

Article

Digital Geospatial Twinning for Revaluation of a Waterfront Urban Park Design (Case Study: Burgas City, Bulgaria)

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Abstract

Digital twins play a crucial role in linking data with practical solutions. They convert raw measurements into actionable insights, enabling spatial planning that addresses environmental challenges and meets the needs of local communities. This paper presents the development of a digital geospatial twin for a residential district in Burgas, the largest port city on Bulgaria’s southern Black Sea coast. The aim is to provide up-to-date geospatial data quickly and efficiently, and to merge available data into a single, accurate model. This model is used to test three scenarios for revitalizing coastal functions and improving a waterfront urban park in collaboration with stakeholders. The methodology combines aerial photogrammetry, ground-based mobile laser scanning (MLS), and airborne laser scanning (ALS), allowing for robust 3D modeling and terrain reconstruction across different land cover conditions. The current topography, areas at risk from geological hazards, and the vegetation structure with detailed attribute data for each tree are analyzed. These data are used to evaluate the strengths and limitations of the site concerning the desired functionality of the waterfront, considering urban priorities, community needs, and the necessity of addressing contemporary climate challenges. The carbon storage potential under various development scenarios is assessed. Through effective visualization and communication with residents and professional stakeholders, collaborative development processes have been facilitated through a series of workshops focused on coastal transformation. The results aim to support the design of climate-neutral urban solutions that mitigate natural risks without compromising the area’s essential functions, such as residential living and recreation.

Keywords: digital twin; spatial analysis; urban park; natural hazards; carbon sequestration; urban planning; stakeholders; Black Sea coast; geodesign



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1. Introduction

The challenges of the Anthropocene in urban management are sparking scientific discussions on creating new criteria for spatial and urban development, developing new methods for data collection, and analyzing the areas occupied by cities. They promote interdisciplinary collaboration to enhance the effectiveness of urban planning decisions through

quick yet sustainable solutions that align with the local characteristics of the environment and the region's natural functions [1]. Respect for historically formed knowledge [2], supported by adequate and comprehensive spatial analysis [3], has the potential to refine our spatial urban planning decisions and contribute to the development of urban vitality [4]. The latter focuses on urban and peri-urban forests, which play an increasingly important role in balancing the urban structure [5] and providing valuable ecosystem services for maintaining urban ecosystems [6,7], mitigating the adverse effects of the urban climate [8], improving our living environment, and the quality of green-blue infrastructures [9].

Urban parks are defined as designated open space areas, mainly consisting of vegetation and water, and typically reserved for public use [10]. Urban parks are a significant structural element of urban green infrastructure and are considered to have the highest impact on society, human health and well-being, air and water quality, maintenance of the biodiversity inherent to the area, and, last but not least, social cohesion [10,11].

Of particular interest is managing the benefits of coastal city parks. These parks are highly vulnerable to natural and human-made changes, as they lie at the frontline of a combination of geological (coastal erosion, landslides, soil swelling, and liquefaction) and ecological risks in response to increasing threats from climate change [12], including heat waves, storms, floods, and the spread of invasive species [13]. At the same time, they play a crucial role in attracting and retaining the population [14]. The functionality of waterfront cities, in the broad sense of coastal cities, has historically changed [15] under the influence of geopolitical factors, trade and transport relations, and the industry based on them, or priorities in the service sector, most often related to tourism. This development is accompanied by strong pressure on available natural resources, which, against the backdrop of natural and anthropogenic risks, brings to the forefront of public attention the need for coastal zone regeneration, with a particular focus on restoring and improving urban ecosystem services [16]. However, the success of strategies and plans for adapting coastal cities to climate change depends on a delicate balance with other vulnerabilities in spatial urban development—socioeconomic sensitivity, infrastructure provision, and overall adaptive capacity [17]. Published knowledge on specific types of adaptation in coastal cities, such as ecosystem adaptation, is still limited [12].

Urban coastal green spaces are defined as an emblematic element of the urban landscape, and their functionality in a complex of public benefits (public health, protection of natural and cultural heritage, water and air quality, natural risk regulation) depends on the structural composition and configuration of landscape elements [18] and their integration into the overall green system of the city [16,18]. There is growing attention to the potential of urban forests as nature-based solutions, but delivering effective, practical results depends on addressing a series of challenges, including the provision of region-specific information and the need for interdisciplinary collaboration [19]. Properly addressing contextual sensitivity and taking an individual approach to planning urban forests as nature-based solutions requires synthesizing current information at a scale suitable for the project. This includes considering topographical features, hydrometeorological conditions, soil and biogeographical patterns, the current functionality of the area, ecological risks, and the continuity and heritage of the cultural landscape. High expectations for urban forests are justified when their planning, construction, and maintenance are carried out collaboratively, especially between local authorities and communities [19]. This involves considering land use and competing interests, engaging the public, and exploring opportunities for long-term financing with clear guarantees from relevant local authorities or economic actors involved in the territory's use.

We see such an opportunity in the potential of modern geospatial methods and technologies for providing up-to-date and accurate data on the urban mosaic and infrastructure

functionality, which allow for a better understanding of the changing geography of cities, proactive response to environmental risk, to the changing needs of the community, and the development of effective solutions in urban planning in a delicate compromise between the available priorities in urban development [20]. There is growing attention and research focus on the application of digital twins in the field of spatial urban planning and design to optimize the information provision process, including the collection, processing, analyzing, and presenting the flow of data and information from the real world, thus serving as a tool to support a climate-neutral and sustainable city [21].

Combining digital twin (DT) technologies with Geographic Information Systems (GIS) represents a significant advancement in geospatial analysis. This integration allows for continuous synchronization, resulting in a precise depiction of the physical environment.

Continuous synchronization is essential for maintaining a precise and up-to-date representation of the physical environment. While more frequent synchronization demands significant investments in terms of time, human resources, and computational power, it ensures high efficiency and prevents errors associated with outdated information. Digital twins that are not adequately updated lead to inaccurate analyses, undermine informed decision-making, and carry the risk of implementing plans that do not correspond to current realities, thereby resulting in significant financial and operational challenges. For instance, planning new tree planting based on a digital twin that fails to reflect recent tree removals or new infrastructure would lead to wasted resources and incorrect assessments of green space. It provides decision-makers with dynamic and context-specific insights for more informed decision-making [22].

While this study focuses on spatial urban planning applications, the digital geospatial twin methodology demonstrates significant potential across diverse disciplines and sectors. Beyond urban planning, these technologies support infrastructure management through predictive maintenance, environmental monitoring for conservation efforts, and energy sector applications, including renewable energy planning. Additional applications span emergency management for disaster preparedness, heritage preservation for archaeological documentation, and public health analysis for community wellbeing assessment. This methodological framework's adaptability stems from its core strength of transforming complex spatial data into actionable insights for evidence-based decision-making across any field requiring precise environmental understanding.

Geospatial data are crucial for the design of green urban areas in reflection of local environmental conditions [23]. Digital geospatial twins can facilitate the development of a comprehensive process of interaction with stakeholders in the planning of green infrastructure and the development of intervention scenarios in response to environmental challenges and the compromise-based development of solutions for urban sustainability [24]. This type of spatial planning, which uses geospatial data and analyzes them through geospatial technologies with the active participation of stakeholders, is rooted in the geodesign framework. Data-driven participation methods, such as geodesign, are very promising for supporting strategic planning to make cities and regions more sustainable [25]. Social learning and collective action, as well as geodesign approaches that apply systems thinking using geographical knowledge, are considered key factors for urban transformation that can better provide the qualities valued and needed by society [26]. There are several examples of geodesign practices in resilience planning and resilience thinking with a focus on climate change, disaster risk reduction, and management activities such as floods and sea level rise risks [25,27].

This scientific study is conducted to support the city of Burgas, the main port city on the southern Bulgarian Black Sea coast, in designing climate-neutral urban planning solutions for the improvement and revitalization of the coastal area (at the Sarafovo resi-

dential district). The study aims to provide up-to-date data on the territory by developing a digital geospatial twin and testing the application of the newly obtained data in the development of scenarios for the redesign and renovation of the coastal zone in active interaction with stakeholders.

The following tasks were set during the study: (1) Identification of the current topography of the terrain and vegetation structure to discuss the advantages and limitations concerning the desired functionality of the coastline in response to urban priorities, public needs, and providing an adequate response to contemporary challenges; (2) Monitoring the condition of sites affected by geological risk for targeted planning and design for long-term management; (3) Supporting the calculation of the carbon footprint in scenarios for coastal vegetation restoration; (4) Appropriate visualization of the results obtained to encourage communication with stakeholders.

2. Materials and Methods

The study is based on the implementation of a comprehensive spatial model, developed and applied based on the digital geospatial twin approach, which was created for the Sarafovo district of Burgas and a consistent thematic processing of the results for the development of well-founded data-driven solutions for the improvement of the territory revitalization of the coastal functions. The study follows the principles of the geodesign framework [28–30], and based on this, the digital geospatial twin here acts as an geospatial information and simulation design hub [31], facilitating interactions between geographers, landscape architects and ecologists, urbanists, urban planners, municipal administration, architects, local businesses, and environmental and cultural non-governmental organizations in co-developing scenarios based on climate-neutral urban design principles.

2.1. Site Properties and Conditions

Burgas is the fourth largest city in Bulgaria (253.6 km²) with a population of 188,242 people (average population density—742 people/km²) [32]. It is located on the southern Black Sea coast of the country and is of major importance to Bulgaria's agricultural sector, chemical industry (the largest oil refinery in Southeast Europe), transport and logistics, trade, and tourism. The territory falls within the Black Sea climatic region of the country, with an average annual temperature of 12.7 °C and average annual precipitation of 553.7 mm, with the maximum in November. In spatial terms, despite the predominantly flat nature of the relief, the territory of Burgas city is extremely complex, with a high degree of fragmentation of its parts, mainly due to the density of extensive water bodies—the Atanasovsko, Vaya, and Mandrensko lakes, as well as the Black Sea waters. This geography has determined the development and configuration of the settlement network—seven residential complexes and two new ones under development, as well as eleven quarters, among which is the Sarafovo quarter (Figure 1).

The vision of Burgas for spatial development emphasizes preserving local identity while ensuring access to modern, resource-efficient, climate-adaptive, and competitive economic opportunities. This involves investing in the enhancement of urban spaces, connectivity, and the preservation of a quality natural environment and green infrastructure. The basis for the implementation of these complex tasks is the creation of conditions for increasing the connectivity of green-blue infrastructure by utilizing the advantages of the coastal strip (Compact Zone for Integrated Intervention “Coastal Zone”) [33].

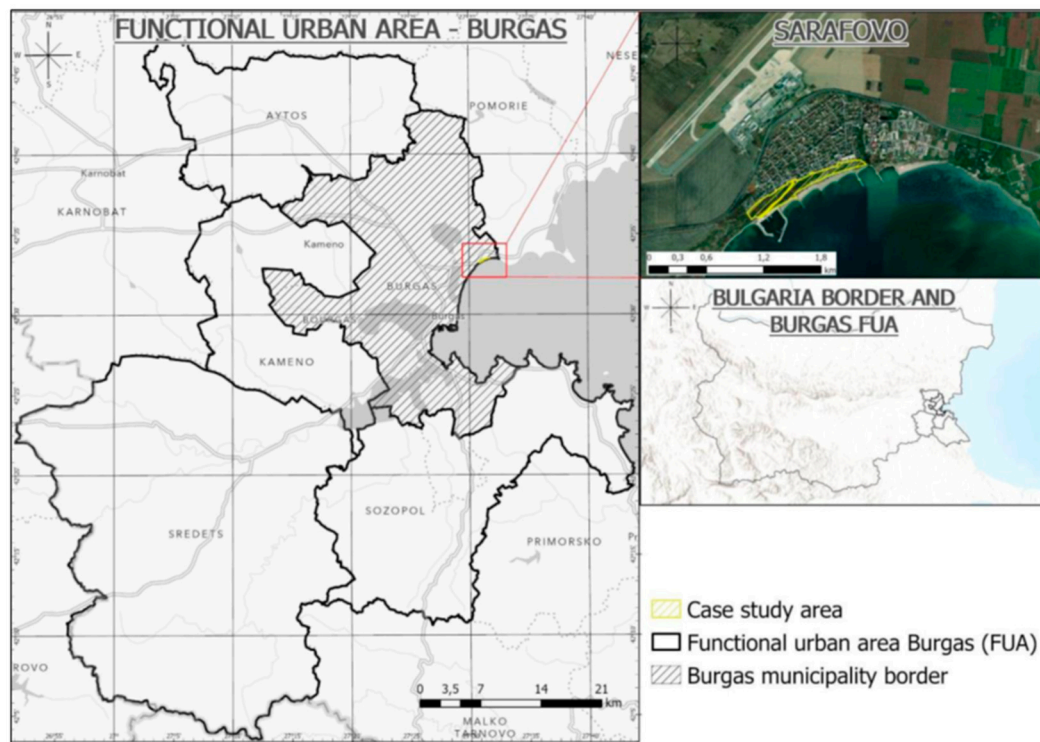


Figure 1. Function Urban Area—Burgas city.

The Sarafovo neighborhood (3500 permanent residents) is located in the northeastern part of Burgas, on the Black Sea coast, and is geographically relatively isolated from the rest of Burgas, even though it is only 10 km away from the city center. To the north of it runs the main Republic Road I-9, and to the northwest is Burgas Airport for passenger transport, both of which create spatial constraints on territorial expansion. In the southwestern and southeastern directions, there are areas designated by the General Development Plan for Residential Construction, which are gradually being implemented and are expected to undergo intensive development soon. The selected project area is located parallel to the coastline, south of the Sarafovo district. The total area is 140,974.8 m², divided into two properties. It was selected based on the strategic goal of achieving unified connectivity of green areas along the coastline of Burgas, the desire to build perpendicular connections to the interior, identified needs, and opportunities for intervention in the near future. The first step in this direction is the improvement of the coastal zone, which today has partially degraded vegetation and disturbed terrain (designated as “Public Settlemental Park, Garden”). According to the Master Plan, the coastal land plots are designated for landscaping, which provides a good opportunity for development.

The geographical location and natural features of Burgas Municipality, the mild climate, and extensive water bodies favor the presence of rich biological diversity. The case-study area does not fall within the boundaries of Protected Zones and NATURA 2000 Protected Sites, but it is in spatial proximity to them and can serve a supporting function. To the west lies the protected area of Atanasovsko Lake, a key location on the Via Pontica migratory route for birds in Europe (the northern part of the lake is a maintained reserve (IV, IUCN), while the southern part is the protected area of Burgas Saltworks (VI, IUCN). It is an internationally significant wetland under the Ramsar Convention and BirdLife International. To the east is the Pomorie Lake protected area, also of exceptional value in terms of biodiversity (Figure 2).

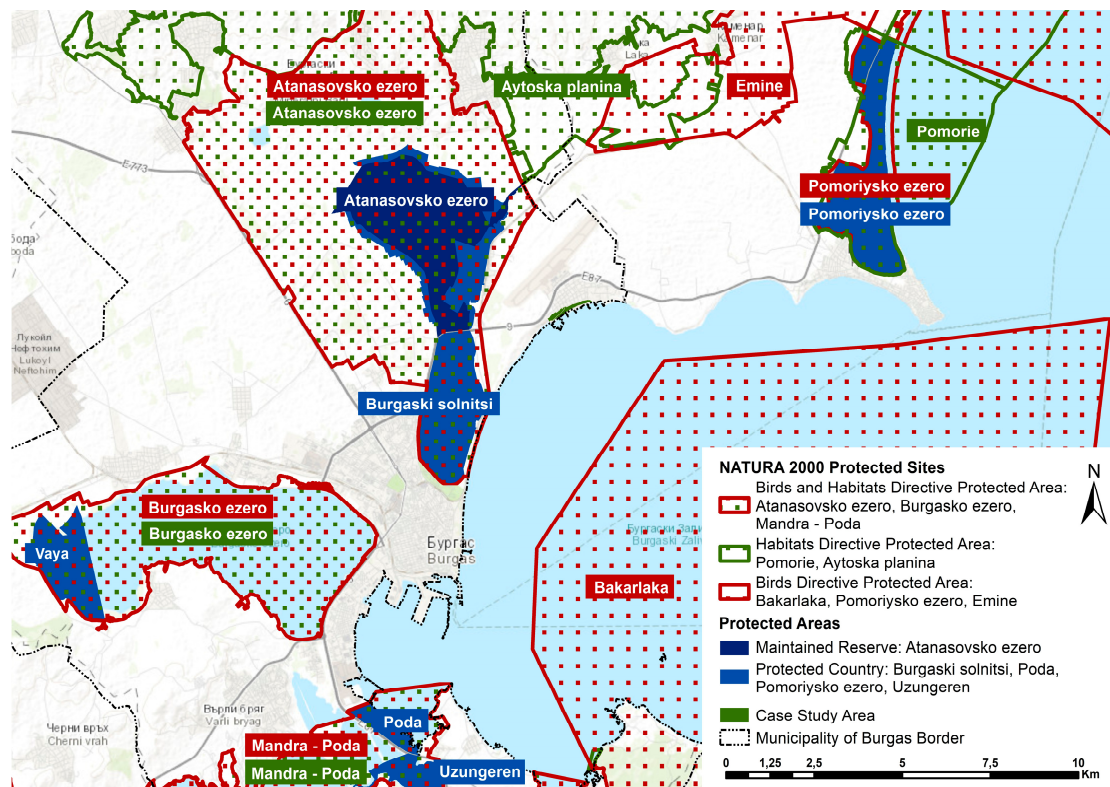


Figure 2. Protected Areas, NATURA 2000 Protected Sites.

Several key challenges have been identified within the area of Sarafovo Quarter, including high density and intensity of development, hindering the connection of coastal greenery with that in and outside urbanized areas, a high proportion of seasonally occupied dwellings, uneven distribution of green areas for public use (such as parks and gardens), and insufficient space relative to the population— $2.4 \text{ m}^2/\text{person}$ with a minimum norm of $20 \text{ m}^2/\text{person}$. The quarter faces issues related to negative impact on biodiversity, noise and dust pollution (all from the proximity to the airport and major road and building characteristics), as well as geological risk in the conditions of a steep coast (130 m from the coast, on land the height increases to 35 m)—coastal erosion, landslides, soil swelling, and, in the immediate vicinity, liquefaction of weak soils (Figure 3). The latter creates a direct need for surface and groundwater management to preserve and strengthen relief forms.

The pilot territory can be defined as undeveloped—there is no alley network and technical infrastructure. In the past decades, numerous anthropogenic interventions have been made in the area, such as land filling from construction, deforestation, artificial leveling of the terrain, parking, and the creation of illegal access paths.

The technical project Coastal Park near Sarafovo quarter was developed in 2009 and included the construction of reinforcement systems, a network of alleys, and a wide range of themed spaces. The project was not implemented due to a low degree of respect for the topography and the need for serious interventions in the terrain, and at present, the project is not applicable as a result of the serious natural and anthropogenic changes in the landscape. The redevelopment of the conceptual and technical design requires up-to-date and detailed spatial data, carried out in consultation with a wide range of stakeholders, including representatives of key professions, educational and scientific institutions, administrative bodies, local communities, non-governmental organizations, and businesses (beach concessionaires, salt producers, and active parties involved in the operation of Sarafovo Fishing Port).

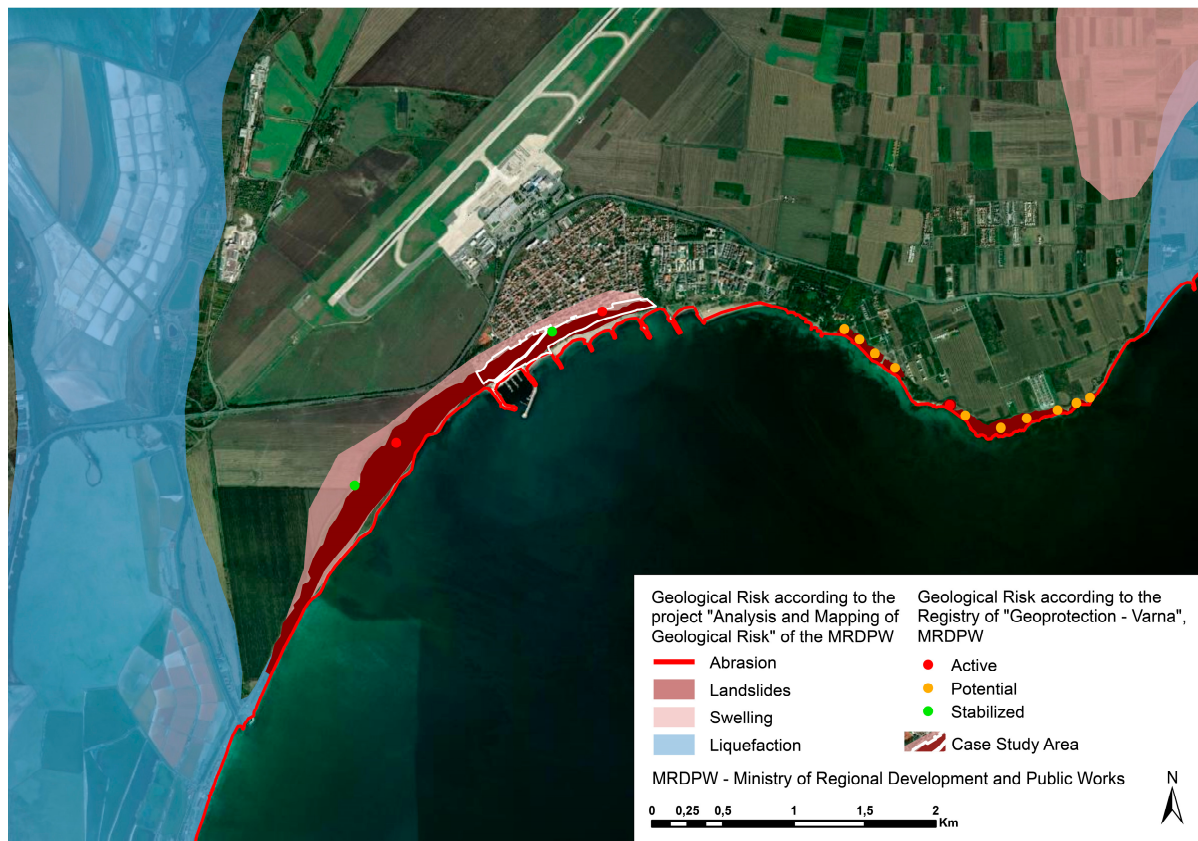


Figure 3. Geological risk of the territory.

2.2. Digital Geospatial Twin—Field Observations

The creation of a digital twin for the Sarafovo district is grounded in a multi-tiered geospatial data acquisition approach. The primary objective of the field campaign was to generate accurate, high-resolution spatial datasets for characterizing both built and natural environments. The adopted methodology integrates aerial photogrammetry, ground-based mobile laser scanning (MLS), and airborne laser scanning (ALS), enabling robust 3D modeling and terrain reconstruction under varying land cover conditions (Table 1). Each method was selected to address specific observational challenges: while photogrammetry excels in capturing visual and structural detail in open areas, it struggles in densely vegetated zones; conversely, LiDAR systems provide elevation and volumetric data even in occluded or shadowed areas. The combination of these complementary methods supports a more holistic and precise representation of the study area. All spatial datasets were referenced to the Bulgaria Geodetic System 2005—BCS2005 coordinate system (EPSG:7801).

Table 1. Summary of data acquisition techniques for the digital twin development.

Feature	Aerial Photogrammetry	Ground-Based Mobile Laser Scanning	Airborne Laser Scanning (ALS)
Method	Structure-from-Motion (SfM) Photogrammetry	Mobile Laser Scanning (MLS) with SLAM	Airborne Laser Scanning (LiDAR)
Platform	SenseFly eBeeX (Fixed-wing UAS, AgEagle Aerial Systems Inc., Wichita, KS, USA)	Operator on foot and bicycle	Multirotor UAS
Sensor	SenseFly AeriaX (High-resolution RGB camera, AgEagle Aerial Systems Inc., Wichita, KS, USA)	GeoSLAM ZEB Horizon (LiDAR with integrated RGB camera, GeoSLAM, Nottingham, UK)	mdLiDAR1000HR (LiDAR, Microdrones, Madison, AL, USA)

Table 1. Cont.

Feature	Aerial Photogrammetry	Ground-Based Mobile Laser Scanning	Airborne Laser Scanning (ALS)
Primary Data	1223 high-resolution nadir RGB images with precise geotags.	Georeferenced 3D point cloud and synchronized RGB imagery.	High-density 3D point cloud
Key Deliverables	-Orthophoto Map (2.5 cm) -Dense RGB Point Cloud (~208 M points) -Digital Surface Model (DSM) -Digital Terrain Model (DTM)	-Colorized Point Cloud (~53 M points) -High-accuracy DTM (sub-5 cm) -Topographic cross-sections and profiles	-Classified Point Cloud (multiple returns) -High-accuracy DTM (10 cm)
Advantages	-Excellent for capturing realistic color and texture. -Highly efficient for mapping large, open areas. -Produces high-resolution, visually intuitive orthophotos. -Cost-effective for generating initial base layers.	-Superior at capturing data under dense vegetation. -Excellent for modeling vertical surfaces (facades) -Provides very high detail and accuracy at ground level. -Flexible and portable in complex/confined spaces.	-Penetrates vegetation to accurately map the bare-earth. -Provides highly accurate elevation data (Z-values). -Unaffected by shadows or ambient light conditions. -Efficiently fills data gaps over large, inaccessible areas.
Disadvantages	-Struggles to penetrate dense vegetation canopy. -Data quality is affected by shadows and poor light. -Poor at capturing vertical surfaces from nadir flights. -Can produce geometric distortions in occluded areas.	-Limited spatial coverage can be time-consuming. -Inaccessible in very overgrown terrain. -SLAM accuracy can drift in large, featureless areas. -Data can be noisy due to moving objects (people).	-Lower point density on vertical surfaces. -Canopy data quality can be affected by wind. -Higher equipment and operational cost.

2.3. Aerial Photogrammetric Mapping

An aerial photogrammetric survey was conducted in August 2022 over the Sarafovo area using the Ag Eagle eBeeX (AgEagle Aerial Systems Inc., Wichita, KS, USA) (Figure 4a). This fixed-wing unmanned aerial system (UAS) was strategically selected over a multirotor alternative due to its superior flight endurance and efficiency, making it ideal for mapping large, contiguous areas like the entire Sarafovo quarter with minimal operational interruptions. The platform was equipped with the AeriaX photogrammetric camera, chosen for its high image fidelity and minimal geometric distortion. Flight planning and mission execution were managed using Ag Eagle's official flight management software, eMotion (version 3.20). The flight plan includes a horizontal mapping mission configured for 80% frontal and 70% lateral image overlaps at a nominal altitude of 120 m above ground level (AGL), achieving a ground sampling distance (GSD) of 3 cm/pixel.



Figure 4. Remote Sensing Equipment: (a) Ag Eagle eBeeX Fixed-Wing UAS; (b) GeoSLAM Zeb Horizon LiDAR; (c) mdLiDAR1000HR Multirotor UAS.

The mapping was conducted on a sunny day with minimal wind, as these conditions are critical for ensuring consistent illumination and maintaining the stability of the UAS platform. A total of 1223 nadir aerial images were captured under clear sky conditions to reduce shadowing and radiometric variation. Image processing was carried out using Pix4Dmapper (version: 4.5.6). This software leverages Structure-from-Motion (SfM) algorithms, a computational method chosen for its proven ability to derive high-density 3D data from unstructured 2D image sets. The SfM process analyzes the overlapping images to simultaneously determine the camera's position for each shot and reconstruct the scene's geometry, which is the foundational step for generating the dense point cloud and subsequent products.

The processing resulted in a comprehensive suite of geospatial deliverables. The foundational dataset is a dense, RGB-classified 3D point cloud containing approximately 208 million points, which provides a detailed 3D representation of all surface features. From this point cloud, two key elevation models were generated: a 10 cm resolution Digital Surface Model (DSM) capturing the top-most surfaces of buildings and vegetation, and a corresponding Digital Terrain Model (DTM) representing the bare-earth topography after filtering out non-terrain objects. Finally, a seamless, true-color orthophoto map was produced at 2.5 cm resolution, offering a geometrically corrected and distortion-free visual base layer for the study area.

Despite favorable weather, some urban areas displayed reduced accuracy due to shadows cast by high-rise structures and occlusion in narrow streets, leading to localized DSM distortions. These limitations were mitigated through manual editing and data fusion with LiDAR products. RTK GNSS corrections were applied during flight, achieving horizontal accuracy of approximately 2 cm and vertical accuracy of 3 cm. A set of independently measured checkpoints was used for geometric validation. To ensure broad interoperability, these deliverables were exported in industry-standard formats, such as GeoTIFF for the raster models and orthophoto and LAS for the 3D point cloud, allowing for easy use in virtually any geospatial software.

2.4. Ground-Based Mobile Laser Scanning

To complement aerial observations and capture terrain features under vegetation, a ground-based mobile laser scanning (MLS) survey was carried out in March 2024 using the GeoSLAM Zeb Horizon system (Figure 4b). This handheld, SLAM-enabled scanner was selected for its portability, high point density, and suitability in complex, vegetated environments. The system is co-equipped with a synchronized camera, enabling the capture of RGB imagery to colorize the resulting 3D point cloud and enhance visual interpretation. Furthermore, its extended battery life supports continuous data acquisition, which was essential for covering the large and fragmented project area in a single or double field session.

Crucially, its ground-level perspective is also essential for capturing detailed data of vertical surfaces, such as building facades and all vertically positioned infrastructure elements. These features are inherently hidden or poorly represented in nadir-oriented aerial datasets. To ensure comprehensive coverage across the study area's diverse terrain, the survey was conducted using a flexible traversal strategy. The operator proceeded on foot in complex or confined spaces, such as forested zones and narrow pathways, to maximize data resolution and capture fine-scale ground features. A bicycle was employed to efficiently scan long, linear infrastructure like roadways, significantly increasing the speed of data acquisition without compromising quality.

Data acquisition was conducted under stable daylight conditions and with minimal wind to reduce motion artifacts caused by vegetation movement. Furthermore, the survey

was intentionally timed to periods of low public activity to avoid noise and “ghosting” artifacts in the point cloud, which are commonly caused by moving pedestrians. The raw point cloud was processed using GeoSLAM Hub software (version: 6.2.1), where SLAM algorithms corrected for drift and optimized spatial alignment.

The primary deliverable from the MLS survey is a high-density, georeferenced 3D point cloud (LAS format) comprising approximately 53 million points. This point cloud is fully colorized using integrated camera imagery and classified to distinguish between ground returns, vegetation, and man-made structures, achieving a vertical accuracy of sub-5 cm. Based on the filtered ground points, a 10 cm-resolution Digital Terrain Model (DTM) was generated, providing a detailed representation of the bare-earth topography. For direct engineering use, specific topographic cross-sections and profiles were also extracted as vector datasets to support design applications.

The system successfully captured fine-scale topography and ground features beneath dense vegetation, but terrain inaccessibility in several overgrown zones limited scanning coverage. Manual segmentation and noise filtering were employed during post-processing to resolve ambiguities caused by vegetation clusters and underbrush.

2.5. Airborne Laser Scanning

An airborne laser scanning (ALS) survey was conducted in June 2024 to enhance vertical accuracy and resolve remaining spatial data gaps, especially in areas where photogrammetric and ground-based methods were constrained. The mission used a mdLiDAR1000HR system mounted on a multirotor unmanned aerial system (UAS) (Figure 4c). This platform was strategically chosen for its ability to fly slowly and at low altitudes over complex terrain, which is essential for achieving high point density, while the LiDAR sensor’s capacity to penetrate vegetation canopy makes it superior to photogrammetry in forested zones. The system integrates high-frequency pulse-based LiDAR with precise GNSS/IMU positioning (RTK/PPK).

A pre-defined grid flight pattern with 80% sidelap was executed at 100 m AGL with a 70° field of view, producing a point density of 150–300 points/m² to ensure complete area coverage. The flights were performed under calm and clear weather conditions to minimize UAS drift and wind-induced vegetation motion. For safety reasons and due to the operational weight of the platform, the survey area was secured and cleared of all unauthorized personnel during the mission. This focused particularly on vegetated slopes, infrastructure corridors, and transitions between open and forested terrain.

The post-processing of the raw LiDAR data yielded a set of key deliverables. The primary output is a classified 3D point cloud (LAS/LAZ format), which includes multiple returns (first, intermediate, last) essential for detailed canopy and ground characterization. From this, a 10 cm resolution Digital Terrain Model (DTM) was derived using progressive morphological ground filtering algorithms.

Although the ALS system achieved consistent performance, wind-induced vegetation motion introduced noise into the canopy point cloud, and terrain steepness in certain segments affected return density uniformity. These were addressed through trajectory adjustment, filtering, and multi-pass flight data merging.

2.6. Using Digital Geospatial Twin Results to Calculate Carbon Footprint in Coastal Development and Improvement Scenarios

Our previous studies demonstrate the vulnerability of the city of Burgas to climate change, particularly regarding its exposure to the urban heat island effect [34]. Utilizing the geographical characteristics of the Sarafovo district, we analyzed the area, structure, and condition of contemporary vegetation using data from a digital geospatial twin. This analy-

sis enabled us to calculate the potential contribution of vegetation to carbon sequestration under various coastal development scenarios.

For the study, the “Methodological guidelines for the preparation of consolidated documentation to prove climate resilience (including climate change mitigation and adaptation)” of project proposals under the Operational Program “Environment 2021–2027” of the Republic of Bulgaria [35] were applied. The urban coastal park project discussed here aligns with the concept of “Green Infrastructure in Urban Environments.” Its sustainability is evaluated based on the carbon absorption capabilities of growing biomass. The planned green spaces will feature a variety of trees, shrubs, and grasses, as well as combinations of these elements. The absolute emissions of the project are calculated for a standard year of operation: $t\text{ CO}_2\text{e/yr}$ = average annual carbon sequestration ($t\text{ CO}_2\text{e/yr}$).

Average annual carbon sequestration by tree species is calculated using the following formula:

$$\begin{aligned} \text{Average annual carbon sequestration } \left(\frac{t\text{CO}_2\text{e}}{\text{year}} \right) &= \left[\text{MAI} \left(\frac{\text{m}^3}{\text{ha} \cdot \text{year}} \right) \right] \times [\text{BCEF}] \times [1 + R] \times \left[\text{CF} \left(\frac{t\text{C}}{t\text{ dry matter}} \right) \right] \times \left[\text{CCF} \left(\frac{t\text{CO}_2\text{e}}{t\text{C}} \right) \right] \\ &\times [\text{Forest area (ha)}] \end{aligned}$$

where the following sources of information are applied:

MAI ($\text{m}^3/\text{ha}/\text{year}$) (mean annual increment). The data presented here are taken from the IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 4—Forests [36], using the average value for hardwoods in temperate climates. The resulting MAI value is 0.956 m^3 (for deciduous species) and 0.706 m^3 (for coniferous species).

BCEF (biomass conversion and expansion factor). BCEF values are consistent with EIB Project Carbon Footprint Methodologies, 2023 [37]: $0.621\text{ t}/\text{m}^3$ (for deciduous species) and $0.464\text{ t}/\text{m}^3$ (for coniferous species).

R (below-ground biomass to above-ground biomass ratio). R is estimated conservatively based on expert knowledge and is consistent with the EIB Project Carbon Footprint Methodologies 2023 [37]: 0.24 (for deciduous species) and 0.29 (for coniferous species).

CF ($\text{tC}/\text{t dry matter}$) (carbon fraction). The value used here is in line with the EIB Project Carbon Footprint Methodologies, 2023 [37]: 0.48 (for deciduous species) and 0.51 (for coniferous species) $\text{tC}/\text{t dry matter}$.

CCF ($\text{tCO}_2\text{e}/\text{tC}$) (carbon conversion factor)—The value used here is in accordance with the Methodological Guidelines: conversion factor for C to $\text{tCO}_2\text{e} = (12 + (16 \times 2))/12 = 3.67$. $\text{CCF} = 3.67\text{ tCO}_2\text{e}/\text{tC}$

Forest area (ha)—Different values assumed in the development scenarios are used here. For the zero scenario, the carbon footprint of existing vegetation was calculated as follows: broadleaf tree species cover $69,550\text{ m}^2$, coniferous tree species cover 4968 m^2 , and the current area covered by shrubs and grasses is $24,839\text{ m}^2$. For scenario 2, the calculations were made using the following values: broadleaf tree species 3740 m^2 , coniferous tree species 910 m^2 , and $12,092\text{ m}^2$, according to the planned area for landscaping with shrub and grass species.

The assessment of emissions/removals from shrub and grass species is based on an assessment of changes in carbon stocks in living biomass and soil. The approach is consistent with the National Greenhouse Gas Inventory [38], where it is assumed that all changes in biomass carbon stocks occur during the first year. To calculate changes in annual carbon stocks in living biomass, the following equation is applied:

$$\text{The annual change of carbon stock in biomass} = A_{\text{conversion}} \left(L_{\text{conversion}} + \Delta C_{\text{growth}} \right)$$

where the following sources of information are applied:

$$L_{conversion} = C_{after} - C_{before}$$

$$L_{conversion} = C_{after} - C_{before}$$

$$A_{conversion} - \text{annual areas of the lands converted to grassland, ha yr}^{-1}$$

$$L_{conversion} - \text{carbon stock in the biomass of lands which were converted to grassland, tonnes C ha}^{-1}$$

$$\Delta C_{growth}$$

– change of the carbon stock in the biomass in the first year after the conversion tonnes C ha^{−1}

– 5.24 tC/ha for shrubs and grasses

$$C_{after} = 0$$

$$C_{before} = 3.56 \text{ tC/ha for annual crops (calculated for Bulgaria)}$$

Soil carbon stocks 20 years after conversion to grassland are assumed to be 86.96 tC/ha, i.e., 4.35 tC/ha/yr.

For a comprehensive assessment of carbon sequestration, the results of the two formulas are summarized here, which corresponds to the guidelines of the methodology [35].

Field analyses have shown that the broadleaf tree vegetation currently consists of *Acer campestre*, *Fraxinus angustifolia*, *Morus alba*, *Juglans Regia*, *Ficus carica*, *Prunus dulcis*, *Cydonia oblonga*, *Pyrus communis*, *Celtis australis*, as well as *Robinia pseudoacacia*, *Gleditsia triacanthos*, and *Maclura pomifera*. Among the conifers are *Cedrus libani* and *Pinus nigra*. The shrubs found here include *Rosa canina*, *Rubus caesius*, *Prunus spinosa*, *Daphne mezereum*, *Elaeagnus angustifolia*, *Sambucus nigra*, *Paliurus spina-christi*, *Humulus lupulus*, and *Clematis vitalba*. On degraded land, *Ailanthus altissima* and *Amorpha fruticosa* are found. The most widely represented grass species are: *Agrostis capillaris*, *Amaranthus albus*, *Chenopodium ficifolium*, *Convolvulus arvensis*, *Xanthium strumarium*, *Phragmites australis*, *Cynodon dactylon*, *Cichorium intybus*, and *Suaeda maritima*.

Scenario 2, which includes plans for new landscaping, aligns with the List of Suitable Tree Species for Parks, Land Improvement, and Forest Plantations established by the Bulgarian Ministry of Environment and Water in 2023. This list is informed by expert opinions regarding the sustainability of urban vegetation, considering the impacts of climate change on Bulgaria's landscape. Scenario 2 features a high percentage of grass areas (72% of the areas designated for landscaping) to strengthen landslide slopes and in locations where terrain terracing is planned. These changes are expected to enhance soil quality, improve drainage, and reduce surface runoff.

2.7. Data-Driven Visualization, Communication, and Co-Creation

To achieve sustainable development despite the potential consequences of ongoing climate change, a sustainability planning methodology is needed that enables and ensures the participation of local communities, policymakers, and other stakeholders. In this regard, geodesign and related methods offer opportunities to improve urban sustainability planning [25]. Co-creation is a key principle, with regular public consultations involving representatives from key professions, educational and scientific institutions, administrative bodies, local communities, non-governmental organizations, and businesses to gather input and collaboratively shape the design and functionality of the waterfront. Data-driven platforms enable transparent decision-making and allow for real-time feedback from the community on environmental conditions and the use of public spaces.

The results of the digital geospatial twin were used in the preparation of meetings and workshops with stakeholders in June 2024 in applicable visualization materials, in the development of routes for field observations, and in the preparation of arguments in discussions of the available limiting factors and opportunities in the intervention area. On 12 June 2024, a series of consultations was held using a web GIS application (ESRI ArcGIS Field Maps, version 24.3.0) (Figure 5). During this event, a field workshop was conducted with a team of experts from various fields involved in the international REVALUE project. Out of a total of 33 participants (12 architects, 7 GIS engineers, 7 municipality representatives, 3 landscape architects, 1 landscape ecologist, 1 ecologist, 1 geographer, 1 urban planner), 12 are university representatives, and had the opportunity to share their ideas for the design and future development of the project area. Each proposal is marked on the ground using the GIS mobile application (ESRI ArcGIS Field Maps, version 24.3.0) and its ability to record the GPS position of the user. Based on a preliminary review of international examples of contemporary waterfront parks, the local administrative team compiled an initial list of thematic zones. In the application, these were presented as a drop-down list (Table 2), and participants in the exercise had the opportunity to add their individual suggestions as notes.

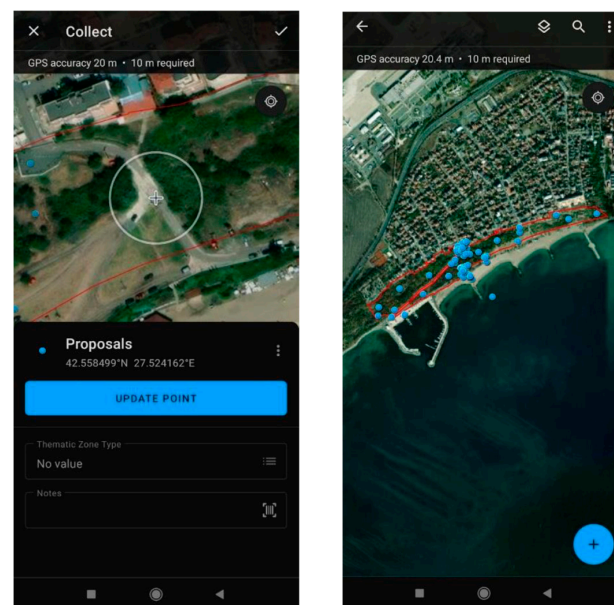


Figure 5. Visualization of the GIS mobile application (ESRI ArcGIS Field Maps, version 24.3.0).

Table 2. Proposals for the development of the project area (for the field workshop).

Type of Proposal	Count
Location identified as important, but no proposal for utilization specified	8
Panoramic terrace	10
Zone for prolonged stays and social interaction	2
Zone for children's playground	2
Zone for sports playground	7
Green arc corridor	3
Zone for afforestation	4
Botanical garden and aroma garden	4
An outdoor cultural events area with terraced seating and stage/small celebrations	1

Table 2. *Cont.*

Type of Proposal	Count
Zone for presenting local life and history—fishing, local fishing communities	1
Zone for local craft products and foods	1
Zone for observing the natural environment, plants, and animals;	1
Zone for ecological education and practice of nature—based solutions	1
Zone for science of geography, geology, climatology. Technological systems for monitoring natural components and biodiversity, including demonstration zones	1
Zone for practice by students in artistic disciplines/Schools, Art centers and National Academy of Art—Burgas	2
Zone for rope construction for children and adults	1
Zone for extreme aerial sports	1
Zone with Monuments	2
Zone for picnic	9
Zone for meditations /with small water feature	4
Zone for off-leash dogs	1
Zone for temporary exhibitions	1
Zone for bicycle rental	4
Zone for parking personal bicycles	5
Zone for parking personal cars	2
Café	2
Other individual proposals outside of the proposed thematic zone list (drinking water fountain, benches, half plant arc for shade, pathways, bike parking station) (Please explain in “notes” field)	13

The 3D models and interactive maps from the Digital Geospatial Twin were applied during public consultations and partner meetings, including the Impact Model Workshop (12 June–14 April 2024), to obtain location-specific needs, desires, and views of stakeholders and experts. Recurring themes highlighted the desire that the park be kept “natural” and to use nature-based solutions to stabilize soils, implement non-invasive, low-impact solutions to improve pedestrian access to the beach, preserve perennial trees and vegetation, remove invasive species, ensure natural air conditioning of the park by promoting marine air corridors, improve viewpoints and limit sealed surfaces, and particularly unregulated parking adjacent to the beach. The intersection of interests is the strengthening of the salt marsh bodies and the drainage of rainwater without affecting tourist activity during the summer season (the Sarafovo district is a popular weekend destination for the residents of the city of Burgas).

3. Results

3.1. Digital Geospatial Twin—New Data on the Territory and Situation Analysis

The developed digital twin of the Sarafovo district represents an integrated, multi-layered model that fuses geospatial data acquired through three distinct methods. It combines the visual information and texture from aerial photogrammetry (orthophoto mosaics and 3D models) with the precise three-dimensional geometry obtained from airborne and ground-based laser scanning (high-density point clouds). This combination of technologies creates a unified digital replica of the physical territory, which accurately maps both the visible elements—such as buildings, infrastructure, and vegetation—and the underlying terrain hidden beneath them. This holistic, multi-dimensional model

serves as the foundation upon which the subsequent analyses of the existing conditions were performed.

3.1.1. Land Cover Analysis and Green Infrastructure Deficit

The generated 2.5 cm resolution orthophoto map enabled precise land cover classification, meticulously delineating impervious surfaces (buildings, roads, parking lots) from pervious ones (green spaces, bare soil) (Figure 6). The quantitative analysis of this data, integrated with cadastral and urban planning information, provided empirical evidence of the registered rapid and often inadequately supported urban expansion, linked to the construction of multi-family buildings up to 15 m in height. The most significant finding of this analysis is the objectively established critical deficit of green space. The calculated value of merely 2.36 m² per capita falls drastically short of the minimum standard of 20 m² per capita, providing an indisputable, data-driven argument for the necessity of targeted interventions to increase green infrastructure.



Figure 6. Surface type classification—based on the processed aerial photogrammetry data.

Data analysis identified ground disturbances, including those caused by illegal vehicle passage and parking, as well as degraded vegetation (Figure 7a,b). The current perspective on the contemporary situation provides a fundamental basis for discussing potential interventions in the coastal zone. These interventions aim to balance the spatial structure of the entire neighborhood, considering its functional characteristics and adjacent features such as the airport, main national road, and the protected Atanasovsko Lake lagoon.



Figure 7. (a) Unauthorized parking areas visualized by orthophoto map; (b) Degraded vegetation visualized by orthophoto map.

3.1.2. Detailed Topographic Analysis and Geological Risk Refinement

The LiDAR data were pivotal for creating a high-precision Digital Terrain Model (DTM) with a 10 cm resolution, which, for the first time, revealed the detailed topography concealed beneath dense vegetation (Figure 8). This model enabled not just a visual assessment but the quantitative derivation of key morphometric parameters such as slope, aspect, and surface curvature (Figure 9). Based on calculations within the scanned area, the average terrain slope was determined to be 12.45 degrees, categorizing it as moderately sloped. Distinct sections with steep gradients exceeding 40 degrees are predominantly located between the developed areas and beachfront walkways of the surveyed territory. The highest observed slopes range between 50 and 60 degrees. By integrating the DTM with existing geological risk registries, the boundaries of active and potential landslide zones were delineated with sub-meter accuracy, significantly exceeding the precision of previously available maps. The analysis established a direct spatial correlation between unregulated pathways and parking areas on one hand, and the zones with the highest susceptibility to erosion on the other, thereby demonstrating the anthropogenic contribution to slope destabilization. The data were also applied in the design of drainage systems and other soil stabilization measures, permissible during the construction phase of the coastal park.

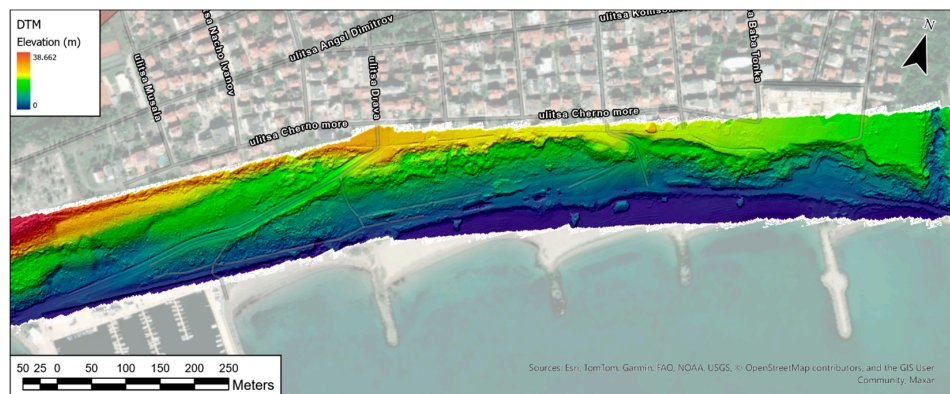


Figure 8. A precise digital terrain model obtained from aerial laser scanning.

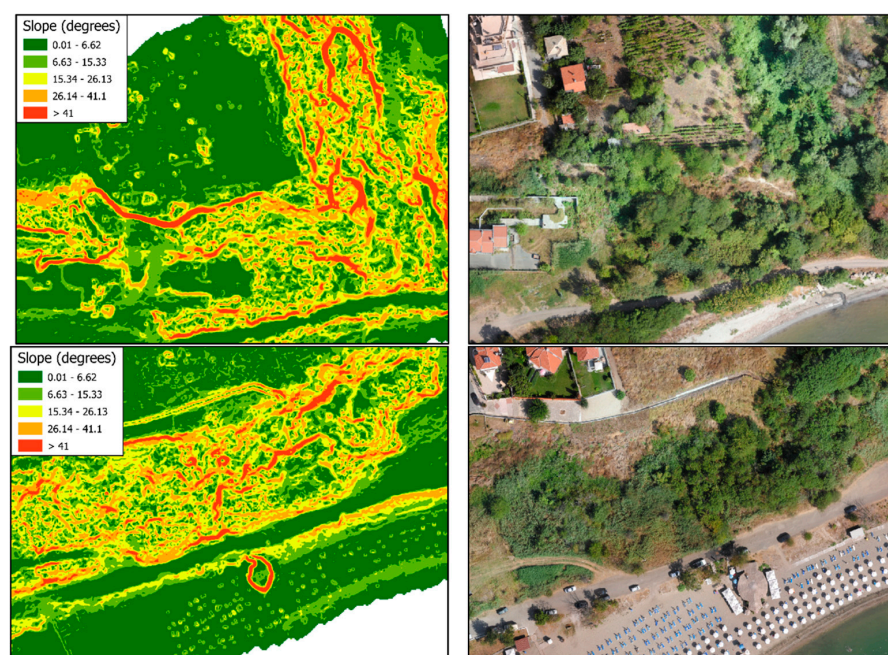


Figure 9. Slopes (in Degrees) from Digital Terrain Model and Current Site Conditions.

3.1.3. Three-Dimensional Structural Analysis of Vegetation

The combined use of terrestrial and airborne LiDAR data facilitated a shift from a traditional two-dimensional analysis of vegetation to a comprehensive three-dimensional assessment of its structure and architecture (Figure 10). Through point cloud segmentation, attribute data were extracted for individual trees, including their height, crown diameter, and overall volume. This approach allowed for the characterization of not only the areal extent but also the vertical complexity and density of the vegetation canopy. The analysis was further supported by field verification from landscape ecologists, allowing for the distinction between degraded areas needing restoration and those with naturally developed secondary vegetation. The latter, while performing a certain soil-stabilizing function, was characterized by low structural complexity and limited ecological value.

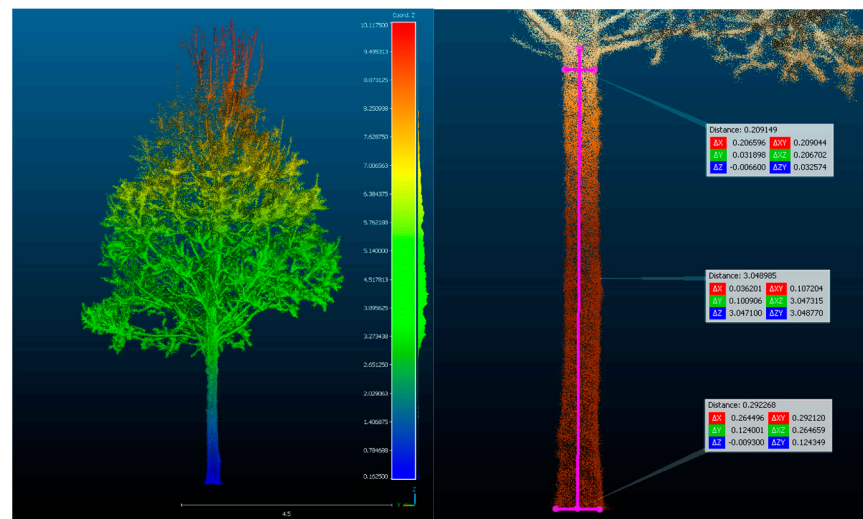


Figure 10. Segmentation and calculation of attribute data for individual trees.

The summary analysis of the above-mentioned newly generated data on the terrain and vegetation made it possible to calculate the carbon storage potential under different scenarios for the development of the territory. For the current situation, data on areas and types of vegetation (broadleaf, coniferous, shrub, and grass) were used, while for the future, data from the design team on those designated for removal and newly planned ones were used. The information is intended to support data-driven decision-making in the planning and design of the coastal area and the assessment of short- and long-term impacts.

3.2. Utilizing New Data for the Development of Coastal Development Scenarios

3.2.1. Scenario 0—Maintain the Existing Situation

The digital geospatial twin is applied as a corrective measure in analyzing the available information about the territory—Development zones according to the Master Plan of Burgas Municipality, Types of Ownership of properties, Way of permanent use of properties, Natura 2000 Protected Sites, Protected Areas, Types of Green Spaces, Transport Systems. Additionally, by comparing contour lines from 2009 and 2024 (via DTM), it identifies terrain dynamics caused by landslides, soil swelling, coastal erosion, and a wide range of anthropogenic interventions. A spatial analysis of the territory in the two land properties under consideration has been developed to assess the current situation. The findings indicate that approximately 29.52% of the area is currently deforested and disturbed (Figure 11). However, the existing vegetation, which mainly consists of deciduous trees and shrubs, plays a vital role in regulating coastal processes and influencing the local climate. Our calculations show a carbon sequestration rate of 24.3903 tC/ha/year.



Figure 11. Visualization of Scenario 0: The existing situation of the territory.

If the current situation and trends continue, we can expect deforestation to spread, fragmentation to increase, and biodiversity to be permanently damaged to the point of no return.

3.2.2. Scenario 1—“Construction of Parking Areas”

The scenario was developed in response to the identified shortage of parking spaces in the neighborhood. The pronounced elevation of the terrain is considered a limiting factor for pedestrian tourist traffic to the beach during the active summer season, which leads to a demand for parking spaces near the shore and, consequently, deforestation. The scenario is in line with the requirements of local businesses, beach concessionaires, and tourism representatives (hotels and restaurants). The case study area is not suitable for construction of underground parking facility due to a combination of geological risks, high groundwater levels, and the inability to support landscaping with tree vegetation on ground level. The total area designated for parking would amount to 21,947.89 m² (Figure 12), representing 15.56% of the park’s total territory. According to the current Master plan /Land-use plan, the land plots are designated as “zones for landscaping, sports, and attractions” with an allowable building density parameter of up to 25%. Within these limits, the plan permits the construction of public service buildings and parking areas, and the paved surfaces of the alley network are not included in the calculation. The parking areas shown in the scenario remain below the allowable building density. No interventions are planned to improve the existing vegetation or enrich it further through afforestation. The zoning parameters outlined in the Master plan for the property permit a maximum building density of 25%. This allows for the construction of a building or parking lot with a height of up to 7 m, while also requiring a minimum of 25% green space, without altering

the intended use of the area. Hypothetically, Scenario 1 complies with these parameters; however, a comprehensive analysis of the results from the digital twin indicates that it does not support a sustainable ecosystem or a favorable ecological status for the park. Investing in parking areas would meet the expectations of local business stakeholders and partially enhance visitation. This will lead to disruptions of the green space, impacting both its sustainability and environmental quality. Implementing this scenario would reduce the current carbon storage in the waterfront area's green spaces by approximately 22%. The construction of numerous parking spaces would provide only a partial solution within a limited residential area. In addition, opportunities for mitigation and adaptation to climate change are limited, and geological risk is significantly exacerbated by the high proportion of sealed soils and the load on the ground.



Figure 12. Scenario 1: Construction of parking areas—type of usability.

3.2.3. Scenario 2—“Enhancing Green Areas”

The scenario is based on the identified deforested areas, considering them as priorities for intervention (Figure 13). It represents a balanced option, including a set of measures for coastal improvement through: (1) Reinforcing degraded terrain, clearing degraded vegetation, and replanting to stimulate regulating ecosystem services—microclimate, surface water collection and drainage, and groundwater drainage, reinforcement and maintenance of soil structure; (2) Providing a network of paths with minimal slopes for pedestrians and cyclists, adapted to the terrain conditions; (3) Concentrating the construction of parking areas on the northern border of the properties and completely removing traffic from the landscaped area; (4) Protection, restoration, and enhancement of the natural environment and creation of conditions for recreational, sports, and educational activities.



Figure 13. Scenario 2: Increasing the green areas.

In the considered scenario, the parking areas amount to 4998.66 m², of which 3869.28 m² are located in deforested areas of the park and represent 2.74% of its total area. These values are well below the allowable building density of 25% according to the Master plan. The areas designated for re-greening amount to 37,754.12 m², representing 26.78% of the park's total area.

The impacts of this scenario cannot be considered in the short term due to the need for specific weather conditions for planting new vegetation and the several years required for strengthening, growth, and the commencement of ecosystem services. In the long term, the total carbon storage from increasing biomass = 11.4248 tC/ha/yr. This outcome is expected to enhance the carbon storage values of the current landscaped area of the coastal zone by nearly 27.8%.

3.2.4. Application of Scenarios for the Subsequent Design of the Coastal Park

Based on the data and analyses from the digital geospatial twin, the scenarios developed, and the expected short-term and long-term impacts, we can summarize that Scenario 2 reveals several advantages that align with our goals for an effective and climate-neutral revaluation of the territory in response to public expectations. Future development will focus on this to achieve and exceed the expected results. After the project implementation, the quantity of green areas will exceed 29 m²/p, satisfying around 40% of the residential areas within a 300 m distance.

The conceptual design for the Coastal Park is based on the Vision: Preservation, restoration and emphasis of valuable natural features, sustainable management of geological risk, improvement of the connectivity of green and infrastructure in the conditions mitigation and adaptation to climate changes, and increasing the quality of the urban environment.

Special emphasis is purposefully placed on the structuring and functional organization of the park with an attitude towards naturalness and aesthetics, with details from local culture, ecological sustainability, and full-fledged regulating ecosystem services, as well as achieving year-round attendance and a high degree of accessibility for all people.

The alley network is planned parallel to the horizontals of the terrain to achieve minimal interference with the topography with natural, soft forms. The predominant longitudinal slope does not exceed up to 5% (Figure 14). This value is based on national legislation (REGULATION No. RD-02-20-2 of 20 December 2017, on the planning and design of the communication and transport system of urbanized areas (For bicycle lanes—Annex 8 to Article 62); REGULATION No. 2 of 29 June 2004 on the planning and design of communication and transport systems in urban areas—For pedestrian paths, Art. 115 (8) and For bicycle lanes, Art. 119 (1)), which does not specify exact parameters for pedestrian areas but sets requirements for bicycle lanes. Pedestrian and bicycle traffic is encouraged, with automobile traffic being taken outside the boundaries of the Coastal Park. Due to the presence of public service facilities at the beach, Sarafovo Fisherman's Port, and the Canal Pumping Station, it is necessary to provide conditions for the passage of service vehicles only at certain time intervals, as well as special regime/police vehicles, emergency medical assistance, and fire.



Figure 14. Accessible routes.

Multiple thematic zones have been identified, based on the proposals received in the Impact Model Workshop and field activities with participants from the Re-Value project, and further developed by planners and designers. Among them are playgrounds with thematic Black Sea and forest elements in the areas with the corresponding ecosystems, Panoramic terrace, Amphitheatre, Rope park and rope bridge for children and adults,

Zones for prolonged stay and social interaction, Zones for sports—pump track and bike skills, Museum and park “Navigation” for representing the local life, communities, and culture, Dog park, and many more (Figure 15). All of them help to create a recognizable and functional coastal park, recognized by local communities and visitors, and emphasizing the coastal, forest, and urban ecosystem along with local culture.

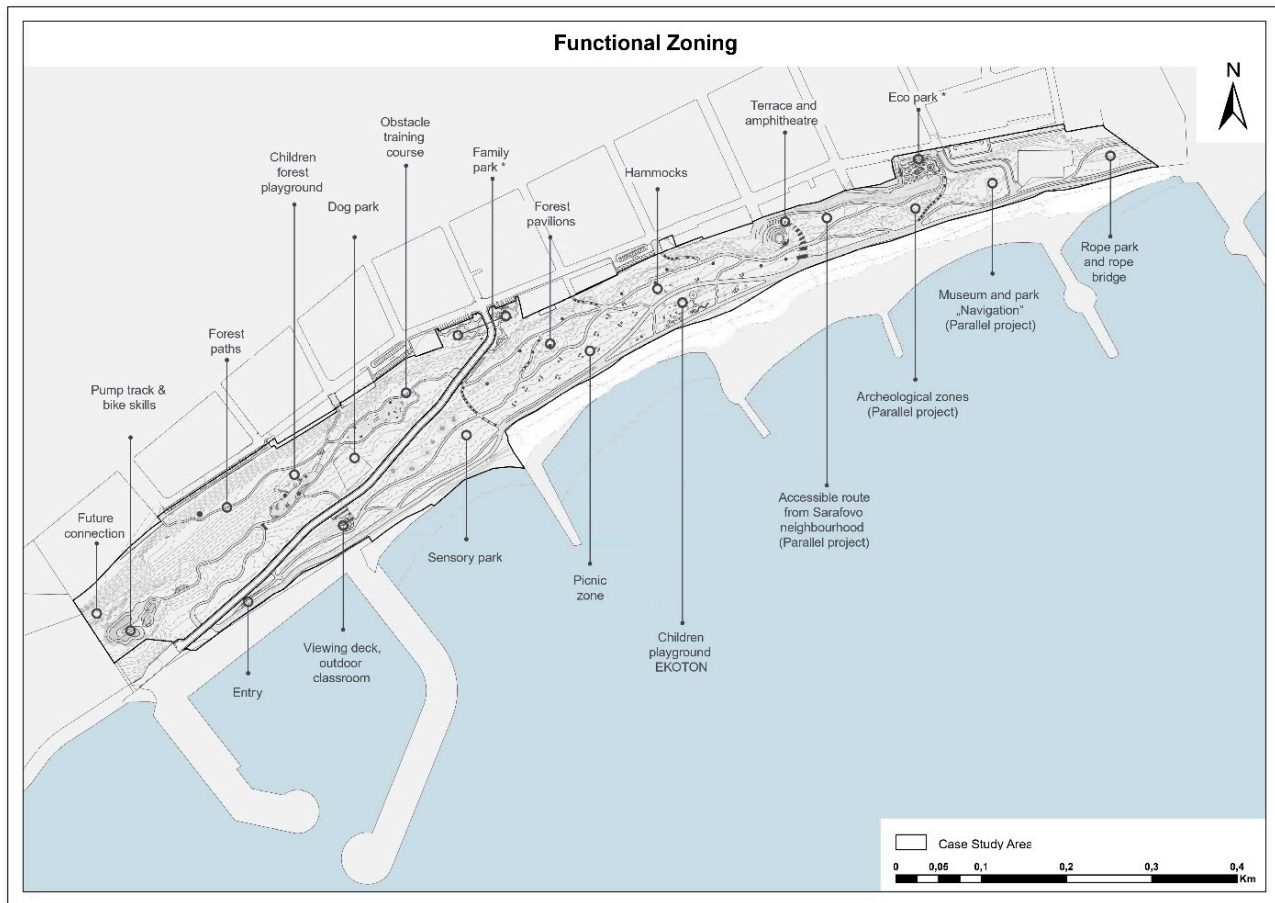


Figure 15. Functional Zoning.

Planting new vegetation can be carried out with the support and involvement of local communities through a series of events dedicated to the reforestation of selected species in specifically designated locations. A key outcome of this process could be the strengthening of community bonds around a shared, socially significant goal, as well as improved attitudes towards the vegetation and its future preservation.

4. Discussion

The developed digital geospatial twin of the Sarafovo district is an integrated digital replica of the physical territory, created through a combination of high-tech geospatial data and scientific methods. In the course of this study, it is of fundamental importance to overcome differences in data about the territory (scales, periods, methods of collection and organization, tools, accuracy, and purpose) and to combine the information into a single, precise model of the territory. This approach creates an information environment for active and productive cooperation between all actors involved in the planning and implementation of territorial interventions. In the context of the project, this digital model is a key tool.

4.1. Precise Mapping of Risks (e.g., Active Landslides, Erosion Zones) Based on Real Geological and Topographic Data

Monitoring inherited natural hazards in urban environments, such as landslides, is a serious challenge for the Bulgarian Black Sea coast. The Ministry of Regional Development and Public Works of the Republic of Bulgaria maintains structures for analyzing and mapping geological risks. These are represented as polygons or points with associated attribute data for registration code, risk levels, and affected area [39,40]. The digital geospatial twin provides a realistic, up-to-date picture of the risk circumstances and allows changes over time to be tracked. At the same time, this is an expensive solution for individual projects, and the rational approach would be for municipal structures to maintain and periodically update a digital twin of the city. This would enable the systematic tracking and reporting of current and future interventions. It would also provide a basis for comparing the initial, expected, and achieved results, as well as their impacts on a broader territorial scale. The recommended update intervals depend on the type of elements being monitored—annual updates are appropriate for technical infrastructure and construction, while a five-year cycle is more suitable for vegetation. In the context of the current territory and the conditions of a changing geography, such comparisons would be particularly valuable for geological risk management, afforestation success, and carbon sequestration, both within the site itself and as part of the broader neighborhood and citywide context. Digital twins support not only initial analysis and monitoring but also timely decision-making for interventions and the achievement of higher long-term outcomes.

4.2. Reassessment of the Advantages and Limitations Derived from Topography

Along with the vulnerability analysis, the identification of local topographical characteristics provided information for refining the alley network and thematic zoning of the park area so that the indicators relevant to such a project could be taken into account in the configuration of the landscape [18] concerning the quality of the coastal environment and public perception [41]—landscape aesthetic with a variety of natural and cultural elements for sports, recreation, cultural and educational activities, panoramic views, types of flooring and plant compositions.

4.3. Contemporary Vegetation Cover

The full utilization of urban forest functions, including their role as nature-based solutions, directly depends on object-oriented information and data quality as a basis for interdisciplinary collaboration [19]. The precise data generated in the course of this study greatly assisted in diagnosing the current state of the vegetation cover, both independently and in the context of the complex terrain. In some cases, the precise depiction within a digital twin necessitates data collection at different times of the year, directly addressing the varying phenological stages of trees. When detailed data on individual tree structure are required, optimal acquisition occurs during winter when deciduous trees lack foliage, enabling active sensors to extensively scan and map intricate tree parts. Conversely, for accurate canopy volume data, such as for biomass estimations, it is paramount to collect information during the period of maximum leaf development, ensuring the full extent of the tree crown is captured. The carbon footprint analysis carried out here was used as an argument in the discussion of development scenarios and in support of the final decision on the details of the urban park design. Here, we again defend the thesis that the full potential of the digital geospatial twin can be realized by discussing ecological phenomena on various scales. The current park design can be viewed in the context of the overall green-blue infrastructure of the city of Burgas. Such a spatial analysis would highlight the

role of the park in carbon sequestration and the discussion of locations and types of new green infrastructure based on the ecosystem services demand [42].

Development and implementation of a Coastal Park concept will contribute to improving access to green areas for the residents and visitors of the Sarafovo quarter. However, in spatial terms, they do not provide a comprehensive solution, and in the future, other solutions should be sought for the establishment of small urban gardens in connection with green corridors to support their functionality and effectiveness. The project considers the implementation of green corridors to ensure the connectivity between coastal green spaces and those within the urbanized areas. However, such corridors are extremely limited due to the nature of land ownership, spatial configuration, and the high density of existing development.

Analyses based on the digital geospatial twin helped track the changing conditions in the development of the Sarafovo district, so that the new landscaping would stimulate the sustainability of the entire urban structure [43] and become the focus of the future construction of a unified green system for the district. The study of the structure of contemporary vegetation has been taken into account in the specific selection of plant species for new landscaping, structural combinations, and location. The species are both suitable for urban park design, representative of local biodiversity and at the same time ecologically resilient to the current and expected effects of climate change, to avoid costly challenges in the management of the park over time [44].

4.4. Visualization and Collaboration—3D Models Serve for Public Consultation by Clearly Demonstrating the Effects of the Scenario Proposals

Experience from contemporary practices shows that sustainability planning processes that use a geodesign approach can be improved with the help of more data-driven inputs and research on the usefulness of integrating data-based modeling and simulation into a collaborative scenario planning process [25]. The visualization of the territory, the subject of discussion and planning of interventions, is a very powerful tool regarding deeper engagement and better understanding of the needs and desires of, as well as a user-friendly sharing platform for, local stakeholders, residents, and visitors, allowing us to build a shared understanding of geodesign principles and apply them to a real-world problems. In our case, this is most clear in terms of demonstrating the high vulnerability of the terrain to active landslide processes and deformations of the modern coastal profile. The latter served as a strong argument in support of the construction of a coastal park, including in the direction of expanding the vegetation cover, zoning to achieve load balance, and isolation of vulnerable areas, as well as a reasoned concentration of critically needed parking areas in locations outside the park space.

The presented digital geospatial twin was not used in the discussion of engineering scenarios regarding traffic and other necessary socio-economic factors. Simultaneously, the digital twin emphasizes the most critical elements related to the functioning of the coastal strip we focus on—the coastal road, the port, and the internal road network in the neighborhood. Discussing these elements alongside other available information on daily travel and traffic congestion helped shape the final decision to suggest parking areas and to expand the intervention zone by including the current beach strip within the urban coastal park project area. Results from our experimental research on climate simulations are not presented here, which, given the proven predisposition of the territory to drought, the urban heat island effect, and flash floods during the period of winter precipitation, is very necessary to improve awareness in urban planning. Based on our previous research in the Burgas area [34], we consider this a necessity, which should, however, be carried out through a digital geospatial twin of the entire territory of the city of Burgas, which, in combination with appropriate data, e.g., thermal photogrammetry [34], would provide

data to develop a general vision for the adaptation of the urban structure to climate change. We entirely share the understanding that adaptation measures for coastal cities should be designed with even greater attention to future hazards, exposure, and vulnerability [17], to promote the speed of their transformative adaptation [12].

The development of a high-fidelity digital twin for the Sarafovo district was accompanied by significant operational, technical, and resource-related challenges. The primary operational constraint was the study area's location within the controlled airspace of Burgas Airport, which necessitated a complex coordination and approval process with air traffic control authorities, restricting flights to narrow, pre-approved temporal and spatial windows. On the contrary, in the design process, the proximity to the airport does not constitute a constraint, as the project does not include any buildings or elements subject to height restrictions. Furthermore, the dynamic urban environment itself presented logistical hurdles; pedestrian and vehicle traffic required data acquisition to be scheduled during periods of low activity to minimize occlusions and motion artifacts. From a technical standpoint, the integration of heterogeneous datasets from three different sensor types was a major challenge, demanding meticulous post-processing to ensure seamless alignment and manage varying error characteristics and point densities. Environmental factors, such as inconsistent lighting affecting the radiometric quality of the photogrammetry, required careful planning and subsequent manual data cleaning. The manual editing aimed to mitigate inherent sensor limitations and rectify automatic processing anomalies, striving to meet a target positional accuracy typically within 10 cm for the point cloud data, consistent with high-resolution geospatial applications. Any potential deviation from this stringent quality control, driven by inconsistencies in manual intervention, directly influences the dataset's accuracy by introducing localized inaccuracies in feature representation and measurements. For example, if unmitigated positioning errors are allowed to persist, the digital twin would be severely hindered from being accurately integrated with other crucial datasets, such as cadastral data or other foundational spatial data, compromising its utility for comprehensive urban planning.

Finally, the project faced considerable resource challenges, not only due to the high cost of specialized hardware and software but also the immense volume of data generated, which demanded significant computational power and extensive, labor-intensive manual intervention for classification, refinement, and quality assurance.

5. Conclusions

The digital twins are a scientific and practical bridge between data and solutions. It transforms raw measurements into evidence for action, enabling planning that considers both environmental challenges and local community needs. This makes it indispensable for sustainable development in complex urban and natural environments. On the other hand, climate change is a fact, and it is obvious that it will have an increasingly negative impact on all geosystems that support life and balance on our planet. It will undoubtedly have an increasingly negative impact on urbanized areas, with cities that do not create conditions for the effective adaptation of their systems to these changes and their impact on the geographical environment being particularly affected. It should be borne in mind that this adaptation is a long-term and systematic process that must take into account the serious inertia of territorial development. Most cities rely on infrastructure systems that were designed and built under different conditions and are based on data that no longer accurately reflect the characteristics of the local climate and conditions, which puts them at serious risk. In this regard, modern geoinformation technologies, including digital geospatial twins, are among the key tools supporting adaptation processes in cities, both by providing an adequate basis for effective planning and management and for carrying

out the necessary monitoring and response to changes in the geographical environment and the associated risks and threats.

A digital twin of a coastal residential neighborhood has been created to facilitate specialized geodesign and discussions with various stakeholders regarding three intervention scenarios in the coastal zone. The ultimate decisions focus on redesigning and constructing a coastal urban park that addresses critical environmental challenges in the area—such as active landslide processes and climate vulnerability—while also enhancing recreational opportunities and expanding public access to the coastline. The digital twin has been instrumental in integrating information from diverse sources into a cohesive model, significantly aiding interdisciplinary collaboration and public discussions during the reassessment of the coastline and the redesign of the urban park.

The present study shows only some of the possibilities of these technologies and tools. They clearly demonstrate both their serious potential to provide adequate information resources to support spatial planning processes and their capacity to integrate with other technological capabilities and systems towards the creation of “smart” and adaptive cities. The applied possibilities of these methods and tools, integrated into the concept of digital geospatial twins, are a “natural” solution that will define the framework for operational and strategic planning and management of urban systems in the near future. Today, spatial planning and management are carried out in a context of increasing “saturation” of all procedures with technological innovations. For this to happen in Bulgaria, it is necessary to encourage local authorities to implement these solutions, both by providing funds for technological improvement and increasing their technological capacity, and by working to improve knowledge and skills [45].

Finally, it should be borne in mind that adaptation to climate change is a global policy with specific local dimensions. Unlike the typical mechanism for structuring and shaping policy instruments, climate change adaptation does not draw on past experience and data but relies on complex simulations and models to provide the information base on which it can be developed.

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