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Assessing Urban Resilience with Geodesign: A Case Study of Urban Landscape Planning in Belgrade, Serbia

Sandra Mitrović [1], Nevena Vasiljević [1,*], Bojana Pjanović [2] and Tijana Dabović [2]

[1] Department of Landscape Architecture, Faculty of Forestry, University of Belgrade, Kneza Višeslava 1, 11000 Belgrade, Serbia; sandra.mitrovic@sfb.bg.ac.rs
[2] Department of Spatial Planning, Faculty of Geography, University of Belgrade, Studentski Trg 3, 11000 Belgrade, Serbia; bojana.pjanovic@gef.bg.ac.rs (B.P.); tijana.dabovic@gef.bg.ac.rs (T.D.)
* Correspondence: nevena.vasiljevic@sfb.bg.ac.rs; Tel.: +381-64-1153-857

Abstract: Resilient cities have emerged as novel urban ecosystems that respond to the increasing challenges of contemporary urban development. A new methodological approach is needed to measure and assess the degree of resilience of the urban landscape during the ongoing planning process, considering different planning and design scenarios. Based on this consideration, the first attempt of this study was to develop a resilience index that summarizes the application of resilience theory in urban landscape planning. Is geodesign an appropriate tool to assess urban resilience? This was the main research question and the topic of the workshop "IGC—Resilient City of Belgrade" at the Faculty of Forestry, University of Belgrade (Master Landscape Studio). The main result of this research is a model for urban resilience assessment with IGC geodesign, which allows to measure scenario changes through developed resilience indicators (index), which are determined by a set of parameters (area, redundancy, diversity, porosity, carbon sequestration, edge type, edge length, etc.). The methodological approach allows quantifying the impact of adopted innovations in geodesign scenario proposals, which plays a crucial role in strengthening the connection between landscape planning and design. In the context of the novel urban ecosystem, future urban landscape planning should focus on resilience as a measure to achieve sustainable development goals, supported by geodesign as a collaborative and spatially explicit negotiation tool.

Keywords: geodesign; urban landscape; resilience assessment; landscape planning; resiliency index; geodesign

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1. Introduction

The society of the 21st century is an urban society. The result of the global urbanization process is an urban fabric that cannot be captured by the nineteenth and twentieth centuries. Scholars and professionals conceptualized the city as a novel urban ecosystem [1]. This new city will be the most populated habitat in the world, and the phenomenon of spatial expansion is four times larger than the population [2]. With the modern spatial development of cities, the need for greater use of natural resources increases, and proportionally to these activities, the sensitivity of cities to disasters caused by population migration and climate change increases. Novel urban ecosystems have "no analog" and are progressively becoming the subject of research to understand their origins, ecological trajectories, and opportunities for developing new management goals and planning approaches [3]. In contemporary visions of sustainable cities, a resilient city represents the desired and ultimate goal.

Resilience is a measure of the system's capacity to absorb change, and some ecosystems are more resilient than others [4]. Although the concept of resilience is related to the ecological aspect of analyzing and assessing the state of the ecosystem [5], it appeared in landscape management in the 1990s [6–8]. The concept of resilience is comprehensive and complex, which complicates and challenges its application to contemporary urban planning and design [9]. Nevertheless, measuring urban resilience is necessary in order to operationalize the concept into a more normative approach to urban planning that shifts from a pure descriptive/analytical assessment to defining a spatial support system that aids system transformation in a long-term and co-evolutive manner [10].

Ahern [3] proposed some strategies for an interdisciplinary discourse on urban sustainability and resilience in urban landscape planning. These include biodiversity, urban ecological networks and connectivity, multifunctionality, redundancy, modularity, and adaptive design [3,11,12]. The concept of resilience (as opposed to the concept of sustainability, which implies maintaining a stable state) is beneficial to urban planners and designers who strive to create cities and urban landscape forms that are adaptable to changing conditions and needs [13,14].

The urban landscape form that is congruent with the "deep structure" or enduring context of a city's natural environment will be more resilient (Spirn, 1984). In the context of urban planning at different scales, it is particularly important to design resilient landscape structures as a desired outcome. "No matter how well one understands a city's history, its ecosystems, and its enduring context, no matter how carefully one tries to anticipate the future, there will always be unforeseen circumstances to which a city must adapt" [4]. To reduce uncertainty and unpredictability, geodesign applies systems thinking to urban planning and design, seeking to understand the big picture in a dynamic of territorial transformation in terms of short- and long-term change. The potential of the geodesign framework is seen as a tool that creates scenarios that anticipate the future under different circumstances [15,16].

In order to measure and evaluate the degree of urban landscape resilience in the context of the ongoing planning process, it is crucial to develop a new methodological approach that takes into account different planning and design scenarios. Based on these considerations, the first attempt of this study is to develop a resilience index that summarizes the application of resilience theory in urban landscape planning. The study area is the Municipality of Belgrade (Belgrade), which is an optimal context for this study considering that the Master Plan of the City of Belgrade (until 2041) has just been drafted and is currently being adopted by the City Parliament. In the age of new technologies and new data, urban landscape planning needs tools that are more site-specific and use-oriented. At the same time, it should inspire a new generation of university students and prepare them for new approaches to collaborative landscape analysis and planning. Is geodesign an appropriate tool for assessing urban resilience? That is the main research question of this paper. Based on a review of the student workshop "IGC—Resilient City of Belgrade" which was held at the Faculty of Forestry, University of Belgrade (Master Landscape Studio), we will explain why the geodesign scenario is suitable for quantitative assessment of resilience and why it is important to plan and design innovations within ''non-resilient" infrastructure systems, which establishes the link between landscape planning and design across different planning scales.

2. Materials and Methods

2.1. Research Area and Data

The city of Belgrade is the capital and the largest city of the Republic of Serbia. Belgrade and its surroundings are located at the confluence of the Danube and Sava Rivers, on the border between the Pannonian Plain and the Balkans-Šumadija region (44°48′52″–44°50′67″ N and 20°31′68″–20°37′22″ E) (Figures 1 and 2a).

The city area of Belgrade's Urban Master Plan covers an area of 77,851.52 ha, divided into 11 municipalities where 1,376,898 inhabitants, or 18.31% (2022) of the total Serbian population, live [17].

The case study of the IGC Experimental Workshop was conducted at scale, where the boundary edges were defined in a square of 15 by 15 km, focusing on the south-western edge of the city of Belgrade. The area focused on in this paper includes the territories of the following cadastral municipalities (CM): CM Novi Beograd (Figure 2f) and CM Surčin (Srem—Figure 2i), CM Čukarica (Figure 2d,e,h), CM Savski Venac (Figure 2c,g), and CM Stari Grad (Šumadija) and covers an area of 13,700 ha (137.34 km^2).

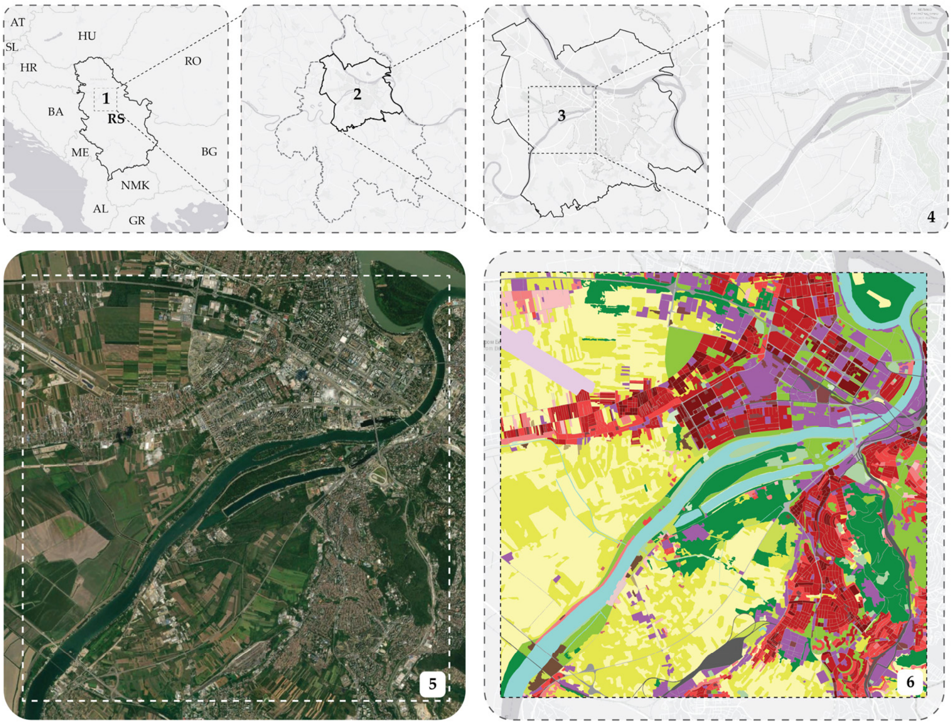


Figure 1. Study area (1) Republic of Serbia; (2) Regional administrative area of Belgrade; (3) Belgrade Master Plan boundaries; (4) case study boundaries; (5) aerial view of the study area; (6) case studyUrban Atlas 2012 database.

Figure 2. Photos of the situation (**a**) Confluence of the Sava and Danube Rivers; (**b**) The Great War Island; (**c**) The left bank of the Sava; (**d**) Košutnjak forest and panoramic view of New Belgrade, Savski Venac, Stari Grad; (**e**) Požeška street—CM Čukarica; (**f**) Blocks 61, 62, 63, and 64, New Belgrade; (**g**) Belgrade Waterfront; (**h**) Ada Ciganlija; (**i**) Agricultural lands of Surčin.

The landscape of the study area is characterized by fluvial, diluvial, and karst relief consisting of alluvial plains of varying widths, with most of the area being considered anthropogenic relief. In morphological terms, it can be characterized as a combination of lowlands and hills with elevations ranging from 73 to 117 m a.s.l. The geographical location gives the area a mild-continental climate with an average annual temperature of 12.7 °C and annual precipitation of 750 mm [18]. The study area includes several landscape character types: (1) the urban landscape of New Belgrade; (2) the urban landscape of the Belgrade Ridge; (3) the marsh landscape of the Sremska Plain; (4) the alluvial landscape of Posavina; (5) the karst landscape of Belgrade; (6) the Zemun plateau; (7) the village of Rakovica, Beli Potok, and Pinosava; and (8) the landscape of the Great War Island (Figure 2b) as the core of the natural area of the Belgrade urban landscape [19]. The Great War Island is an area of the NATURA 2000 and the EMERALD network sites and has integrated its structure, function, meaning, and changes into Belgrade urban cores (Stari Grad, Zemun, and New Belgrade), which is why its value is read and interpreted as an integral part of the urban landscape character.

The study area is characterized by a heterogeneous structure, which can be seen in the complex relief and ecological and cultural patterns. The current form of urban development is characterized by a highly modified and changed environment. Considering the trends of investor urbanism and land use changes, the city of Belgrade is developing towards a non-resilient scenario. As the case study includes part of the natural core of the city of Belgrade (Natura 2000 site—Great War Island), the investigated area represents a dynamic system of sensitive and complex ecosystem services, starting with natural and then cultural ones (Figure 1). Given these circumstances, the application of geodesign and resilience assessment using measurable variables and a quantitative framework is crucial to understanding the urban spatial resilience patterns in Belgrade. By studying the ongoing urbanization pressures and their impact on agricultural land and protected natural areas, this case study aims to shed light on the challenges and opportunities for building resilience in an intensively developing city like Belgrade.

The city of Belgrade is developing intensively at the expense of agricultural land and protected natural areas, and the pressures are located in:

- The open residential blocks of New Belgrade (Figure 2f) and its public green spaces;
- The arable lands of Surčin (Figure 2i), for which the special purpose area of the National Football Stadium was adopted in the Master Plan of Belgrade for 2041;
- Arable land in CM Čukarica in the settlement of Železnik;
- A constant construction pressure is exerted on the free/open areas of the wider zone of protection of the sanitary water sources of the Sava River (Municipality of Čukarica—Topčiderska river basin—Figure 2e, Ada Ciganlija, and Makiš—Figure 2h; Stari Grad municipality—lower plateaus, Beton Hall, Sava Mala—Figure 2c,g; New Belgrade—from the Belgrade Fair to the confluence of the Sava and Danube Rivers—Figure 2a, Zemun) [20].

2.2. The Theoretical Background of Urban Resilience Assessment

"The literature review shows that the concept of resilience can be defined as the system's ability to withstand significant damage [5,21–23] to anticipate, absorb and accommodate or recover from the impact of hazardous events [22,24,25], while maintaining key structural, functional, and identity elements [26]", "absorbing disturbances and achieving a balance", "self-reorganization" and "increasing the capacity for learning and adaptability" [22,27]. The concept of urban resilience emphasizes adaptability, compatibility, and reinforcement of the urban system to reduce risks and adapt to ongoing changes [22,28]. It focuses on embracing change rather than pursuing stable states while recognizing the dynamic nature of urban systems. Resilience is seen as a process or ability rather than a fixed outcome, contributing to instability, change, and the establishment of a new equilibrium [22]. "Urban resilience is not necessarily the ability of a system to go back to the previous state and equilibrium point while the system is experiencing the disruption or shock" [22]. It does not necessarily involve returning to the previous state or equilibrium point during the disturbance.

The ability of novel urban ecosystems to reorganize and recover from disturbances without major changes in their primary structure is defined as "safe to fail" [9]. An even more important "safe-to-fail" position anticipates disruptions and strategically shapes systems so that disruptions are contained and minimized [29]. When presented in this context, the sustainability of the urban landscape encompasses more than just a well-planned urban form. Contemporary urban landscape planning, through the introduction of resilience thinking [6,9,30,31], offers concepts and methods to free planning from its obsession with order, certainty, and stasis. It highlights the uselessness of "blueprint planning"—"fail-safe design"—and addresses complex, profound, and dynamic socio-environmental problems. In the context of urban planning, resilience thinking focuses on persistence, change, and unpredictability from the evolutionary perspective of biologists seeking safe-fail designs. It encompasses creating an environment that supports the well-being of its residents and enhances the physical infrastructure of the city to minimize disruption and interference caused by environmental factors [6,9,30,31]. In light of characteristic urban dynamics and disturbances, Ahern [9] proposed five strategies for urban planning and design to build urban resilience: multifunctionality, redundancy, modularization, (bio and social) diversity, multi-scale networks and connectivity, and adaptive planning and design. "Carlos and Eduarda [6,29] found that urban system resilience needs to be assessed against the criteria of multifunctionality, self-sufficiency, modularity, diversity, and flexibility in the context of learning and adaptability; Suárez et al. [6,32] outlined the key factors for maintaining resilience in urban systems, including diversity, modularity, tightness of feedbacks, social cohesion, and innovation; and Zhang et al. [6,33] selected the assessment indicators for urban system ecological resilience based on the resilience principles of diversity, slow variables, openness, social capital, and ecosystem services" [6].

For urban landscape planning, resilience assessment of urban landscape structure becomes an important tool for evaluating/measuring the impact of changes envisaged by urban plans. In order to transform the resilient city, which is theoretically a complex system, into a quantifiable dimension, researchers are trying to develop criteria and measurable indicators for urban resilience assessment. To measure indicators of urban landscape resilience, the answer to the question "resilience of what?" set by A. Sharifi and Y. Yamagata [34], Fariba et al. [22] proposed an assessment of the structure and function of urban landscapes based on the spatial organization of (1) the components of the natural environment and (2) the components of the built environment. When significant relationships between structural landscape features and ecological functions are established, landscape metrics-based approaches are useful tools for planning [11,35–37]. The size of landscape elements (AREA) is one of the fundamental metric parameters that alone can provide essential information about the characteristics of landscape stability at different levels of organization. The number and size of natural landscape elements (NP, SHDI, and EDGE) indicate the intensity of fragmentation and can be interpreted as a spatial indicator of the degree of biodiversity [11,35–38]. These structural and functional relationships support the anticipation of the ecological consequences for plans and designs of the landscape and ultimately help to make landscapes more sustainable.

With previous studies in mind, a resilience index is a combination of several indicators that can be converted into parameters to be applicable in the urban landscape planning process (Figure 3).

2.3. Research Methodology

The geodesign framework was applied in this study to design and evaluate scenarios from an urban resilience perspective (Figures 3 and 4). The study analyzes the current state of the investigated area and compares it with different design scenarios developed. Scenario evaluation can help address the problems of former and future planning results and is an effective tool to bridge the gap between the assessment and planning stages. The geodesign framework involves the creation of Steinitz's six models: the representation, process, evaluation, change, impact, and decision-making models. This study, like most of the IGC studies, was conducted following IGC guidelines (https://www-igcollab.hub.arcgis.com/pages/workflow, accessed on 16 May 2023), with the methodological approach adapted for the purposes of the Landscape Planning and Design Studio. The studio was conducted at the Faculty of Forestry, University of Belgrade, and taught on a voluntary basis to 12 students of the Department of Landscape Architecture using the proposed methodological framework (Figure 4):

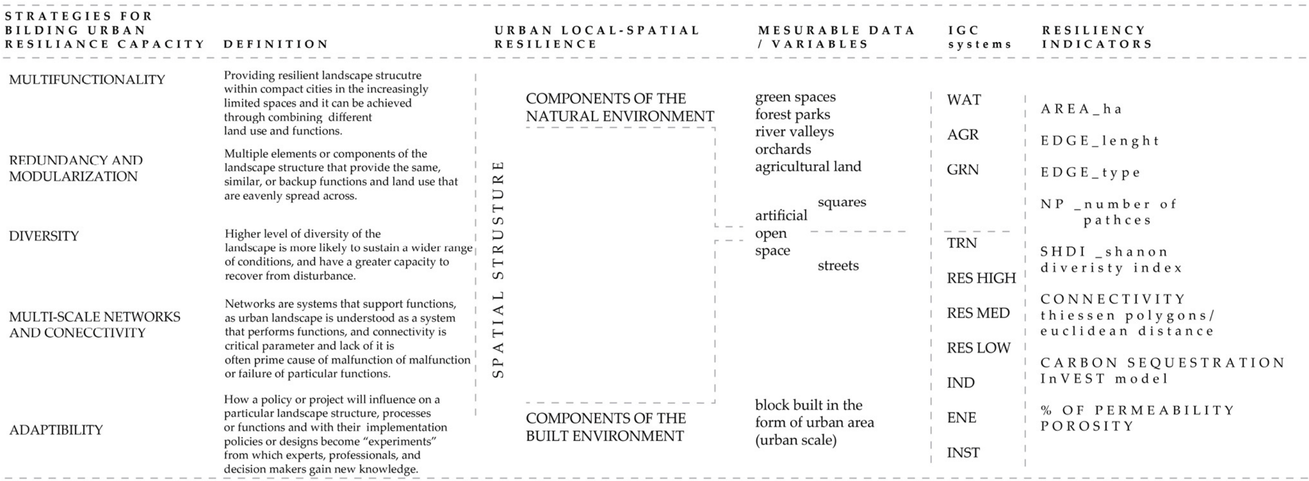


Figure 3. Resiliency index development [9,22,36].

Phase 1: Scope and Context follow the (1) definition of the study area and (2) organization and implementation of the IGC workshop. The workshop follows the steps (current state evaluation) and subphases such as (a) knowledge building phase (process model); (b) landscape structure interpretation (representation model); and (c) landscape structure evaluation (an evaluation model that is a critical review of the current landscape structure).

Phase 2: Scenario Design—in correlation with the change model, this phase follows the steps of (1) the definition of the system innovation catalog for selecting projects, policies, and strategies for the future development of the study area and the creation of diagrams/polygons that represent the innovations in relation to the concept of urban resilience and the context of the study area. The second step of this phase is (2) scenario development, which resulted in six proposed scenarios for the future development of the case study, representing three-time stages: 2022, 2035, and 2050, under three scenarios: Early Adopter (EA), Late adopter (LA), and Non-Adopter (NA), which were created in the software GIS and Geodesignhub.

Phase 3: Scenario evaluation—assessment of the impact of the designed scenario proposals. The first step was (1) to define the landscape ecological indicators to measure the resilience index, and the second step was (2) to evaluate the scenario performance, measuring the resilience level for each developed scenario.

Scenario evaluation (the impact model) is aligned with the development of a resilience index that measures landscape structure using metric parameters (Figure 3). In the assessment of Belgrade's urban resilience, landscape elements are considered an integral part of infrastructure systems, where class metrics are applied to evaluate the level of urban resiliency, considering the ecological characteristics (diversity, connectivity, multifunctionality, redundancy, fragmentation), and dynamics of these systems. The concept of parameters used to develop the resilience index was guided by Ahern's resilience strategies and their implementation in landscape metrics by Botequilha Leitao et al. [36] (Table 1). IGC system structure was observed and measured through landscape components of the built and natural environments defined by Gharai and colleagues [22] (Figure 3).

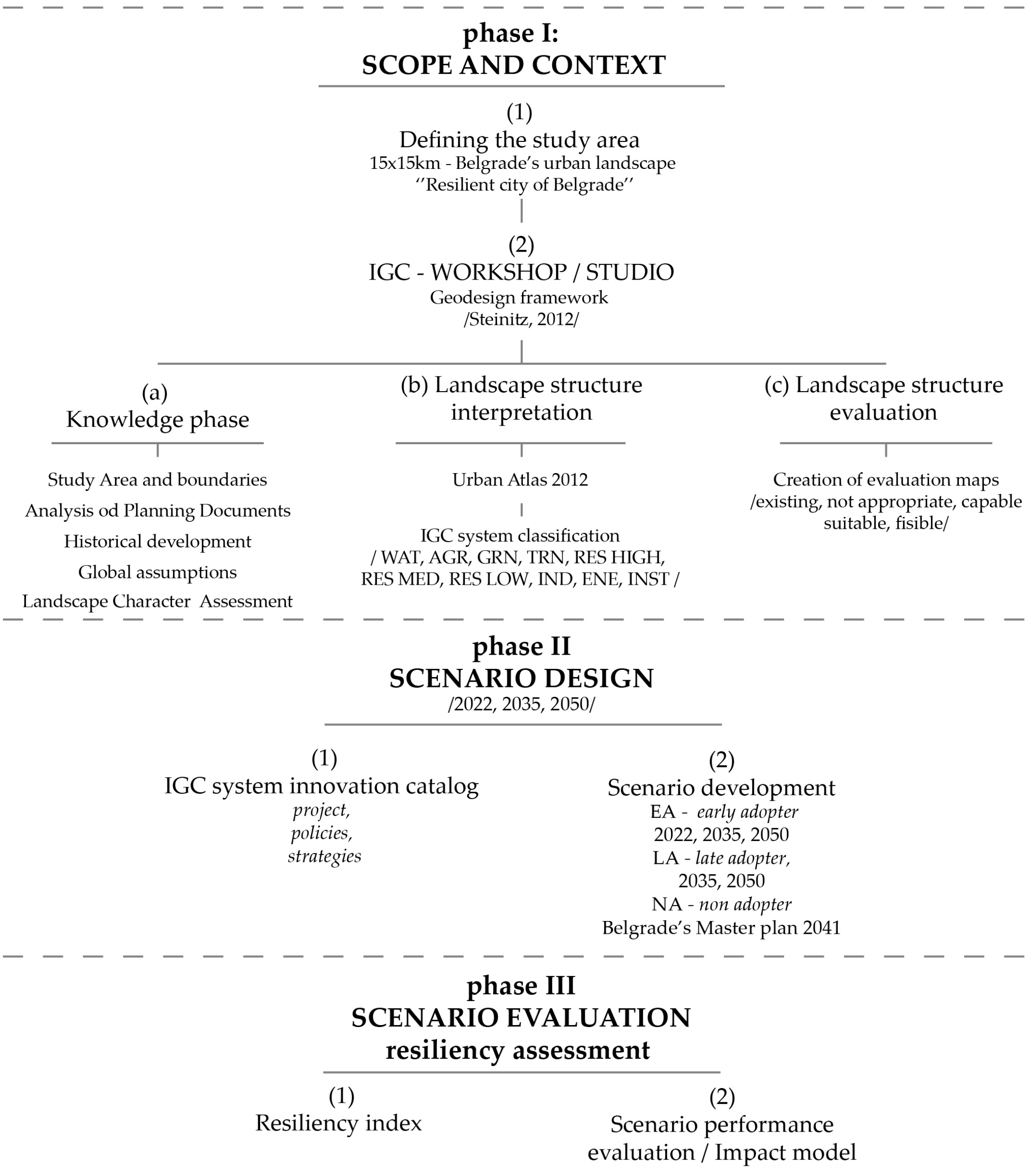


Figure 4. Methodological framework [15].

Changes in landscape structure according to different scenario designs are represented by composition and configuration parameters for components of the built environment (TRN, RES HIGH, RES MED, RES LOW, ENE, IND INST) and the natural environment (WAT, AGR, GRN). The level of change is calculated as the percentage share of the area (AREA) for each system, the total edge length of the system (Total_EDGE_lenght), the edge type (EDGE_type) presented as the length of edge between two adjecent systems (AGR-GRN, WAT-GRN, AGR-WAT), the number of patches as the number of polygons within each system, and the Shannon diversity index (SHDI) The index represents a measure of different types of system polygons and their spatial distribution, expressing dominance as opposed to uniformity. InVest Carbon Sequestration (CSQ) measures the level of CO_2 absorption in plants—above and below ground, in the soil, in the dead matter—where it would contribute to climate change and the % of permeability, for which we used the Copernicus imperviousness database.

Table 1. Resiliency indicators, metric parameter description, and calculation.

Metric Parameter	Concept of Parameter	Calculation Equation	Indicators
AREA_ha	This indicator can be used as a quantitative measure of the transformation process of structural changes in the landscape from the perspective of landscape multifunctionality.	$CAP_i = \frac{\sum_{j=1}^{n} a\sqsupset j}{A}$	**Multifunctionality/ Redundancy and Modu-larisation/Diversity**
NP	More patches and heterogeneity in a single IGC system class ensure redundancy within a landscape and a higher level of resilience and stability.	$PN = \sum_{i=1} P_i$	
SHDI	It measures the diversity of patches within a landscape structure and is a way of measuring the uniformity of different land use patches within a landscape structure. The higher the value of H, the higher the diversity of species in a particular community. The lower the value of H, the lower the diversity. A value of H = 0 indicates a community that has only one species.	$H = -\boldsymbol{\Sigma p i} * ln(p\boldsymbol{i})$	
% of porosity	It indicates the percentage (%) of built and unbuilt area within the landscape structure, shows the capacity of the landscape to infiltrate atmospheric water and the amount of surface runoff, and regulates the local climate.		**Multifunctionality**
Carbon Sequestration	It measures carbon storage in wood, other biomass, and soils. Ecosystems keep CO_2 out of the atmosphere, where it would contribute to climate change.	$\boldsymbol{value\_seq_x} = \boldsymbol{V}\frac{s_x}{q-p}\sum_{t=0}^{q-p-1}\frac{\mathbf{1}}{\left(\mathbf{1}+\frac{r}{100}\right)^t\left(\mathbf{1}+\frac{c}{100}\right)^t}$	
EDGE TYPE	It indicates the transition or ecotone between two different systems, usually used in reference to the terrestrial area under the ecological influence of an adjoining aquatic environment.	Sum value of Edge length between AGR and GRN, AGR and WAT, GRN and WAT infrastructural system	**Diversity/ Multi-scale networks and connectivity**
TE_total edge lenght	It describes the patch area (larger perimeter for larger patches), but also the patch shape (larger perimeter for irregular shapes).	$TE = \sum_{k=1}^{m} e_{ik}$	
ENN	It indicates the spatial distribution of patches of a particular type and their proximity as a factor of ecological functionality.		**Multi-scale networks and connectivity**
system innovations	It represents the possibility of a land use adopting/accepting one or several new functions/land uses/innovations.	Number of adopted inovations	**Adaptibility**

3. Results

This chapter presents the findings of a two-phase urban resilience assessment. The first part, ''Scenario proposal description", presents the scenarios developed during the IGC workshop that focused on the concept of a resilient city (Figure 5). The second part, "Results of scenario evaluation", presents the outcomes of using a developed resilience index to evaluate the scenarios from the first phase to understand how scenarios change in terms of resilience levels.

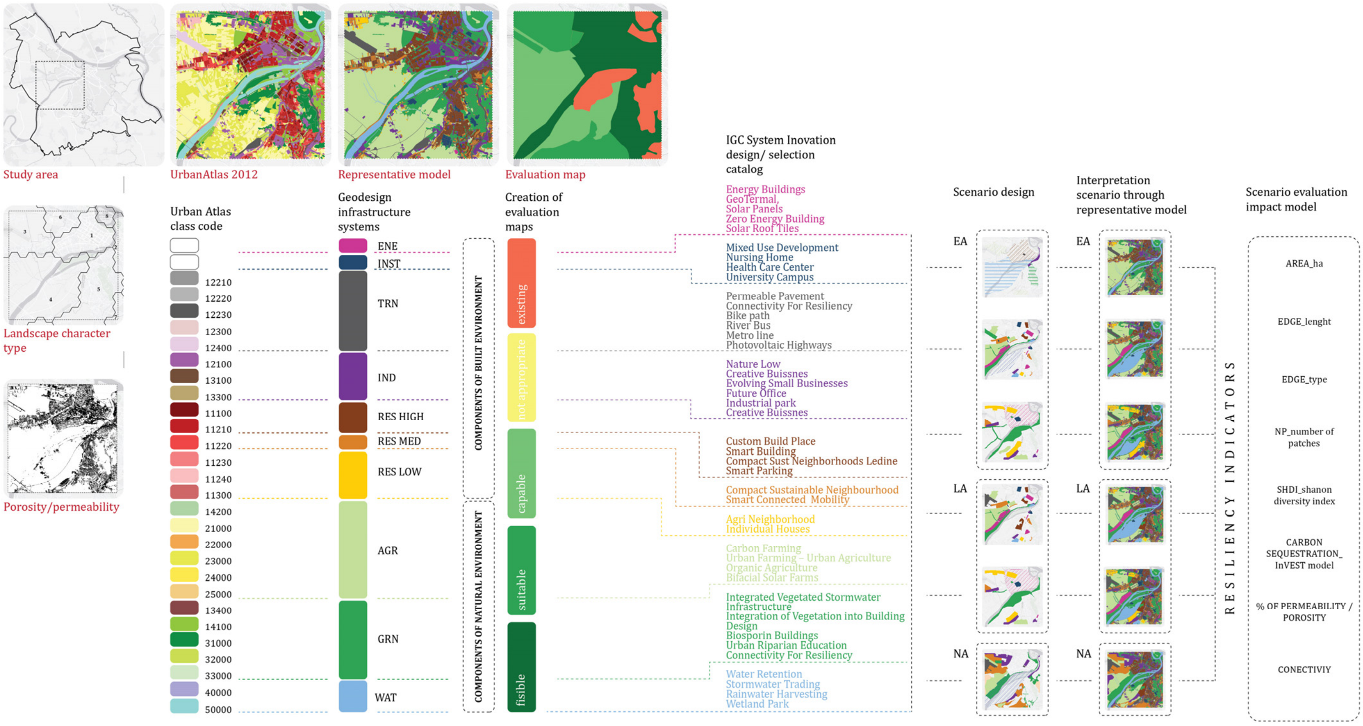


Figure 5. Urban resiliency assessment with geodesign: constructed model.

3.1. Scenario Proposals Desctiption

3.1.1. Early Adopter (EA) Scenario

The scenario of early adoption of innovations foresees the complete abandonment of the idea of building on the Sava water source protection area and the introduction of policies that will ensure its adequate protection, improvement, and use in the future, as well as the elimination of uses that are not appropriate in this part of the study area, such as industry, oil storage, etc. Policies and innovations are also being introduced that lead to the preservation of the current urban form of the New Belgrade's blocks and the protection of agricultural lands within the study area. The scenario assumes the maximization of projects that increase the level of resilience of the urban landscape of the city of Belgrade. These innovations aim to preserve existing close-to-nature areas within a highly urbanized city center, achieving the sustainable development goals (SDG 11) in parallel with protection. The applied innovations in the process of creating a scenario of early adoption within the components of the natural environment are organic agriculture, carbon farming, urban farming, rainwater harvesting, floating wetland parks, water retention, connectivity for resiliency, buffer zones, and green hotels. The adopted innovations within the components of the built environment are biosporin buildings, smart buildings, mixed-use, custom buildings, smart parking, compact sustainable neighborhoods, smart connected mobility, agriculture neighborhoods, individual housing, nursing homes, health centers, university centers, bifacial solar farms, solar panels, geothermal energy, zero energy buildings, solar roof tiles, evolving small businesses, creative businesses, future office spaces, and industrial parks (Figure 6a,b).

3.1.2. Late Adopter Scenario (LA)

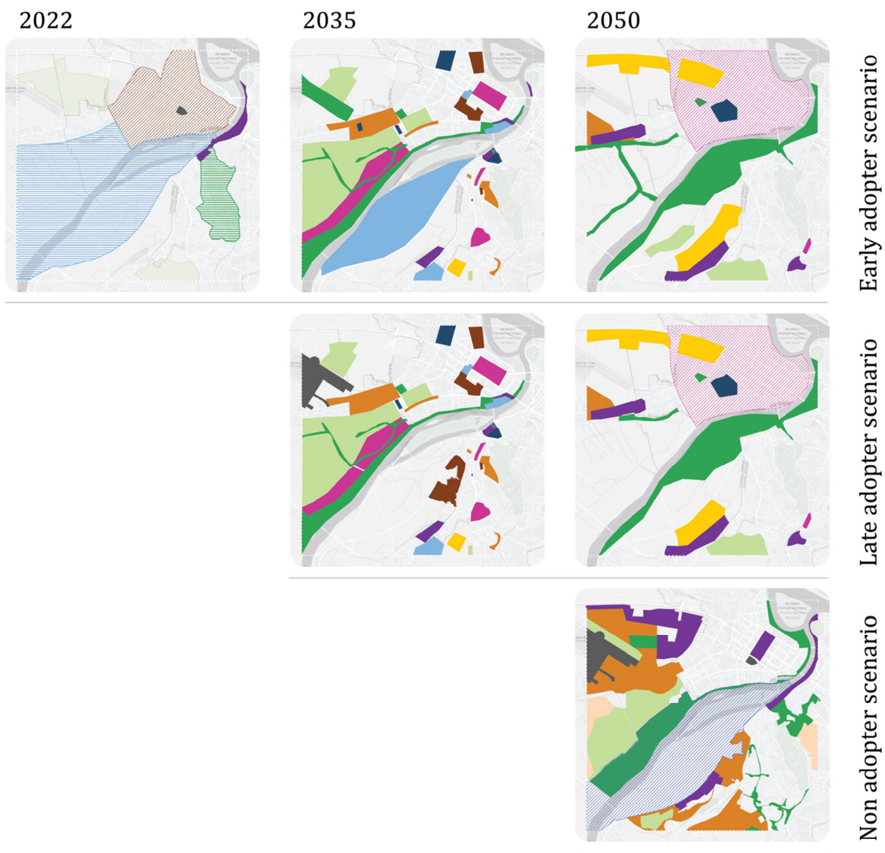
In this scenario, there is no introduction or application of innovations for the period from 2022 to 2035. In this period, planning and development take place within the framework of existing plans and laws. For the study area, this means that high-rise construction begins within the wider protection zone of the Sava water source, conversion of agricultural land into construction land, densification increase of buildings in New Belgrade, and building Košutnjak. At the beginning of 2035, the implementation of innovations will begin in order to reduce the impact of the realized plans and increase the level of the resilience index. The applied innovations in the process of creating a scenario of early adoption to the components of the natural environment are organic agriculture, carbon farming, urban farming, rainwater harvesting, floating wetland parks, water retention, connectivity for resiliency, buffer zone, and green hotel; adopted innovations within the components of the built environment are biosporin buildings, smart building, mixed-use, custom building, smart parking, compact sustainable neighborhood, smart connected mobility, agriculture neighborhoods, individual housing, nursing home, health center, university center, bifacial solar farm, solar panels, geothermal energy, zero energy buildings, solar roof tiles, evolving small business, creative business, future office space, industrial park (Figure 6a,b).

3.1.3. Non-Adoption Scenario (NA)

The non-adoption scenario of innovations is represented by the Belgrade Master Plan, which will be in effect from 2022 to 2041. It is interpreted through infrastructure systems and has no application of innovation; development trends remain in their usual frameworks and do not contribute to the growth of the resilience level (Figure 6a,b).

3.2. Results of Scenario Evaluation

According to Steinitz's model of landscape planning, the scenarios developed during the IGC (EA, LA, and NA) were assessed using indicators of resilience (Table 2). For each indicator, metric parameters were selected to measure changes in the components of the built environment (TRN, RES HIGH, RES MED, RES LOW, ENE, IND INST) and natural environment (WAT, AGR, GRN) (Table 2).



(**a**)

Figure 6. *Cont.*

(**b**)

Figure 6. Scenario design (**a**,**b**).

Table 2. Resiliency index results.

Parametri	EA						LA				NA		Indicators
	2022		2035		2050		2035		2050		2050		
	CN	*CB*	*CN*	*CB*	*CN*	*CB*	*CN*	*CB*	*CN*	*CB*	*CN*	*CB*	
AREA_ha	8725.52	5011.06	8492	5244.93	7854.72	5882.02	8038.74	5697.8	7723.14	6013.51	6825.72	6910.51	**Multifunctionality/ Redundancy and Modularisation/Diversity**
NP	525	1634	616	1530	591	1566	594	1556	587	1573	486	1454	
SHDI	1.7819		1.9904		2.0101		1.9873		1.9907		1.7022		
% porosity	80–100%	0–30%	80–100%	0–30%	80–100%	0–30%	80–100%	0–30%	80–100%	0–30%	80–100%	0–30%	**Multifunctionality**
Carbon SQ	0.35–1.4	0.35–0.7	0.35–1.4	0.35–0.7	0.35–1.4	0.35–0.7	0.35–1.4	0.35–0.7	0.35–1.4	0.35–0.7	0.35–1.4	0.35–0.7	
EDGE_type	143.0930	/	134.5196	/	137.2542	/	129.8100	/	150.6164	/	115.5576	/	**Diversity/Multi-scale networks and connectivity**
TE_Total edge length	983.82	2530.39	932.49	2404.2	952.54	2422.09	909.24	2431.04	919.19	2231.32	828.45	2231.32	
ENN	400–1000 m	0–400 m	400–1000 m	0–400 m	400–1000 m	0–400 m	400–1000 m	0–400 m	400–1000 m	0–400 m	400–1000 m	0–400 m	**Multi-scale networks and connectivity**
Innovation system	0	0	9	13	7	10	9	14	5	10	0	0	**Adaptability**

3.2.1. Results of the Measurement of Multifunctionality, Redundancy and Modularization, and Diversity

The results of measuring the components of the natural environment infrastructure system within the WAT, GRN, and AGR show a decline in EA2022 to EA2050 (8725.52 ha to 7854.72 ha), while LA2050 (7723.14 ha) and NA2050 (6825.72 ha) continue to decrease (Figure 7). In scenario EA2035, 9 innovations are included, including organic agriculture, carbon farming, urban farming, floating wetland parks, connectivity for resiliency, water retention, buffer zones, and enhanced multifunctionality, and another 9 in scenario EA2050, including organic agriculture, urban farming, wetland parks, water retention, urban riparian education, and connectivity for resiliency. The results of measuring the components of the built environment showed increased values in the RES LOW, RES MED, ENE, and IND systems in each scenario (Table 2). The total area of the infrastructure system's changes from scenario EA2022 to EA2050 (5011.06 ha to 5882.02 ha), while from scenario LA2035 to LA2050 there is growth (5697.80 ha to 6910.51 ha). The NA2050 scenario increases by 1899.45 ha compared to the representative model (Table 2, Figure 7). The changes in the built environment result from diverse design approaches aligned with resilience principles. The EA2035 scenario embraces innovations such as compact sustainable neighborhoods, agriculture neighborhoods, health centers, nursing homes, industrial parks, and creative businesses, covering 5244.93 ha; the EA2050 scenario includes compact sustainable neighborhoods, smart connected mobility, individual housing, university campuses, solar panels, geothermal energy, solar roof tiles, and zero energy buildings, covering 5882.02 ha. The NA2050 scenario reflects higher values consistent with urban development trends but does not include innovations (6910.51 ha).

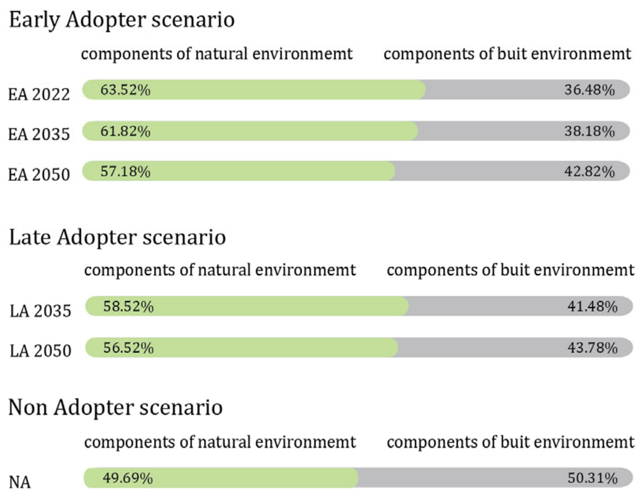


Figure 7. Metrics parameter: Area_ha in %.

The number of patches within the components of the natural environment gradually increases in the EA and LA scenarios, indicating the addition of new patches of infrastructural systems and innovations. The number of patches within the components of the built environment is higher but decreases from the representative model toward the developed scenarios. Limitations in detecting prior innovations could affect the accuracy of these results. The results show a gradual increase in the number of patches within the components of the natural environment in the EA scenario: NP = 525 (2022), NP = 616 (2035), slightly declining in the EA 2050 (NP = 591) due to the implementation and combinations of innovations such as organic agriculture, carbon farming, urban farming, rainwater harvesting, floating wetland parks, water retention, and connectivity for resilience. Similar trends can be seen in LA: NP = 594 (2035) and NP = 587 (2050). The NA scenario has the lowest patch count: NP = 486 (Table 2). The components of the built environment show higher levels than components of the natural environment in a number of patches, but the area of individual patches is smaller in size. The patch count results decrease from the representative model to EA 2050 (NP = 1634), LA 2050 (NP = 1573), and NA 2050 (NP = 1454). The model needs upgrading to recognize innovations adopted earlier so that the results are correct in terms of multifunctionality, redundancy, modularization, and diversity (Table 2).

Combining the results of NP with the parameter AREA_ha indicates increased multifunctionality, redundancy, modularization, and diversity. A smaller patch area but a higher number of patches throughout the area correspond to the resilience principles of redundancy and multifunctionality. The results show a slight increase in multifunctionality in EA and LA due to new functions overlapping with the existing ones.

Diversity analysis was performed using the Shannon diversity index (SHDI) metric, which shows the gradually increasing level of landscape structure multifunctionality within different scenario designs, with higher diversity corresponding to higher multifunctionality due to the implementation of new innovations and their broad spatial distribution. Higher diversity corresponds to higher multifunctionality, resulting from the implementation of new innovations: organic agriculture, carbon farming, urban farming, rainwater harvesting, floating wetland parks, water retention, mixed use, compact sustainable neighborhoods, agriculture neighborhoods, individual housing, nursing homes, health centers, solar panels, bifacial solar farms, creative businesses, and industrial parks. For the EA and LA scenarios, the diversity levels are similar and go from the year 2022 with SHDI = 1.781, which increases the structural diversity, to the years EA2050 SHDI = 2.010 and LA2050 SHDI = 1.9907, while the lowest level of diversity is associated with the NA2050 scenario with SHDI = 1 (Table 2 and Figure 8).

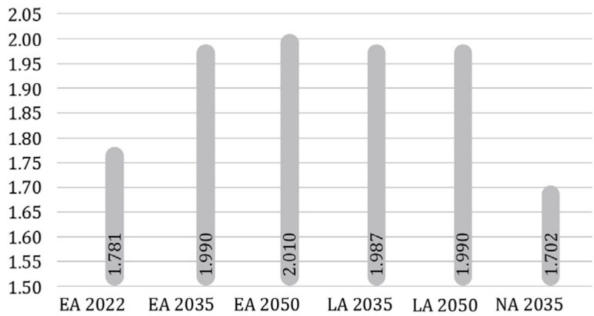


Figure 8. Metrics parameter: SHDI.

The results show a decrease in porosity from the representative model to EA 2022 (63.52%), EA2035 (61.82%), EA2050 (57.18%), LA2035 (58.52%), LA 2050 (56.22%), and NA2050 (49.78%) (Table 2). The soil porosity for the components of the natural environment ranges from 80% to 100% (Table 2).

The results of this analysis are not relevant because the components of the built environment have a higher level of porosity. The model has yet to develop a specific and more accurate method for analyzing the change in porosity within scenarios. The level of porosity for components of the built environment, according to Copernicus for the year 2022, varies from 0% to 30% of soil imperviousness depending on land use change. The results show that the components of the natural environment have a higher level of porosity than the components of the built environment, while the level of porosity has decreased from EA2022 to EA2050 due to the introduction of new innovations in the components of the built environment (RES HIGH, RES MED, and RES LOW) (Table 2).

The extent of carbon sequestration varies with land use change and infrastructure systems within components of the natural and built environments. Larger areas of components of the natural environment correspond to higher levels of carbon storage. The level of carbon storage decreases in the developed scenarios, with the non-adopter scenario having the lowest levels due to increased building and urban development. Larger areas in the natural environment correspond to higher carbon storage, consistent with their total AREA_ha, NP, SHDI, and % porosity. Carbon storage ranges from 0.35 to 1.4 t/ha, depending on AGR, GRN, or WAT infrastructural systems. The larger areas of the built environment correspond to lower carbon storage in AGR, GRN, and WAT systems. Carbon storage for components of the built environment varies from 0.35 to 0.7 t/ha, corresponding to fewer patches, lower SHDI, % porosity, and carbon sequestration. Carbon storage decreases across the developed scenarios (EA, LA, and NA), with NA having the lowest value due to pressures from construction, urban development, and systems such as RES HIGH, RES MED, RES LOW, IND, ENE, and TRN. The analysis of above-ground carbon sequestration shows that GRN infrastructure has the highest storage of 1.4 tons per pixel.

Artificial surfaces, residential, industrial, and commercial areas, transportation, and energy systems store 0 to 0.35 tons of carbon per hectare (Table 2).

3.2.2. Results of Measurement of Indicators of Diversity and Multi-Scale Network and Connectivity

In the built environment, existing roads form a network that connects various components within walkable distance. Connectivity is improved by the development of infrastructure systems like RES HIGH, RES LOW, RES MED, TRN, ENE, and INST. However, there are limitations due to incomplete data and a lack of road network information in certain scenarios. The connectivity of natural environment components increases as scenarios progress from EA2022 to EA2050, thanks to the introduction of innovations such as connectivity, floating wetland parks, and water retention for resilience. These innovations connect patches of GRN infrastructural systems across AGR and WAT systems.

The results of the ecotones between infrastructure systems show that the edges between the components of the natural environment have higher levels of diversity, multi-scale network, and connectivity and decrease from scenario EA 2022 to scenario EA2050 (Table 2). Scenario LA2050 has an edge value of 150.62 m, which is higher than the edge length of scenario EA2050 and results in higher connectivity. A higher level of connectivity among components of the natural environment is the result of the later introduction of innovation and the goal to mitigate the negative impacts of urban development that occurred before the implementation of innovation. The NA scenario shows that the diversity of edges between the components of the built environment is lower, but the connectivity is higher due to dense road networks. The reason for the lower values of edge length between the components of the natural environment is the urban development of RES HIGH, RES MED, and RES LOW (components of the built environment) at the expense of agricultural land and urban green areas. The EA scenario shows the best results due to the implementation of innovations that control and mitigate urban development, while the NA scenario shows lower values due to the lack of implementation of innovations that would mitigate the negative impacts of trending/nonresilient urban development (Table 2, Figure 9).

Figure 9. Metrics parameter: edge type.

The analysis of the total edge length by three developed scenarios according to their development of EA, LA, and NA shows a slight decrease in the edge length of infrastructure systems within components of the natural environment and higher connectivity of infrastructural systems within components of the built environment. The total edge length for developed scenarios within components of the built environment decreases from EA, LA, to NA (Table 2, Figure 10). The decrease in edge length is due to a lack of information within the design innovations and gaps in the model for analyzing changes in the infrastructure system within developed scenarios. The phenomenon of overlapping innovations is recognized in the resilience assessment process. The model can only analyze the visible structures of each scenario design. The most commonly adopted innovation in the process of scenario design is urban farming, which includes adaptation of building rooftops for the production of agricultural goods and food, which means that from the current state where this system is represented by RES HIGH in the scenario design, this area will be part of the natural environment component/AGR infrastructural system.

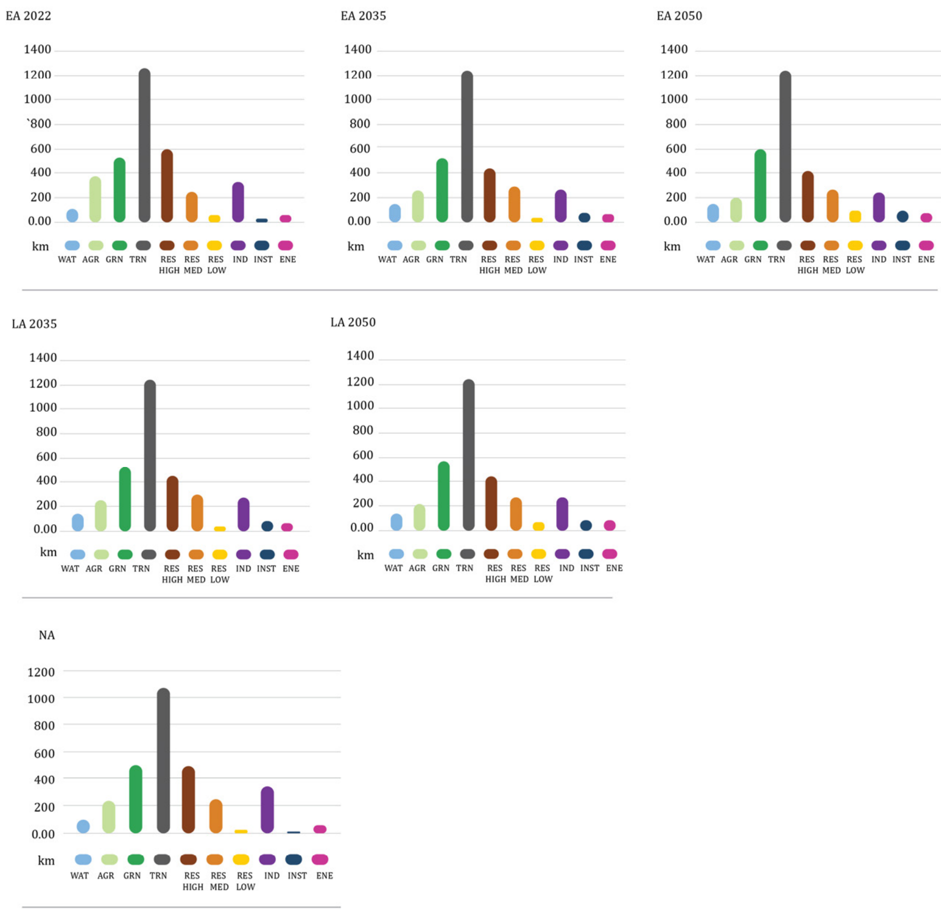


Figure 10. Metrics parameter: Total edge length.

The total edge length of the natural environment components decreases from EA2022 to EA2050 in the developed scenario, followed by LA2050 and NA2050 (Table 2, Figure 10). These changes in the total edge length are caused by urban development and the introduction of innovations in infrastructure systems such as RES MED, RES LOW, ENE, INST, etc.

3.2.3. Results of the Measurement of Indicators of Multi-Scale Networks and Connectivity

The connectivity analysis for EA2022 shows that the existing roads form a fine network, connecting the components of the built environment within walking distances of 100 to 400 m (Figure 11a,b). The results show that the connectivity of the components of the built environment rises as a function of development and changes within the infrastructure systems RES HIGH, RES LOW, RES MED, TRN, ENE, and INST. The analysis of the connectivity of the developed scenarios is deficient in detail. The polygons representing the adopted innovations do not contain information regarding the road network within the innovations for the infrastructure systems RES HIGH, RES LOW, and RES MED.

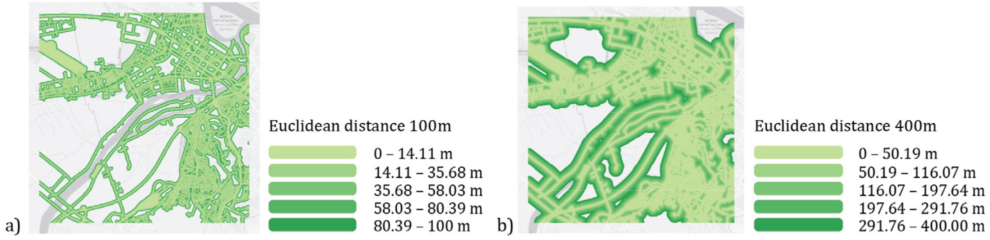


Figure 11. Metrics parameter: ENN—(**a**) Euclidean distance 100 m; (**b**) Euclidean distance 400 m.

The analysis of the components of natural environment connectivity shows a higher level as the scenario evolves from EA2022 to EA2050 and as the patches develop in number and area. In addition, new innovations are introduced, such as connectivity for resilience, floating wetland parks, and water retention for connecting the patches of GRN infrastructural systems across and with AGR and WAT systems. The model created to analyze connectivity results for components of the natural environment (Figure 12) includes components of the built environment that contain more than 50% of green area within their structure (RES LOW and RES MED). They were combined with infrastructure systems WAT, GRN, and AGR, and the results showed that most components of the natural environment are located within 0–400 m and 400–1000 m of RES LOW and RES MED infrastructure systems, respectively. This analysis shows that the level of connectivity increases in the development scenarios for EA and LA.

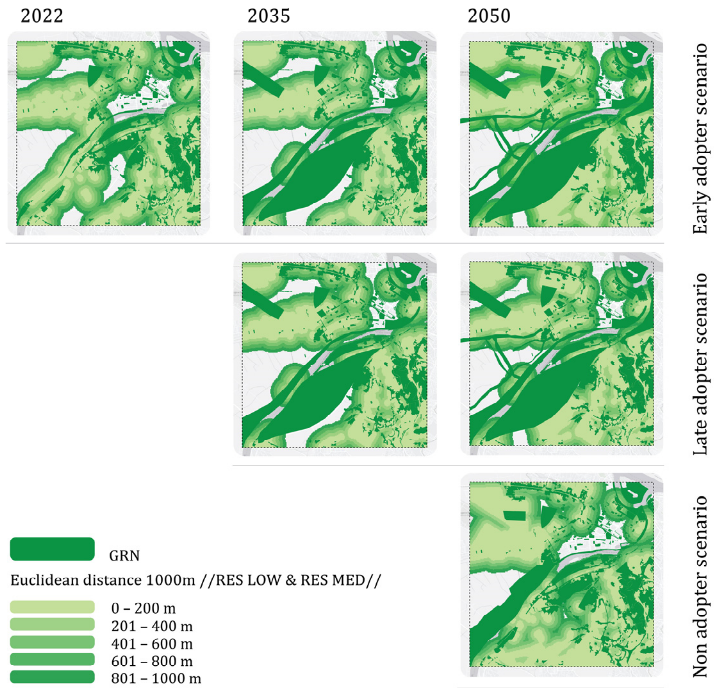


Figure 12. Metrics parameter: total edge length.

3.2.4. Results of the Measurement of the Indicator of Adaptability

The results show that areas dominated by natural components are more receptive to innovation, while those dominated by built components have difficulty accepting new ideas. This implies that if the built environment grows without applying innovations with a high resilience index, landscape adaptability is lower.

In the built environment, more innovations were needed to enhance resilience and adaptability (Table 2). Innovations focused primarily on water, agriculture, and green systems, highlighting their importance for urban resilience. The pursuit of greater resilience drove the adoption of innovation, particularly in the LA scenario, which started later but had the more urgent goal of achieving resilience by 2050. The adoption of innovations contributed significantly to building resilience and adapting the landscape to future challenges.

Most of the innovations adopted within the components of built environments are from WAT, AGR, and GRN system innovations, such as connectivity for resiliency, urban agriculture, urban farming, water retention, solar roof tiles, geothermal energy, and solar panels. The LA scenario showed a different result, where 23 innovations are adopted in the LA2035 scenario, while in the LA2050 scenario, 15 innovations are adopted. The results for the number of adopted innovations in the scenarios EA and LA are similar, as in the LA scenario, the adoption of innovations starts later, but with the urge to reach the goals of a higher level of resilience by 2050, where the number of adopted innovations is higher. For the scenario NA, no innovations were adopted as it is a trend scenario.

3.3. Resilience Index Operationalisation

The operationalization of the resilience index includes a representation of the overall resilience of the landscape across different scenarios (Figure 13). This shows how the dynamic evolution of resilience trends changes over time, reflecting various/different development trajectories, including EA, LA, and NA. The summary of changes/alterations in parameter values in Table 1 provides valuable insights into shifts in key resilience indicators (Figure 13). Parameter values were scored and categorized into a three-tiered scale: high, medium, and low, allowing for interpretation of the resilience index.

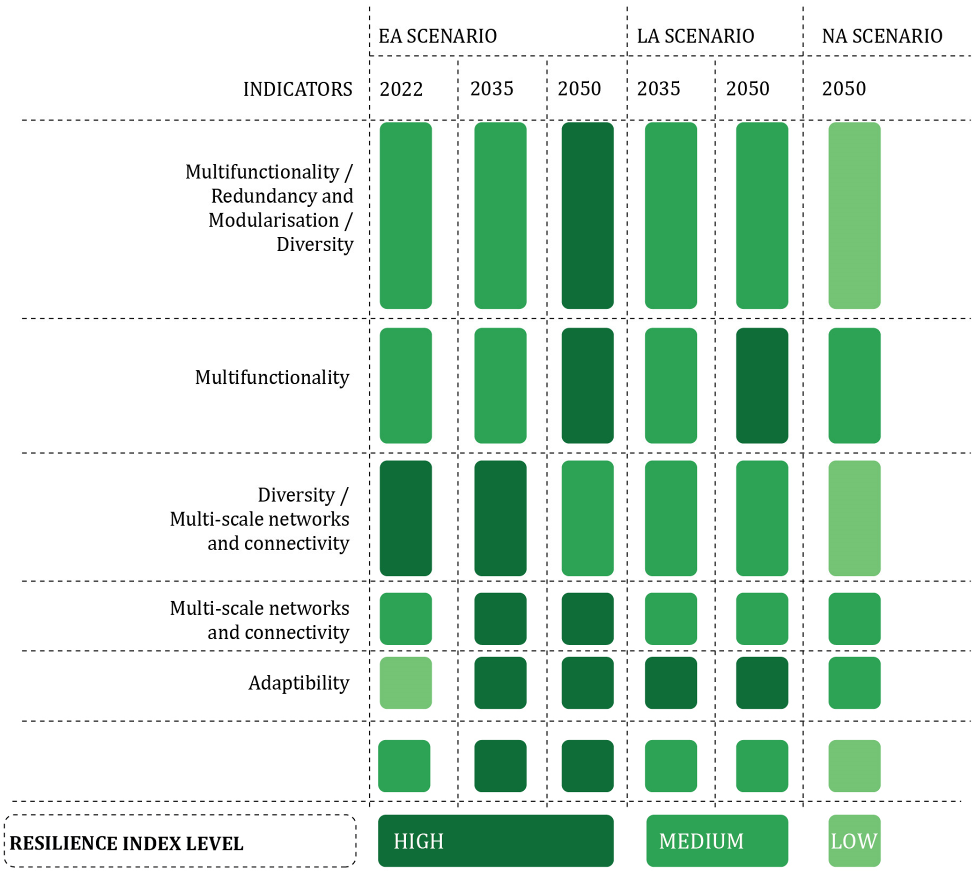


Figure 13. Resilience index level.

The EA scenario shows improvements in multifunctionality and redundancy, connectivity, diversity, and adaptability. These changes are the result of early adoption of innovations such as organic agriculture, carbon farming, and urban farming. By integrating these innovations into the components of the natural environment, a significant increase in diversity, connectivity, and multifunctionality is observed. The application of resilience principles to components of the built environment has led to the incorporation of innovations such as agricultural neighborhoods, custom housing, and compact, sustainable neighborhoods. These additions contribute to the growing adaptive capacity of the study area in the face of unforeseen changes.

Early adoption of innovations based on resilience principles in the landscape planning and design process plays a critical role in increasing the resilience index.

This approach not only increases resilience but also ensures that the study area is well prepared to deal with changing circumstances, which collectively helps the EA scenario achieve a high overall resilience index.

The LA scenario follows similar trends as EA, but with a later introduction of innovations. By 2050, indicators such as multifunctionality and redundancy, connectivity, and adaptability will have significantly improved, while diversity will remain at a medium resilience level. The results of the LA scenario show a higher resilience index. The urgency to achieve higher resilience levels by 2050 is a driving force behind the adoption of resilience-based innovations. The introduction of innovations such as organic agriculture, carbon farming, and urban farming, connectivity for resilience among components of the natural environment, and the adoption of concepts such as agricultural neighborhoods, individual housing, and compact sustainable neighborhoods within the built environment components collectively contribute to achieving a medium overall level of the resilience index.

However, unlike the two scenarios, EA and LA, which apply resilience design principles, the NA scenario is developed following existing planning trends. The resilience assessment results show few improvements in multifunctionality, connectivity, diversity, and adaptability. Consequently, due to the lack of resilience principles, the resilience index in this scenario remains at a low level.

4. Discussion

The future of sustainability and resilience in the 21st century will be determined by the success or failure of cities and their larger urban landscape regions [1,9]. This urban resilience assessment study conducted in the territory of the city of Belgrade suggests that during the process of spatial planning (at the national, regional, and local scales), the level of resilience can be measured, guided, and controlled. The IGC-geodesign as a planning tool supports the assessment of complex potential changes in urban landscape structure, along with various scenario proposals. The paper applies specific landscape metrics [11,35–38] to quantify urban landscape structure in different scenario proposals, considering both natural and built environment components [22].

In contrast to sustainability, resilience emphasizes adaptability to unpredicted conditions [23–27]. Urban planners can benefit from incorporating resilience strategies into their designs to create urban landscapes that can withstand and respond to challenges. The design of resilient landscape structures is of utmost importance at different scales and emphasizes the essential link between landscape planning and design [15,16]. In the study of the Belgrade urban landscape, students created scenario design proposals for the EA and LA scenarios by applying Aherns's resiliency strategies, which are adopted through a type of innovation, while the NA scenario did not.

Geodesign, which applies systems thinking [15,39], played an important role in reducing uncertainty and understanding the dynamics of changes in the Belgrade urban landscape in terms of short- and long-term changes. The results show (Figure 13. Resilience index) that proposals for scenario design and innovations can have a direct impact on future or alternative proposals. This implies that landscape planners and designers can play an influential role in shaping scenarios and ensuring a high level of urban resilience by targeting specific system innovations. By understanding the relationships between structural landscape features and ecological functions [11,33–35], planners and designers can make landscapes more sustainable and resilient.

Since resilience is defined as the system's capacity to absorb changes [23–25,27], some ecosystems are more resilient than others, indicating their ability to adapt and resist disturbances. From this point of view, measuring urban resilience is crucial for operationalizing the concept and moving towards a more module-based approach to urban planning. This will enable the establishment of a spatial support system that facilitates the long-term and co-evolutionary transformation of urban systems.

The study proposes the development of a resilience index to summarize the application of resilience theory in urban landscape planning. Fariba et al. [22] suggest measuring the structure and function of urban systems based on the spatial organization of the components of the natural and built environment, while landscape metrics are a useful tool for assessing and comparing the resilience of urban landscapes [11,35–38]. Parameters such as area, redundancy, diversity, porosity, carbon sequestration, edge type, edge length, and connectivity specified in this paper can provide insights into the resilience of urban systems (Table 1. Measurement of resilience index). However, the individual parameters quantify specific changes in the area, number of patches, or edge length, while their combination provides a broader and deeper understanding of the extent of diversity, degree of fragmentation, % of porosity, carbon sequestration, and so on. This highlights the importance of considering a multi-parameter analysis approach to gain a more comprehensive understanding of resilience.

Further research recommends strengthening the link between landscape planning and design across different planning scales, which can be facilitated by the geodesign framework and the integration of system innovations [15,16]. Detailed descriptions and definitions of system innovations are needed to ensure an informed and relevant evaluation of scenario changes. The reason for the need for more detailed elaboration and description of system innovations is to align them to the same level of detail as the Urban Atlas input data. In our case study, this alignment would include aspects such as porosity and degree of connectivity, as well as area, edge length, edge type, and Shannon's diversity index (SHDI). By harmonizing the level of detail, a more accurate assessment of the impact of the innovation system on the resilience of the urban landscape structure can be achieved.

This research contributes to the interpretation and assessment of the resilience of the geodesign scenario by quantifying the impacts on the components of the natural and built environment. It improves understanding of urban landscape resilience and geodesign as a support system for landscape planning. Through these approaches, practitioners can better understand potential changes in urban landscapes and develop effective strategies to adapt and respond to the outcomes of different scenarios. Scenario evaluation allows landscape planners and designers to communicate to decision-makers what types of innovations should be implemented. If a proposed scenario has a lower level of resilience, indicating the dominance of components of the built environment, future innovations can be directed toward improving components of the natural environment.

5. Conclusions

The constructed model for urban resilience assessment with IGC geodesign (Figure 5) refers to the possibility of measuring scenario changes with developed resiliency indicators (indexes) defined by a set number of parameters and, finally, assessing their impacts. The methodological approach was developed with the idea of quantifying the impact of the innovations adopted in geodesign scenario proposals. In the process of conducting this research, several conclusions have been drawn:

1. The resilience level of the urban landscape structure can be effectively measured by using IGC geodesign scenarios in conjunction with resilience indicators. This model provides a quantitative assessment of resilience levels;
2. The selected landscape metric parameters have proven their effectiveness in measuring changes within various indicators and parameters and provide valuable support to landscape planners and designers. These parameters facilitate the assessment of the resilience levels of planned activities and allow for a comparative evaluation of

different planning scenarios. However, careful consideration should be given to the selection of these parameters;

3. Instead of focusing on already resilient systems such as WAT, AGR, and GRN, there should be a deliberate focus on ''non-resilient" infrastructure systems of the built environment components in order to increase their resilience;
4. System innovations play a critical role in strengthening the link between landscape planning and design across different planning scales. They serve as a direct link between the planning and design processes. However, for the concept of resilience, a more detailed description and definition of system innovations are essential;
5. From a landscape studio education perspective, geodesign appears to be a useful teaching tool to help students understand environmental issues at different scales. Important tasks for students were understanding the methods and terminology of the IGC framework, and because they are trained as environmental planners, they were able to apply the approach in practice.

By measuring changes in the scenario proposal from the perspective of the level of resilience, the geodesign approach provides support for adapting and accommodating new infrastructure system innovations within the urban landscape structure to respond to the negative impacts of urban development and to preserve and maintain the resilient landscape structure. Therefore, a more comprehensive investigation of this issue is required, not only from the aspect of measurement of parameters but also from the perspective of scenario design proposals, innovation design, and negotiations among scientists, urban planners, and designers, as well as decision-makers and stakeholders.

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