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Review paper

SUSTAINABLE URBAN DESIGN OF ISAR HILL (STIP, NORTH MACEDONIA): INTEGRATED APPROACH TO GIS AND LANDSCAPE URBANISM

Katerina Despot[1], Vaska Sandeva[2], Vladica Nikolovska[3]

Abstract

This paper examines the potential transformation of the urban hill of Isar in Štip as a model of sustainable urban design. Through applied theoretical approaches – including planning in dialogue with nature and Landscape Urbanism – the natural, social and urban layers of the space are analyzed. Furthermore, specific scenarios and principles of intervention are proposed that simultaneously protect the ecology and improve the quality of public space. This paper highlights the importance of integrated urban design as a means of promoting sustainable urban environments.

The study applies GIS-based spatial analysis and NDVI (Normalized Difference Vegetation Index) to assess vegetation density and ecological potential.

Key words: *sustainable urban design, landscape architecture, GIS analysis, NDVI, green infrastructure, urban hills*

[1] PhD, Full professor, University "Goce Delchev" – Stip, Faculty of Natural and Technical Sciences, North Macedonia, katerina.despot@ugd.edu.mk, ORCid 0009-0003-5532-1127
[2] PhD, Full professor, University "Goce Delchev" – Stip, Faculty of Natural and Technical Sciences, North Macedonia, vaska.sandeva@ugd.edu.mk, ORCid 0009-0002-9780-8200
[3] M.Sc., Teaching Assistant, University "Goce Delchev" – Stip, Faculty of Natural and Technical Sciences, North Macedonia, vladica.nikolovska@ugd.edu.mk, ORCid 0009-0004-1801-3130

1. INTRODUCTION

Urban environments globally are increasingly facing complex challenges related to accelerated urbanization, climate change, environmental degradation, and declining quality of life [1]. In this context, green infrastructure and landscape architecture-based approaches are emerging as key components of sustainable urban development, providing ecosystem services such as climate regulation, biodiversity conservation, stormwater management, and improving social well-being.

In recent decades, the concept of Landscape Urbanism has redefined the relationship between natural systems and urban form, positioning the landscape as the primary medium through which cities are organized and transformed [2]. This approach emphasizes adaptability, natural processes, and multifunctionality, enabling cities to respond more effectively to environmental and social pressures.

Despite the growing body of research in the field of sustainable urban landscapes, urban hills and elevated terrains – especially in Southeastern Europe – remain significantly under-researched as integrated ecological and social systems. In many post-socialist cities, these spaces are often marginalized, fragmented or insufficiently integrated into urban plans, resulting in missed opportunities for ecological rehabilitation and development of public spaces.

The Isar Hill in Shtip, North Macedonia, is a characteristic example of such an underutilized urban landscape. Although it possesses significant ecological, morphological and cultural values, the space currently faces challenges such as vegetation degradation, erosion processes and lack of structured public accessibility. At the same time, its topographic dominance and spatial position offer strong potential for transformation into a multifunctional urban landscape.

This paper addresses this research gap by proposing an integrative, landscape-based approach for the sustainable transformation of urban hills, using the Isar as a case study. The research combines spatial, ecological and social analysis in order to develop contextually adapted design principles that strike a balance between environmental protection and urban functionality.

The main objective of the paper is to assess the potential of the Isar as a model for sustainable urban design through three key dimensions: (1) ecological rehabilitation, (2) integration of cultural heritage and (3) social activation of public space. In addition, the paper explores how the principles of Landscape Urbanism and nature-based design can be applied to create adaptive, resilient and inclusive urban environments.

2. THEORETICAL FRAMEWORK

2.1 Landscape Architecture and Sustainable Design

Landscape architecture is a discipline that integrates the natural, social and urban context to create functional, aesthetic and sustainable spaces [3]. Sustainable design in landscape architecture is based on principles that minimize negative impacts on nature, optimize the use of natural resources and provide functional and social value to public

space [1]. In the context of the Isar, these principles are crucial for preserving the natural landscape, integrating green corridors and creating public spaces that enable environmental and social well-being.

2.2 Landscape Urbanism

Landscape Urbanism promotes nature as a foundation for urban design and sees it as a structural element that defines the urban fabric [2]. The principles of Landscape Urbanism include:

- Integration of natural processes such as water, topography and vegetation into the urban fabric.
- Dynamic and adaptive systems that allow for flexibility in public space.
- Balancing social needs and ecological function, by creating spaces for recreation, interaction and learning.

Landscape urbanism provides a basis for interventions that not only preserve nature, but use it as a key resource for urban organization.

2.3 Examples of sustainable urban design

International projects show how an integrated approach can transform urban spaces:

- **High Line, New York** – an abandoned railway line that was transformed into a public park with the integration of local vegetation and public paths [4].
- **Superkilen Park, Copenhagen** – a public space that integrates the cultural and social aspects of the local community through multifunctional zones [2].
- **Parque La Mexicana, Mexico City** – an ecologically integrated park that combines recreational, educational and ecological functions [4].

These examples illustrate the application of the principles of Landscape Urbanism and dialogue with nature, with the aim of creating public spaces that are adaptive, sustainable and socially inclusive.

3.METHODOLOGY

This research is based on an integrated methodological approach that combines spatial analysis, ecosystem evaluation and social interpretation of the Isar Hill as an urban-landscape system. The methodology is structured in three main phases: (1) data collection and processing, (2) spatial and ecological analysis and (3) synthesis and development of design principles.

3.1 Data collection and processing

In the first phase, various data sources are used in order to provide a comprehensive analysis of the space:

- Spatial data – topographic maps, orthophotos and satellite data (Google Earth, Copernicus).

- GIS data – digital terrain model (DEM), vegetation and land use layers.
- Statistical data – demographic and urban information (State Statistical Office).
- Field research – visual analysis, photographic documentation and identification of spatial features.

The collected data was processed using GIS tools (QGIS / ArcGIS), in order to create thematic maps and analyze spatial relationships.

3.2 Spatial analysis

The spatial analysis focuses on the morphological and visual characteristics of the Isar Hill. The analysis includes:

- Slope analysis – to identify erosion zones and potential areas for intervention.
- Aspect analysis – to assess solar exposure and microclimatic conditions.
- Viewshed analysis – to identify visual corridors and panoramic points.
- Accessibility analysis – existing and potential pedestrian connections.

The results of this analysis are presented in Figure 1 – GIS spatial analysis of the Isar, which integrates key spatial layers.

3.3 Ecosystem analysis

The ecosystem analysis aims to identify the natural processes and ecological potentials of the site. In this phase, the following are applied:

- NDVI analysis (Normalized Difference Vegetation Index) – to assess the density and health of vegetation.
- Erosion analysis – based on slope and vegetation coverage.
- Hydrological analysis – identification of surface flows and potential water retention zones.
- Biodiversity analysis – assessment of existing and potential green corridors.

The results are visualized through Figure 2 – NDVI map and ecological potentials, which allows a clear interpretation of the state of vegetation.

3.4 Social analysis

Social analysis is based on assessing the use of space by the local population and the level of accessibility. Methods include:

- direct observation of activities.
- mapping of informal paths (desire paths).
- identification of gathering points.
- analysis of the functionality of the space.

This analysis allows for an understanding of the relationship between users and space, which is key to developing sustainable and inclusive design solutions.

3.5 Synthesis and development of design principles

In the final phase, the results of all analyses are integrated into a synthetic model that serves as a basis for the development of design strategies. This phase includes:

- identification of zones with different potential (ecological, social, cultural).
- definition of priorities for intervention.
- development of sustainable design principles (adaptability, reversibility, minimal intervention).

This integrated approach is illustrated in Figure 3 – Isar's Sustainable Transformation Model, which represents a conceptual framework for future interventions.

4. RESULTS

The analysis of Isar Hill showed that the hill represents a complex combination of natural processes, existing infrastructures and opportunities for public space integration. The results are classified into three main aspects: morphology and natural processes, ecosystem potentials and constraints, and design potentials.

4.1 Morphology and natural processes

The topographic structure of the Isar defines the natural drainage, visual corridors and microclimate in the surrounding settlements. The hill provides a natural barrier that influences the distribution of sunlight and winds, which can be used in the positioning of pedestrian paths, recreational zones and stabilisation or protection of high-risk areas. The daily use of the hill by the local population shows natural gathering points and activities, which can be formalized as public spaces without significant interventions [1].

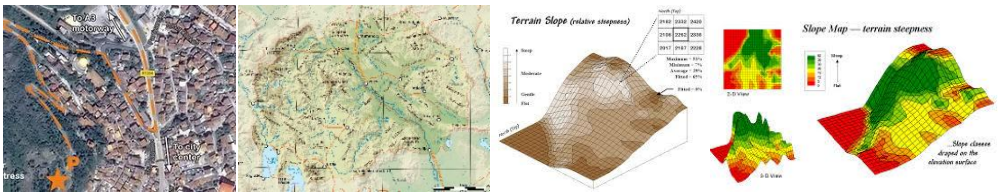


Figure 1. GIS-based spatial analysis of the Isar hill in Shtip, North Macedonia, showing the topography, slope distribution, vegetation patterns, and spatial structure of the terrain. The map integrates multiple spatial layers to identify ecological potentials, areas prone to erosion, and zones suitable for landscape intervention. Source: Author's elaboration using AI-generated GIS visualization.

The GIS-based spatial analysis (Figure 1) reveals the morphological complexity of the Isar Hill, characterized by different slope gradients, fragmented vegetation cover and different visual corridors. Steeper areas are primarily associated with a higher risk of erosion, while moderately sloping zones present favorable conditions for the development of hiking trails and recreational spaces. The spatial structure also highlights the potential for establishing ecological corridors connecting vegetated areas across the hill.

4.2 Ecosystem potentials and constraints

Erosion processes and vegetation fragmentation have been identified as major environmental challenges. However, the Isar has significant potential for establishing green corridors that would connect different parts of the hill and enhance biodiversity. The use of indigenous plant species will allow for soil stabilization and improvement of the local ecology. Watercourses can be used to create natural reservoirs and rainwater management systems, thus reducing the risk of erosion and flooding [3].

Table 1. NDVI classification chart showing the relationship between NDVI values and vegetation density, highlighting ecological quality and levels of degradation

NDVI value	Vegetation category	Interpretation
0.6 – 1.0	Dense vegetation	High biological activity, stable ecosystems, high biodiversity potential
0.3 – 0.6	Medium vegetation	Moderate coverage, potential for improvement through interventions
0.1 – 0.3	Weak vegetation	Fragmented surfaces, increased risk of erosion
< 0.1	No/degraded vegetation	Minimal biological activity, high degradation, priority zones for rehabilitation

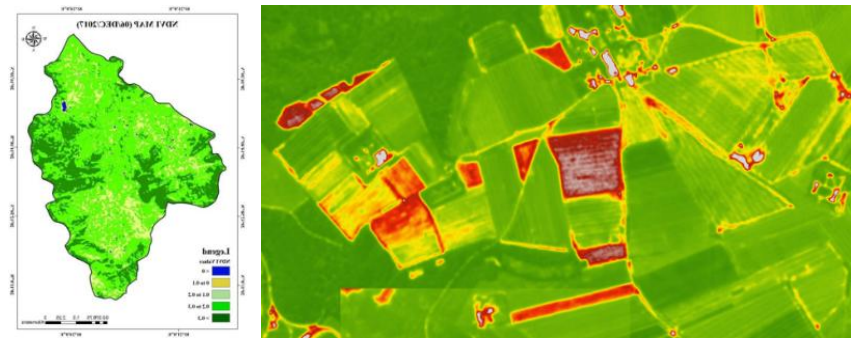


Figure 2. NDVI (Normalized Difference Vegetation Index) analysis of the Isar Hill, indicating the spatial distribution of vegetation density. Areas with higher NDVI values (green) represent dense and healthy vegetation, while lower values (yellow to red) indicate sparse vegetation and potential zones of degradation and erosion risk. Source: Author's elaboration using AI-generated visualization.

The NDVI analysis (Figure 2) provides a quantitative assessment of vegetation density across the Isar ridge. Areas with high NDVI values correspond to zones with dense and relatively stable vegetation, indicating greater ecological resilience and potential for biodiversity conservation. Conversely, areas with low NDVI values reveal fragmented or degraded vegetation cover, often associated with increased erosion risk and reduced ecological functionality. These findings highlight priority zones for ecological restoration and the introduction of native plant species.

NDVI values were classified into four categories representing different vegetation conditions, ranging from degraded areas to dense vegetation cover (Table 1 and Figure 2). This classification allows for a clear interpretation of ecological quality and supports the identification of priority areas for restoration and intervention in the landscape.

4.3 Design potentials

The Isar Hill has the potential to be transformed into an integrated urban landscape system that combines ecological, cultural and recreational functions. Design possibilities include:

- **Recreational trails and corridors –** using the natural topography for pedestrian and bicycle paths, which are integrated with existing green belts.
- **Educational and information points –** creating trails with information boards about the flora, fauna and geological features of the hill, thus encouraging an educational function.
- **Cultural and historical points –** preserving and presenting archaeological sites and historical traces, which are part of the cultural heritage of Shtip.
- **Microclimatic solutions –** integrating tree shades, green covers and water features to improve comfort and protect against extreme temperatures.
- **Socially integrated public spaces –** places for gathering, recreation and activities that increase the sense of community and social interaction [2, 4].

The proposed design intervention is visualized in Figure 3, which illustrates the transformation of the Isar into a terraced, accessible and ecologically integrated landscape. The design incorporates natural materials, adaptive pathways and observation platforms, while preserving the existing topography and enhancing the spatial experience of users.

The integration of these elements creates the potential for the transformation of the Isar from a passive natural hill into a functional, adaptive and sustainable urban-landscape system.



Figure 3. Visualization of the proposed landscape intervention on the Isar Hill, illustrating terraced paths, integrated vegetation, seating areas, and viewing platforms designed according to sustainable and contextually sensitive principles.

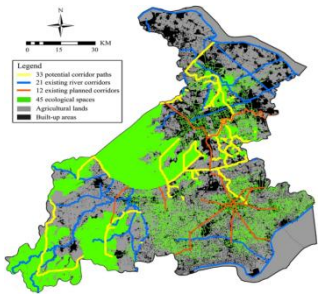


Figure 4. Conceptual model of sustainable transformation of the Isar hill, integrating ecological rehabilitation, social activation and cultural heritage preservation. The model illustrates the spatial relationships between green corridors, public spaces and intervention zones, based on the principles of landscape urbanism and nature-based design. Source: Author's elaboration using AI-generated visualization.

The conceptual model (Figure 4) synthesizes the results of spatial, ecological and social analyses into an integrated framework for sustainable transformation. The model defines key intervention zones, including ecological restoration areas, recreational corridors and cultural nodes. The connections between these zones are structured through a network of green corridors and pedestrian paths, ensuring ecological continuity and social accessibility. This approach reflects the principles of landscape urbanism, where the landscape functions as the primary organizing element of urban space.

5. DISCUSSION

Isar's analysis emphasizes the importance of an integrated approach to the urban and natural landscape. Sustainable urban design is not limited to visual aesthetics, but involves a systematic consideration of the ecological, social and cultural functions of space [1].

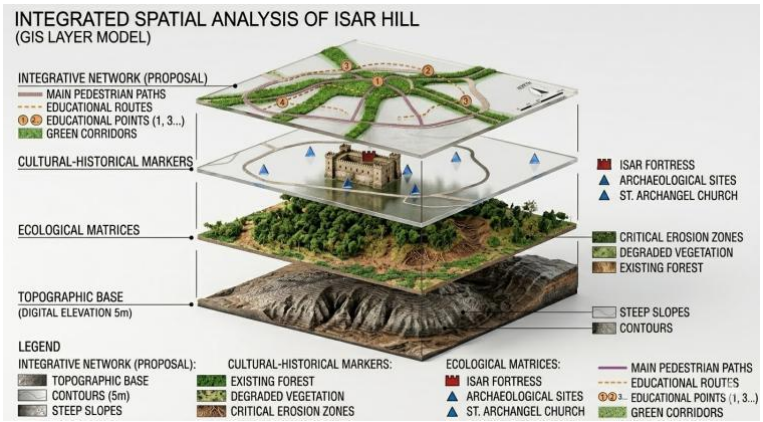


Figure 5. Integrated conceptual model for the sustainable transformation of the Isar Hill based on GIS, illustrating the interaction between the topographic structure, ecological matrices, cultural-historical elements and the proposed pedestrian and green infrastructure networks. Source: Author's elaboration using AI-generated visualization.

The integrated spatial model (Figure 5) illustrates the multi-layered structure of the proposed intervention, combining topographic conditions, ecological matrices and cultural-historical elements into a unified design framework. The model highlights the role of green corridors and pedestrian networks as key structural elements that ensure both ecological continuity and social accessibility.

The interventions in Isar, based on the principles of Landscape Urbanism, allow nature to become a structural element of the urban system, resulting in multifunctional public spaces. The application of green corridors, educational paths and integrated recreational zones increases the quality of the environment, while preserving the natural structure and biodiversity [2].

The discussion also highlights the importance of the adaptability and reversibility of the interventions. The spaces need to be flexible and able to respond to future changes,

such as climate change or increased urban density. This adaptability enables long-term sustainability of the space, reducing the need for radical reconstructions [3].

The application of international examples, such as the High Line in New York and Superkilen Park in Copenhagen, indicates that public spaces that integrate nature and urban life can achieve a high level of social interaction and ecological functionality [4]. Similarly, the Isar has the potential to develop into a public space that not only provides recreation, but also educational, cultural and ecological functions, creating a model of urban-landscape integration that can serve as an example for other urban hills in the country and the region.

A key aspect in the discussion is also the importance of contextuality – any intervention must be adapted to the local natural conditions, the existing infrastructure and the cultural heritage of the Isar. In doing so, planning must respect existing natural corridors, visible lines and ecosystem functions, in order to achieve harmonious and sustainable integration [5]. In conclusion, the discussion confirms that the Isar can be transformed into an integrated public space with significant ecological, social and cultural value, if a systemic and contextual approach is applied that combines the principles of sustainable urban design and Landscape Urbanism.

The results highlight the importance of urban green infrastructure as a key driver of ecosystem services in transitional urban landscapes. The NDVI-based assessment confirms that vegetation density directly influences ecological stability, microclimate regulation, and spatial quality.

6. CONCLUSION

The Isar Hill represents a significant potential for sustainable urban design, as it combines nature, urban fabric and cultural heritage of the city of Shtip. The analysis showed that the space has important natural, ecosystem and morphological characteristics that can be used for the development of integrated public spaces with multifunctional purposes.

The application of the principles of sustainable urban design and Landscape Urbanism enables the creation of public spaces that:

- preserve the natural structure and biodiversity;
- enable adaptive and reversible interventions;
- integrate cultural and historical elements;
- increase social interaction and recreational function;
- provide educational and ecological values.

The results of the analysis and discussion indicate that the Isar can be transformed into a model for urban-landscape integration, which offers functional, ecological and socially valuable spaces. This model can serve as an example for similar urban hills and natural resources in urban environments in Macedonia and beyond.

In the future, further research could focus on specific design solutions, monitoring of environmental effects and analysis of the use of public spaces, in order to confirm the long-term sustainability of interventions. At the same time, the application of a systemic and contextual approach will allow balancing the needs of the community

with the preservation of the natural and cultural values of the Isar [1, 2]. In conclusion, the Isar represents a potential laboratory for sustainable urban design, where nature, urbanism and cultural heritage are integrated to create public spaces with a high quality of life and functional value.

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