural, recreational and utility values. Thanks to these projects, an open urban space which can function as a green, public park was created, as well as recreation areas with walking paths and sports facilities.

The implementation of green infrastructure increasing the adaptability of the urban space under the REURIS and the LUMAT projects were achieved by:

- modifying the riverbed using soil bioengineering methods to increase the biodiversity of habitats and establish a zone of protecting river waters against pollution;
- increasing the retention capacity by creating a semi-natural pond with a wetland;

- effecting sustainable water management, including improvements to the existing rainwater drainage system;
- creating a stable plant cover with the use of native species and building educational paths;
- maintaining a land-use balance;
- strengthening local decision-making processes by means of the project planning and implementation process [97–99];
- remediation and phytostabilization of the top layer of the heap by planting plants limiting the mobility of heavy metals in the soil (uptake or stabilization of pollutants in the root zone);
- restoring native flora (increase in biodiversity);
- creating places for recreation and relaxation (industrial playground, vantage point);
- creating a didactic and scientific trail (educational boards, witnesses of history—a metallurgical tank, a block of dolomite);
- increasing the investment attractiveness of the area by increasing green areas in the city (reduction of urban heat islands);
- conducting training aimed at strengthening local identity and boosting the ecological awareness of residents regarding the perception of land and soil as an environmental resource;
- creating structures for the implementation of action plans and links between partners, public authorities and residents (creating formal interactions between cities included in the functional urban area in the scope of selected tasks);
- improving safety and communication (creation of pedestrian and bicycle connections with neighboring districts);
- improving the health of residents by promoting a healthy lifestyle (walking, cycling, outdoor gym) [91,100].

Protecting river waters against pollution was achieved in both cases by modifying (restoring) the riverbed (in Katowice on a 2.2-km stretch of the Ślepiotka River) and planting plants which have collected and stabilized pollution in the root zone. The harmful impact on the environment in the form of migration of pollutants into groundwater and into the food chain has been limited by reducing the bioavailability of heavy metals in the soil. The creation of a permanent vegetation cover on the reclaimed area will serve to prevent any leaching of pollutants into the soil profile. Moreover, the introduction of native and non-invasive plants has contributed to an increase in biodiversity. Maintaining the balance of land use by increasing the extent of green areas has boosted the investment attractiveness of the area and reduced the impact of surface sealing. Improvements made to the existing rainwater drainage system have contributed to increasing the retention capacity, especially in Katowice, by introducing wetlands. The creation of an industrial playground plan in Ruda Śląska, along with educational paths and walking paths, has led to the creation of pedestrian and cycling links with neighboring districts. On the other hand, fostering formal interactions between partners has strengthened local decision-making processes, which also take into account the opinions of users and residents. The latter are increasingly willing to join in the co-creation and co-responsibility for creating the space in which they live.

On the basis of the projects analyzed here, it can be seen that strengthening the adaptability and resilience of urban spaces to the effects of climate change is achieved through the following: integrating activities in planning and strategic space management; involving local citizens in decision-making processes that affect the increase in biodiversity; and increasing the retention capacity of reservoirs and the use of rainwater or the sustainable use of land resources. The above elements have significantly improved the aesthetic, residential and investment values of these post-industrial areas.

6. Discussion

Planning green infrastructure in order to adapt to climate change forces the integration of each type of capital, but above all, it necessitates a holistic and integrated city manage-

ment system [5,82–84,86] This system requires the creation of a network of structural and functional links between natural and anthropogenic resources and the humans living in a given system. Although technology is not directly mentioned in the principles of green infrastructure planning, it is clearly related to the stages and procedures of creating such forms as green roofs or vertical gardens [61,62]. The core of the planning principles for green infrastructure adapting to climate change are features relating to its biodiversity, network connections and multifunctionality.

Polish strategic documents at the regional and national level lack guidelines on the implementation of green infrastructure [84]. With the simultaneous lack of a coherent spatial planning system and the growing fragmentation of ecosystems, Poland is increasingly losing its natural potential to create green infrastructure. The main barriers include the lack of guidelines, legal regulations and effective instruments. The documents contain only general recommendations on preventing the fragmentation of ecosystems, maintaining ecological connections and restoring degraded and anthropogenically transformed areas [84].

The above analysis makes it possible to determine the conditions that should be included in strategic and planning documents in order to use green infrastructure to adapt to climate change and mitigate its effects. The management of green infrastructure resources can be considered in relation to the risks, threats and effects of climate change. As confirmed by the implementation of the REURIS project in Katowice and the LUMAT project in Ruda Śląska, GI elements can contribute to reducing the vulnerability of urban systems to threats by increasing green areas [101]. These activities will significantly reduce the negative effects of urban heat islands [33], lowering the average annual air temperature in the city. In order to reduce the risk of flooding (water retention and surface water runoff) caused by more frequent and prolonged rainfall [7], the preservation of natural riverbanks and the creation of corridors along rivers and canals, a sustainable urban drainage system and retention reservoirs are used. The protection and enhancement of natural capital also affects the economic situation of the city, as the creation of pocket parks and rain gardens enables better management of the urban microclimate [102,103]. With the help of green infrastructure, the effects of climate change are mitigated by improving biodiversity [25–27,44], creating and maintaining existing habitats, increasing green and recreational areas and improving the quality of filtered water. The integration of green and blue infrastructure with gray infrastructure takes place by increasing the density of bicycle and pedestrian paths in the city while ensuring the protection of the natural ecosystem. When adapting to climate change, the great importance of cooperation between public authorities and the involved participants in the projects being implemented should not be forgotten. The literature includes many examples of projects implemented successfully at various levels of urban planning and management, thus showing the possibilities of using and disseminating knowledge that raises the awareness of the society and potential partners.

The cities selected for the study represent areas burdened with the legacy of traditional industry and the negative effects of restructuring (Chorzów, Świętochłowice) and centers where mining activity is still carried out (Ruda Śląska). Considering the specificity of these cities, difficulties related to transforming the existing economy toward a low- and zero-emission economy should be anticipated. These difficulties will particularly concern the social and environmental costs of shaping new development paths for the city. The need to restructure Poland's raw material and energy sector results in the need to transform the functional and spatial structure of cities. Thus, it requires a change in the approach to issues related to spatial planning and shrinking cities [104], regulations and management, cultural and environmental values [17], migration and unemployment, matching competences to the needs of new technologies, social inclusion and exclusion [105,106], the commercial and residential real estate market and the scale of post-industrial areas and abandoned areas [20,107], as well as liquidation processes and the emergence of new business models.

Outlining new development paths for this region requires searching for new concepts of development and technological changes conducive to sustainable socioeconomic trans-

formation and striving to respect the elements of the natural environment. An important dilemma in defining new development paths that strengthen the resilience of post-mining regions is the need to transform the existing functions performed by post-industrial areas. The emergence of problems related to designating new functions, especially for post-mining areas, generates the need to change local and regional land-use strategies and to seek a balance between social and economic needs.

Increasing the potential of greenery in sustainable cities requires implementing effective adaptation measures in public spaces based on blue-green infrastructure. The functional and spatial concept of cities should be of a systemic nature [61], as only such an approach strengthens the resilience of cities to threats resulting from climate change. The role of spatial planning in adapting cities and strengthening their resistance to climate change should promote the development and effective implementation of green infrastructure, which improves the quality of life and the aesthetics of public spaces.

When considering the role of green infrastructure planning in post-industrial cities undergoing social and economic transformation, it is particularly important to consider whether projects mainly of district scope, and without maintaining a network of spatial connections, will be able to generate or strengthen the ability to adapt to or mitigate climate change. According to the authors, the barriers (i.e., structural/operational, regulatory and legislative, cultural and behavioral) discussed in this paper may effectively limit the development of the city's adaptability and resilience. We propose that in order to successfully implement green infrastructure projects, all enabling factors should be taken care of at different stages of their implementation. What this means is that at the design stage, for example, the high level of interaction between spatial planning policy and local/regional/national that needs to be achieved by ecosystem services should be demonstrated [108,109]. At this stage, a high level of involvement from stakeholders should be ensured, involving them in the c [110]. The project concept should outline common and clear goals for both partners and stakeholders. Therefore, it is necessary to ensure cross-sectoral cooperation, clearly defining the roles and responsibilities of public and private entities [108,109]. The flexible structure of the project should help to develop ideas freely, to choose activities and to identify factors affecting the timeframe or making it difficult to secure financial resources for its successful implementation [111]. At this stage, attention should be paid to continuously raising public awareness and involving stakeholders in order to define priorities based on the opinions of the local community and experts [111,112]. At the stage of implementing a green infrastructure project, care should be taken to secure sources of financing and obtain opinions from various interested sectors. Ensuring the investment is perceived positive by public decision-makers and the general public is especially important [109]. In the maintenance and monitoring phase, a strong network of relations between institutions, non-governmental bodies and the local community should be forged. Finally, it is important to secure a source of long-term financing for the project and strengthen the organizational structures dealing with the maintenance of the investment after its completion [108,111–114].

7. Conclusions

This article emphasizes the need to translate the theory of climate adaptation at the local stage into the practice of spatial planning and indicates one such way, i.e., green infrastructure. Better planning and design of green infrastructure reduces vulnerability and increases the urban system's resilience and adaptability. This is especially important in the cities and (post-)industrial regions discussed in the article, such as Katowice.

Preliminary conclusions from research on the effects generated by projects implemented as part of green infrastructure indicate its significant impact on bolstering the adaptive capacity of cities. Adaptation is achieved mainly through the regeneration of degraded urban spaces and transforming them to perform new functions, rational space management and the coexistence of urbanized and green space. Implementing green infrastructure to counteract climate change at the local level should serve to improve the

ecological condition and protect the biodiversity of open spaces in the city, locally secure excess water and prevent flooding by applying engineering solutions for natural systems. As a consequence, this would increase the residential, cultural and recreational values of the area. As indicated in the article, when implementing green and blue infrastructure in large cities of a post-industrial region, attention should first be paid to the elements that comprise the economic and social resources, as well as the effectiveness of the governance and planning system. In order to increase the adaptability of post-industrial cities, the authors suggest maintaining investment continuity (minimizing the dispersion of projects) and spatial coherence, providing financial resources to maintain the effects generated by the project after its completion and increasing the environmental awareness of users of a given space by including them in decision-making processes. The barriers resulting from the above factors may appear at each stage of the project, in some cases preventing its implementation.

The concept of green infrastructure has become one of the most efficient and effective planning tools for mitigating climate change as well as adapting to it. In order to obtain the most effective benefits from the use of green infrastructure, activities in the field of planning and managing urban space should be integrated. In large and (post-)industrial cities, green infrastructure should also be a key element of the city's spatial policy.

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