Exploring the Urban Green Infrastructure Index: A Case Study of Zagreb, Croatia

Hrvoje TOMIĆ, Samanta BAČIĆ, Miodrag ROIĆ, Goran ANDLAR, Croatia

Key words: green infrastructure, digital cadastre, e-Governance, geoinformation, land management, real estate development, property valuation

SUMMARY

Nowadays, with more than half of the world's population living in urban areas, ensuring sustainable development is crucial. Urban green infrastructure planning is a proven effective tool that offers social, ecological, and economic benefits, thus significantly enhancing the quality of life in cities. Optimal use of spatial resources is a complex task typically involving a considerable amount of spatial data, handled by spatial planning systems. This system sets rules and divides space into zones where certain construction activities are permitted or restricted. It commonly utilizes data from land administration systems. A land administration system (LAS) encompasses all processes, activities, and institutional frameworks used for managing land and its resources. This includes recording, registration, administration, regulation, and management of land rights, as well as the implementation of policies and laws related to land use. LAS incorporates geodetic, legal, administrative, and technical components to ensure efficient land use and protection of property rights. Urban green infrastructure can be viewed as one of the many factors influencing property valuation, which can be used in spatial planning to ensure a consistent network of urban green infrastructure within a city or municipality. This approach optimizes resources and monitors progress in priority areas. Property valuation assessment is a core function of LAS, where transparent property value data sharing is essential for fair planning, taxation, and other land management operations. Based on the case study of Zagreb, this paper researches the correlation between the urban green infrastructure index (developed and further explained in Samanta Bačić's doctoral thesis) and property values extracted from the Zagreb city's land management system. The primary use of this data is to identify hotspots - areas lacking sufficient green infrastructure on one hand, and valuable areas with higher property prices on the other. Depending on desired outcomes, these data can be periodically, completely automatically determined and be used to track trends and, by harmonizing this eco-service, regulate property prices to mitigate spikes in high-priced areas. It's important to note that urban green infrastructure is just one of many factors, and disparities exist between property prices and the urban green infrastructure index in certain areas. The greatest benefit of the proposed methodology lies in using existing geoinformation solutions for sharing and monitoring this factor which can be considered as a key performance index (KPI). Similarly, the same procedure can be used to determine values of other factors, explaining spatial planning priorities or land management systems improvements through enhanced geoinformation-based decision-making in a clear and transparent manner.

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1. Introduction

With over half of the global population now residing in urban areas, the need for sustainable development has become increasingly critical. When integrated with the land administration system (LAS), urban green infrastructure plays a vital role in improving the quality of life by optimizing resource use and enhancing property management. This paper investigates the relationship between green infrastructure and property values in Zagreb, highlighting how geoinformation infrastructure can support efficient and effective land management and urban planning. Optimal use of spatial resources is a complex task typically involving a considerable amount of spatial data, handled by spatial planning systems. This system sets rules and divides space into zones where certain construction activities are permitted or restricted. It commonly utilizes data from land administration systems. A land administration system encompasses all processes, activities, and institutional frameworks used for managing land and its resources. This includes recording, registration, administration, regulation, and management of land rights, as well as the implementation of policies and laws related to land use. LAS incorporates geodetic, legal, administrative, and technical components to ensure efficient land use and protection of property rights. Conceptually model by Land Administration Domain Model (LADM), a standard describing fundamental concepts, data structures, and functionalities necessary for land and property rights management. The main goal of LADM is to facilitate interoperability among different land administration systems worldwide. LADM enables information exchange between different LAS-es, crucial for efficient land management, transparency in property rights, and support for economic development and sustainable urban planning.

The analysis of previous research has revealed a large and growing number of studies on green infrastructure, while the number of studies focused on the valuation of green infrastructure in land management is significantly smaller (Bačić et al., 2022). The analysis showed that most research is more focused on the ecological and social benefits of green infrastructure, with less emphasis on its economic benefits. Several other authors reached the same conclusion in their systematic reviews of the green infrastructure literature (Ersoy Mirici, 2022; Van Oijstaeijen et al., 2020; Ying et al., 2022). The main challenge in valuing green infrastructure in land management is considered to be the lack of adequate spatial data infrastructure. Apud et al. (2020) developed a GIS-based tool to support urban green infrastructure planning. Literature review further shows that increasing importance is being placed on green spaces in urban areas, with more emphasis on their benefits. Green infrastructure has a positive impact on various aspects of life and brings numerous economic benefits, including increasing land and property values, making it essential to plan and invest in it. Based on the reviewed literature, we conclude that while there are certain methods to demonstrate the value and cost-effectiveness of green infrastructure, there are no unified or concrete models for valuing green infrastructure elements within land management processes to more clearly justify the return on investment. Therefore, such models and their requirements need to be researched.

1. Concepts of Green Infrastructure

Urban green infrastructure as a concept was introduced within the framework of sustainability and resilience, particularly in urban areas. Investing in green infrastructure makes economic sense because a single area can provide multiple benefits, provided its ecosystems are in healthy condition. Such healthy ecosystems offer society a range of valuable goods and services that are economically, socially, and ecologically important (European Commission, 2014).

In its strategic document on green infrastructure, the European Commission defines green infrastructure as a strategically planned network of natural and semi-natural areas that are designed and managed to deliver a wide range of ecosystem services and preserve biodiversity in both urban and rural areas. This means that green infrastructure is not just any green space, but specifically those areas that provide at least one ecosystem service, whether it be supporting, provisioning, regulating, or cultural services (European Commission, 2013).

Green infrastructure can mitigate climate change risks, help reduce the effects of urban heat islands, and lower the risk of flooding (Garcia et al., 2020; Reynolds et al., 2020; Shade et al., 2020). It also improves air quality, with various scientific studies showing that this contributes to a higher quality of life and better physical and mental health (Engemann et al., 2019; Kim & Miller, 2019; Nawrath et al., 2021). Additionally, it supports biodiversity conservation through the preservation and restoration of natural habitats (Brunbjerg et al., 2018; Roggema et al., 2021). Unlike gray infrastructure, which typically serves only one purpose, green infrastructure is multifunctional, providing numerous social, ecological, and economic benefits (Hansen & Pauleit, 2014; Korkou et al., 2023), both in rural and urban settings, and therefore requires strategic development.

2. Methodology

The primary aim of the paper was to explore the relationship between the newly established green infrastructure index and property prices through its potential applications in land management procedures. The green infrastructure index can be quantified in numerous ways, but regardless of the method used, it is possible to integrate the data with spatial planning systems and mass property valuation systems and utilize it in land management processes. It is anticipated that this data could help standardize the level of green infrastructure, leading to more balanced spatial development and reducing pricing hotspots.

Urban green infrastructure can be viewed as one of the many factors influencing property valuation, which can be used in urban planning to ensure a consistent network of urban green infrastructure within a city or municipality. This approach optimizes resources and monitors progress in priority areas. Property valuation assessment is a core function of LAS, where transparent property value data sharing is essential for fair planning, taxation, and other land management operations. Based on the case study of Zagreb, this paper researches the correlation between the urban green infrastructure index (developed and further explained in Samanta Bačić's doctoral thesis) and property values extracted from the Zagreb city's land management system. The primary use of this data is to identify hotspots - areas lacking sufficient green infrastructure on one hand, and valuable areas with higher property prices on the other.

The value of land is determined through specific valuation processes, which can be conducted individually or through mass appraisal. In cadastral records, information about mass appraisal

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is most commonly recorded, which can be the result of individual data collection over a certain period (Roić, 2012). The value of land is influenced by its current use, but also by its potential future use, as determined by land-use zoning, land-use planning regulations, and the permitting processes (Williamson et al., 2009). The value of urban land depends on the availability and use of nearby lands, implying that the location of the land, as well as the surrounding infrastructure and environment, are the most important components of land value (Clapp et al., 2023).

3. Study area: the City of Zagreb

To facilitate the evaluation of green infrastructure and prioritize its implementation, a model was developed for assessing urban green infrastructure in land management, specifically applied to the City of Zagreb. This city was chosen due to its status as Croatia's capital, issues with construction encroaching on green spaces, and the availability of spatial data. Various spatial data were collected from Zagreb, including information on land use from the City Office for Economy, Environmental Sustainability, and Strategic Planning, and data on green infrastructure from the City Office for Renovation and Construction. Based on the conducted analyses: tree availability analysis, availability of public green spaces, water surface availability analysis, land surface temperature analysis, and brownfield area analysis, the Green Infrastructure Index for the City of Zagreb was determined using the multi-criteria methods. The Green Infrastructure Index was determined at three different levels: for residential and mixed-use zones, for local councils, and for city districts. This research analysed data from 16,251 zones within these districts (Figure 1) to evaluate the green infrastructure's role and potential improvements in land management.

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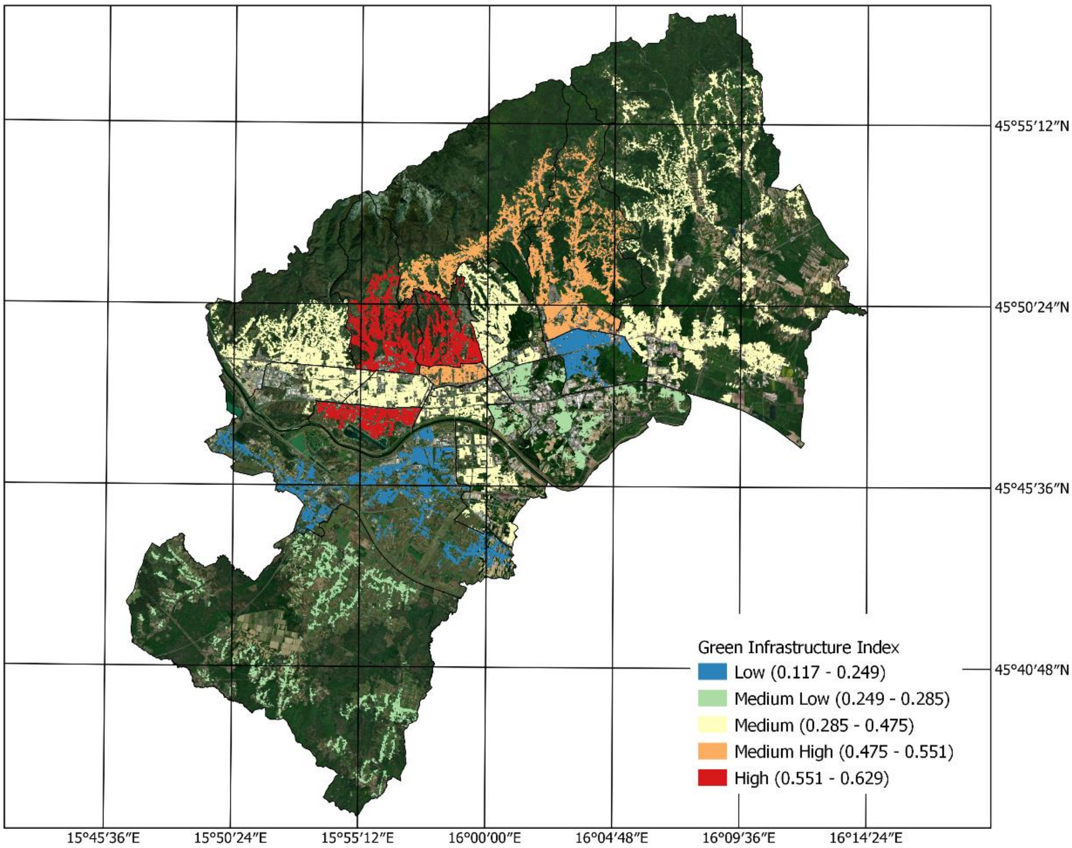

Figure 1. City of Zagreb's Green Infrastructure Index

Figure 1. shows that the city districts of *Črnomerec* and *Gornji Grad - Medveščak* have the highest green infrastructure index, which is expected due to their proximity to *Medvednica* and the large parks near their residential and mixed-use zones. *Trešnjevka - jug*, located along the Sava River and home to the Jarun Recreational Sports Center, also scores highly. In contrast, *Donja Dubrava* and *Novi Zagreb - Zapad* have the lowest green infrastructure index, notably lower than other districts. Despite being the city's narrowest center, *Donji Grad* has a relatively high green infrastructure index, attributed to its numerous public green areas near residential and mixed-use zones.

Although presenting green infrastructure at the level of city districts provides a broader overview and general trends, for use in land administration and spatial management systems, the model was defined at a much more detailed level. The smallest spatial unit associated with green infrastructure data (further explained in Samanta Bačić's doctoral thesis) is the pricing block or land use zone. This allows for the detection of smaller variations in the distribution of green infrastructure within individual city districts. The index was determined using existing spatial data and automated processes, enabling periodic and sequential updates to monitor the implementation and trends of green infrastructure services.

4. Results and discussion

Data from the mass valuation information system clearly show a strong correlation between price and location, indicating that the price per square meter of building land is significantly

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higher in the city center compared to the periphery (Figure 2). This is, of course, expected due to the typical dynamics of spatial development. The data is stored in the mass valuation system within a collection of real estate transactions, which allows for the extraction of approximate values by value blocks, typically entire or partial land-use zones from spatial planning. Within each land-use zone, the spatial development conditions are the same, and it can be inferred that all properties within that polygon have approximately the same unit value.

Some areas, however, deviate from the concentric circles constructed around the city centre. These include areas north of the city centre, the *Podsljemenska Zone*, and areas near sports and recreational centres like *Lake Jarun, Lake and Park Bundek*, or *Maksimir Park*.

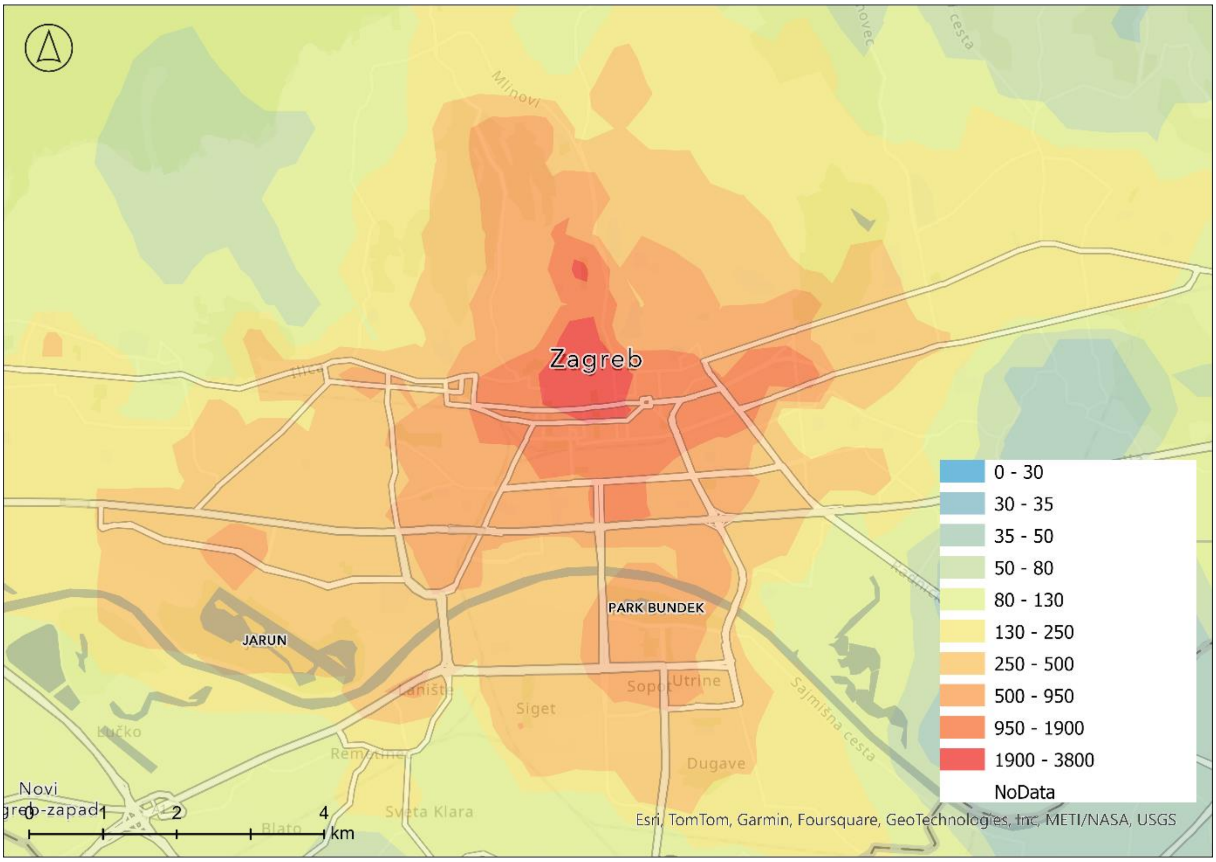

Figure 2. Thematic representation of land value by residential and mixed-use zones [€ /m²]

For a clearer presentation of the Green Infrastructure Index values, the values determined by the previously described analyses were approximated with an interpolated surface based on the most detailed level of data—land-use zones—to provide a smoother representation of the entire city's area. The previously mentioned trends are also visible here, highlighting areas of the city with better-implemented green infrastructure and, accordingly, a higher Green Infrastructure Index (Figure 3).

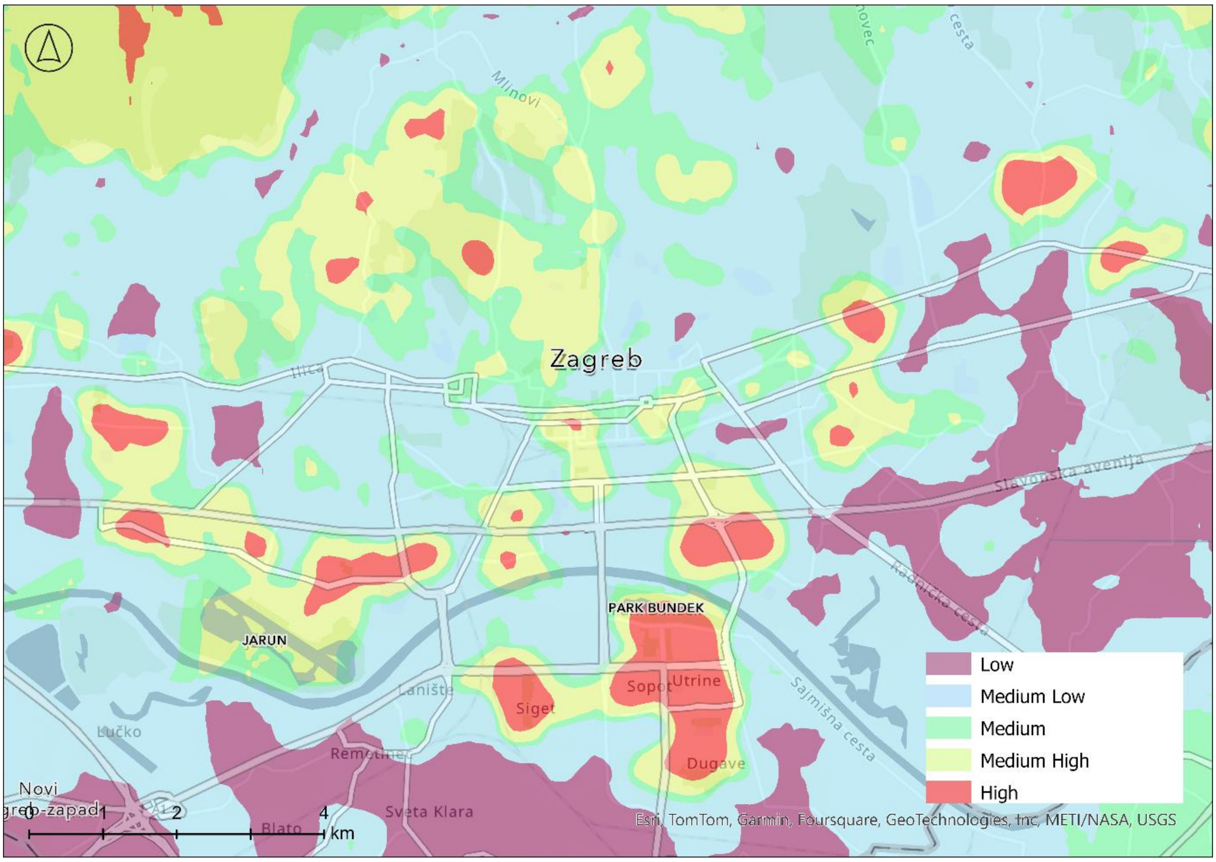

Figure 3. Thematic representation of Green Infrastructure Index

By taking the values of the Green Infrastructure Index as an individual, partial measure, it is possible to observe differences in the approximate values of price blocks in roughly similar locations at the level of price blocks. At the following two selected locations, a positive correlation between the Green Infrastructure Index and the approximate value within the price block can be observed.

In the example of *Novi Zagreb* (the part area south of the Sava River): *Trokut* and *Trnsko* neighbourhoods (Figure 4) — it is clearly visible that *Trnsko* (the eastern part of the Figure), which was planned with a lot of greenery and has a higher Green Infrastructure Index, has a higher average unit price, even though it is relatively close to the *Trokut* (the western part of the Figure).

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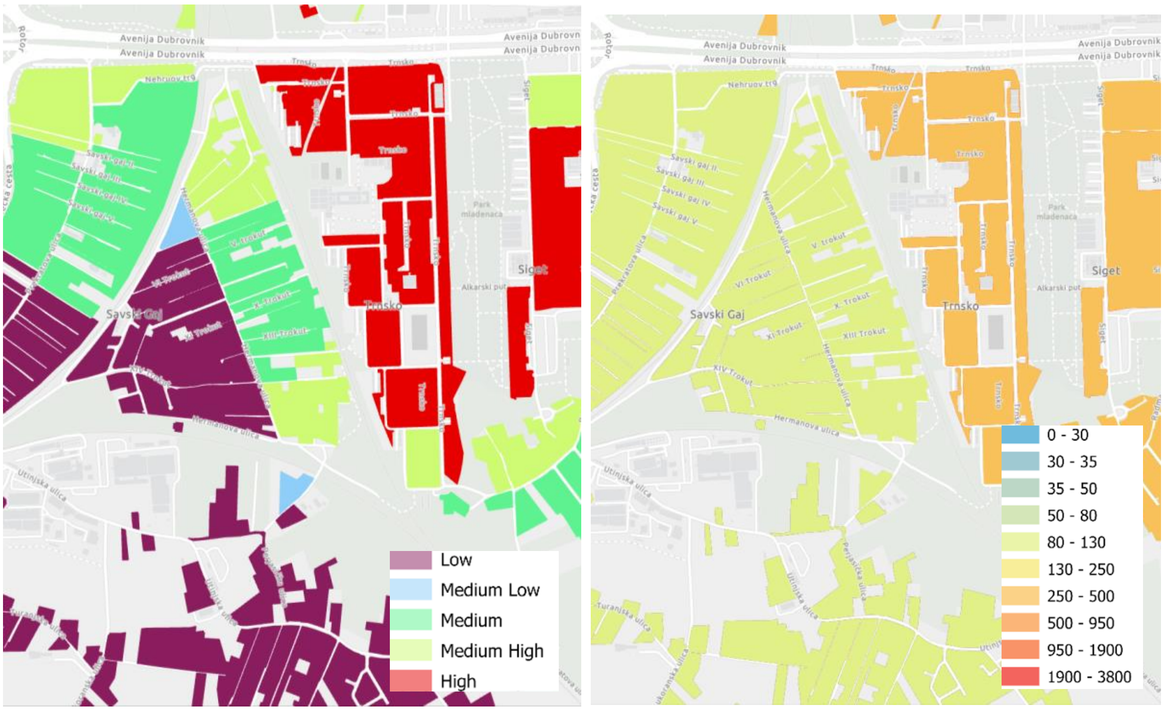

Figure 4. Comparative view: Trokut - Trnsko; Green Infrastructure Index values (left) and approximate price of price blocks –[€ /m²] (right)

Another example of a positive correlation is the zones east of the city center, east of *Heinzelova Street*. Here, it is evident that the area south of *Ulica kralja Zvonimira* has higher Green Infrastructure Index values as well as higher approximate price values for price blocks, even though these areas are spatially similarly located and connected in relation to the city center (Figure 5).

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Figure 5. Comparative view: north and south from Kralja Zvonimira Street; Green Infrastructure Index values (left) and approximate price of price blocks – [€ /m²] (right)

Looking at the previously presented examples, we can say that they demonstrate a positive impact of green infrastructure on land values. Therefore, these examples suggest that by implementing green infrastructure in certain areas, the availability of services and land values could potentially become more balanced, reducing extreme differences, especially among residential and mixed-use zones located in the same area.

5. Conclusion

Green infrastructure is currently the focus of many studies. However, only a relatively small number of studies examine green infrastructure for land management purposes. While green infrastructure is crucial for achieving sustainable development goals, it is also important to pay attention to sustainable land management. In other words, when planning green infrastructure, more attention should be given to land management to maximize benefits and land value, and to potentially balance the availability of services in areas where green infrastructure is planned. Therefore, this study evaluates green infrastructure in the context of land management, developing a model for assessing urban green infrastructure and determining a Green Infrastructure Index, which is further compared with land values.

At this stage of the study, we examined the relationship between green infrastructure and land value using a simple comparison. However, to utilize the Green Infrastructure Index in land valuation processes, it is necessary first to develop a valuation model based on other, primarily spatial, factors. Green infrastructure is just one of many urban services, and it is impossible to study it in detail individually without considering other factors.

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BIOGRAPHICAL NOTES

Hrvoje Tomić works as an Associate Professor at Department of Applied Geodesy, University of Zagreb, Croatia. In 2010 he received his Ph.D. from University of Zagreb for the thesis: “Geospatial Data Analysis in Purpose of Real Estate Valuation in Urban Areas”. His main research interests are GIS and DBMS technology in spatial data handling. Hrvoje Tomić has participated on several projects and has published several papers.

Samanta Bačić works as a Senior Assistant at the Department of Geodesy and Geoinformatics, University of Split, Croatia. In 2024 she received her Ph.D. from the University of Zagreb for the thesis: “Development of Valuation Model of Urban Green Infrastructure in Land Management”. She participates in the Horizon Europe project DesirMED and has published several papers.

Miodrag Roić graduated in Geodesy from the University of Zagreb, Faculty of Geodesy. In 1994, he received a PhD from the Technical University Vienna. Since 1996, he is a professor at the University of Zagreb, Faculty of Geodesy. He was Dean of the Faculty for 2011-2015. The topics that he specializes in are land administration systems, engineering geodesy, cadastres and geoinformatics. He is a corresponding member of the German Geodetic Commission (DGK) and many other national and international scientific and professional institutions.

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