Open Data Supporting GIS-based Walkability Assessment: Case Study for City of Zagreb, Croatia

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Abstract

The study presented in this paper aims to contribute to the broader discourse on urban planning challenges by presenting a preliminary walkability assessment for the city of Zagreb, Croatia. Using the open-source OS-WALK-EU walkability assessment tool and open government and data from OSM, we demonstrated how data-based walkability assessment can provide information to support relevant policy making. The assessment considered two walkability user perspectives, one focused on enjoying free time and other on daily obligations (e.g. commuting to work). Preliminary findings indicate that walkability index scores are higher in the city centre and decrease towards the periphery for both user perspectives. Additionally, the results indicate that despite different user perspectives give different walkability scores, these are almost uniform across Zagreb, making all the assessed districts equally attractive for both, enjoying free time and do daily obligations.

1. Introduction

The world is experiencing increased urbanization, with over half of the global population now residing in urban areas (Ritchie et al., 2024). This trend places significant pressure on urban infrastructure, the environment, and quality of life, prompting changes in urban management strategies. To mitigate the negative impacts of urban population growth, many cities are turning towards smart planning and the development of sustainable and resilient cities (de Lima et al., 2022). In its resolution on the Sustainable Development Goals, the United Nations highlights the importance of making cities more resilient and sustainable, emphasizing that transportation and mobility are crucial to achieving this objective (United Nations, 2012). Rafiemanzelat et al. (2017) further argue this perspective, asserting that walking and cycling, as forms of "green" transportation, are fundamental to the concept of sustainable cities.

Walkability, which measures how pedestrian-friendly an urban environment is, focuses on understanding and quantifying the interaction between the urban environment and pedestrians. However, the results of walkability assessments can vary significantly depending on the evaluation approach used (Telega et al., 2021). Subjective approaches rely on input from individuals, capturing their personal perceptions, while objective approaches use data-based information systems, such as GIS, to provide information (D’Orso and Migliore, 2020). Modern urban planning, aiming for sustainable cities, emphasizes data-driven decision-making (Bokolo, 2023), making objective walkability assessments a reliable foundation for developing policies and interventions.

Data and technology are crucial for objective walkability assessments. The rise of open data initiatives like OpenStreetMap and the European Open Data Directive of 2019 has made numerous datasets publicly available for unrestricted reuse, and many community-developed software tools have been released under open licenses. These advancements have significantly improved walkability assessment methods, increasing both their number and sophistication over the years.

Given the global imperative to create sustainable and resilient urban spaces, this study aims to contribute to the broader discourse on urban planning challenges by presenting a preliminary walkability assessment for the city of Zagreb, Croatia. Drawing on the importance of urban mobility for the design of sustainable and resilient cities and the potential of open data and technologies, this paper seeks to leverage official and volunteer-collected open data, alongside open technologies such as the OS-WALK-EU plugin for QGIS. The objective is not only to identify key factors influencing walkability but also to offer insights into how urban spaces can be optimized to enhance residents' quality of life. This goal will be pursued through the identification of relevant open data sources, their application in spatial analysis tools, and the comprehensive examination of factors influencing walkability.

2. BACKGROUND

This section explores the importance of walkability in sustainable urban development while emphasizing its multifaceted nature and role in policy-making processes. Additionally, it concerns different GIS-based walkability measures and highlights the advantages of utilizing open data and technologies in the walkability assessment process.

2.1 Walkability in Sustainable Urban Development

Sustainable urban development integrates principles of environmental protection, social equity, economic prosperity, and resilience to ensure cities can thrive while meeting the needs of current and future generations (Hiremath et al., 2013). In their work, Telega et al. (2022) conclude that the primary obstacles to achieving sustainable cities are issues related to transport, land use, spatial planning, environmental protection, social justice, and green construction. They also argue that the concept of sustainable urban development should encompass the spatial dimension of sustainability, alongside social, economic, and environmental dimensions, as it reflects the extent of human activities within the environment.

The United Nations' 2012 Resolution on Sustainable Development Goals (SDG) emphasizes transportation and mobility as central to sustainable development, linking them to economic growth and improved accessibility (United Nations, 2012). Additionally, the Sustainable Cities and Human Settlements goal of SDG promotes non-motorized mobility, such as walking and cycling, to foster more inclusive, safe, resilient, and sustainable cities. On a European level, the Urban Agenda for the European Union highlights walking and cycling as low-cost, zero-emission, and active mobility forms (European Commission, 2021). These modes of transport not only help mitigate climate change effects but also encourage physical activity, leading to better health conditions and an enhanced quality of life.

Creating walkable urban areas, whether old or new, where mobility is achieved through walking or cycling, is central to sustainable urban development. Evaluation of how much urban areas are walkable is usually done through walkability assessments. The multifaceted nature of walkability, which captures various environment-to-human impacts, enables the measurement of progress and guides development towards goals of sustainability.

2.2 Multifaceted nature of walkability concept

Although there is no single definition of walkability, there is a consensus on its meaning. Walkability is typically described as a measure of how pedestrian-friendly an urban area is. The literature links walkability to various aspects of everyday life, emphasizing its positive impacts on health, socialization, and economic and environmental stress levels (e.g., Rafiemanzelat et al., 2017; Kim et al., 2024; Stafford and Baldwin, 2018). These diverse findings highlight different scientific approaches to walkability, which may not always overlap. Furthermore, the literature distinguishes between various user profiles for which walkability is assessed. For example, some authors note that walkability of an area differs across age groups (Liao et al., 2020; Bayar and Yilmaz, 2022; Stafford and Baldwin, 2018), while others consider human disabilities as a criterion for walkability evaluation (Stafford and Baldwin, 2018; Campisi et al., 2021).

Further on, the literature distinguishes between subjective, objective, and mixed walkability assessment methods based on the evaluation approach used. Subjective methods typically involve self-reported instruments, such as surveys, that capture people’s impressions of walkable areas. In contrast, objective approaches rely on observational measures processed through tools like GIS (Telega et al., 2021; Stafford and Baldwin, 2018). These objective methods are more common in sciences that analyse spatial data. Mixed methods, as described by Telega et al. (2021), combine self-reported information with data collected directly or obtained from secondary sources.

Regardless of the approach to assessing walkability, the impacts of the urban environment on humans can be observed. The primary difference is however the specific characteristics of walkability being measured.

2.3 GIS-based Walkability in Support to Policy Making

Data-driven policy making relies on the collection, analysis, and interpretation of diverse datasets to inform decisions and shape effective interventions (van Veestra and Kotterink, 2017). By leveraging robust and comprehensive data, policymakers can identify trends, assess needs, predict outcomes, and allocate resources efficiently. Data are central to this approach as they can reveal critical insights into various aspects of urban life, such as urban accessibility, environmental impacts, and social demographics. This evidence-based approach allows for the development of targeted policies that address specific issues, improve public services, and enhance overall quality of life (Hwang et al., 2021). For instance, data-based walkability assessment can inform which specific urban environments do not support pedestrian mobility, where urban infrastructure is not developed enough, or which parts of the urban area miss specific contents.

Geographic Information Systems (GIS) play a crucial role in supporting data-based policy making by providing a powerful platform for collecting, managing, analysing, and visualizing spatial data (Boroushaki and Malczewski, 2010). GIS integrates various types of data, allowing policymakers to see relationships, patterns, and trends that might not be apparent from raw data alone. In the context of walkability, GIS facilitates a data-driven approach though enhanced data contextualization which leads to creation of more specific and comprehensive policies and interventions. For example, GIS helps to map pedestrian pathways, analyse the connectivity of sidewalks or identify areas lacking pedestrian infrastructure. By visualizing this data spatially, planners can make informed decisions about where to invest in new infrastructure, improve existing facilities, and prioritize interventions to enhance walkability.

2.4 GIS-based Objective Measures of Walkability

The literature reveals various approaches to GIS-based walkability assessments, tailored to evaluate different dimensions that influence travel behaviour and walking. These dimensions, known as the 5Ds, include density, destinations, design, destination accessibility, and distance to transit (Fina et al., 2022). In their work, Horak et al. (2022) indicate that these dimensions form the base for creation of one-dimensional walkability measure that captures the complexity of urban spaces. Depending on how these dimensions are addressed, the body of knowledge identifies three main types of walkability indices: environmental (statistical), accessibility-based, and mixed indices (Horak et al., 2022).

Environmental (statistical) indices, such as the Walkability Index, use environmental indicators to gauge how urban characteristics influence walking but does not consider distances. In contrast, accessibility-based indices, like Walk Score, calculate distances within the road network to evaluate proximity as a measure of walkability. Mixed indices, such as Area Walking Potential or the OS-WALK-EU walkability index, combine proximity data with environmental characteristics to assess pedestrian-friendliness (Horak et al., 2022). By merging more objective indicators (proximity as an exact measure) with potentially subjective ones (choice on environmental characteristics to be considered), these indices tend to be more comprehensive, providing a broader understanding of the impact of the urban environment on pedestrian behaviour.

2.5 Role of Open Data and Technologies in Walkability Assessment

Open data is defined as data that is accessible to anyone for any purpose, without restrictions on reuse (Ayre and Craner, 2017).

Over the past few decades, the global spread of open data initiatives has significantly increased the availability of open data, largely driven by governments releasing their own datasets (open government data). This growing interest in open data is tied to its numerous benefits. According to Janssen et al. (2012), these benefits can be categorized into three main areas: political and social, economic, and operational and technical. Among these, political and social benefits are the most recognized, particularly in relation to open government initiatives (Mutambik et al., 2021). Political benefits are often considered separately and are closely linked to policy- and decision-making processes (Harrison et al., 2011). This proves that the use of open (government) data in the context of walkability can contribute to creation of policies that lead to sustainable urban development.

In the European context, open data gained momentum in 2019 with the adoption of the Open Data Directive (EU 2019/1024). This directive has made government-produced data publicly available for reuse. The publication of official government data as open data meant that other sources, primarily from citizen-led initiatives like OpenStreetMap, were no longer the primary data used in geospatial analysis. While citizen-collected data is often perceived to have quality issues (Tavra et al., 2024), it can be highly valuable, especially when corresponding official data is absent. The release of spatial data within open data initiatives has not only increased the diversity of available data but also spurred the development of new and more comprehensive walkability methodologies. This is evidenced by numerous recent papers that utilize open data for walkability assessments (e.g., Ye et al., 2024; He and He, 2023; Fina et al., 2022).

The advancement of data-based walkability assessment methods is propelled by the availability of open data and supported by open-source tools and technologies. According to Mobasheri et al. (2020), open geospatial tools play a crucial role in addressing societal challenges like creation of sustainable cities. The importance of open-source solutions is evident in their widespread adoption across various practical applications, with expectations for continued growth in the future. Academia is a significant user of open-source technologies (Mobasheri et al., 2020). Its active involvement in the development of new open-source solutions and new theoretical concepts puts it in the right position between the use of open-source technologies, open data and the development of innovative walkability assessment methods.

3. MATERIALS AND METHODS

This section outlines the implementation of an objective, GIS-based walkability assessment for the city of Zagreb, Croatia. It details the technology and data utilized to support the walkability assessment and discusses the resulting findings.

3.1 Area of interest

The city of Zagreb is the capital of Croatia located in the northern part of the country (Figure 1). With area of 641km^2 and population of 767 000 it is the highest populated and among most densely populated cities in Croatia (National Bureau of Statistics, 2022). Its urban pattern makes it a typical central European city where population is mostly concentrated in and around city centre. Zagreb is administratively divided into 17 urban districts of distinct urban environment and demographic composition. Urban environment is in many shaped by Zagreb's geographic location – sloped landscapes in foothills of Medvednica mountain on the north and plains of Sava riverbanks on the east, north and south. However, city is dedicated to promoting healthy lifestyle and sustainable urban mobility with well-developed pedestrian and cycling infrastructure. There is in total 238km of pedestrian and cycling paths and 15km of dedicated bike lanes integrated in city's street network (City of Zagreb, 2024).

Due to city's population primarily being concentrated in districts closer to the city centre, walkability assessment is performed for 11 city districts covering this area: Podsused – Vrapče, Stenjevec, Črnomerec, Trešnjevka – sjever, Trešnjevka – jug, Gornji grad – Medveščak, DOnji grad, Trnje, Maksimir, Peščenica – Žitnjak, Donja Dubrava (Figure 1).

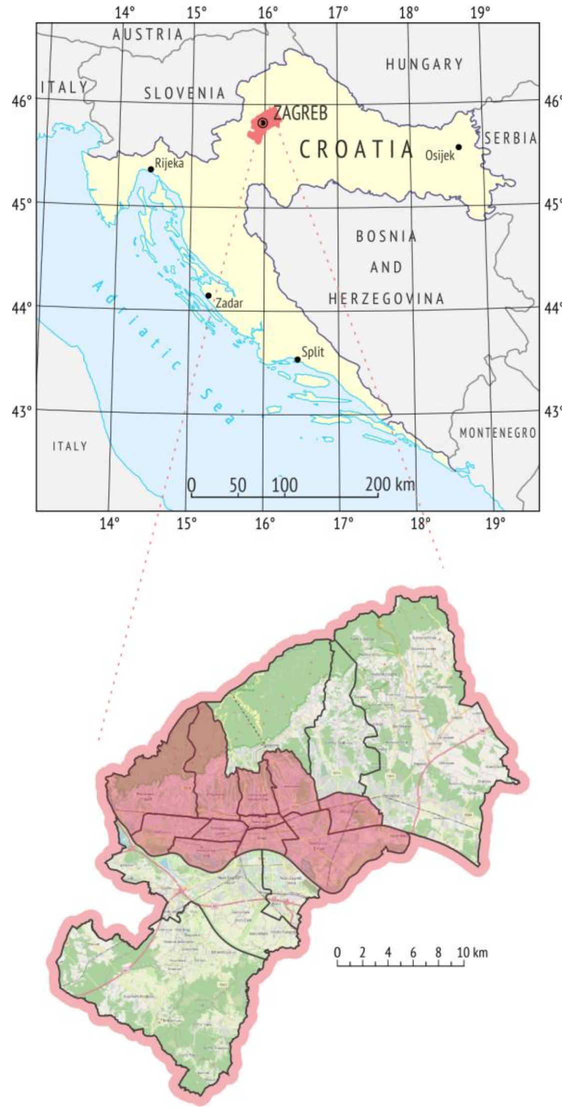

Figure 1. Geographic location and administrative boundaries of the city of Zagreb. Highlighted in pink are the city districts examined in this study.

3.2 Walkability Index OS-WALK-EU

The walkability assessment in the city of Zagreb was performed using the mixed walkability index OS-WALK-EU (**O**pen **S**ource **Walk**ability tool for **E**uropean **U**nion). Developed by a research group in 2022, this index is recognized as the first tool enabling free and open walkability assessment with pedestrian routing for proximity calculations (Fina et al., 2022). Unlike other walkability indices, OS-WALK-EU is specifically designed for European cities, which are typically more compact than those in the United States or Australia.

OS-WALK-EU is not only a walkability index but also an assessment tool available as a QGIS plug-in. It enhances existing walkability approaches with three key improvements: (1) it utilizes established proximity calculation methods to create an easy-to-use assessment tool applicable to entire cities or regions, (2) it allows users to import their own data, and (3) it is fully customizable regarding thresholds and content. Offered as a free plug-in and tailored to the OpenStreetMap data structure, this tool promotes the use of open data and open-source technology in walkability assessments.

As a mixed walkability index, OS-WALK-EU combines environmental indicators (residential density, points of interest - POIs, share of green and blue infrastructure, and slope) with accessibility-based indicators (proximities to amenities and pedestrian radius of activity) to assess pedestrian-friendliness (Fina et al., 2022). Accessibility-based indicators use pedestrian routes and the radius of activity to calculate distances to POIs. Since multiple POIs are reachable from single starting point, tool introduces weights for POIs to favour those closer to the starting point. However, this can lead to incomparable results across the area of interest, so the final index values are normalized to a range of 0-100. A zero-index value indicates a less walkable area, while a value of 100 signifies a highly pedestrian-friendly urban area (Fina et al., 2022).

3.3 Research Materials

OS-WALK-EU walkability index is based on four main data: residential density, amenities, green and blue infrastructure and (optionally) slope (Fina et al., 2022).

Residential density refers to the population density of an area. Within the European Union, residential density data is provided in standardized grid cells that conform to the European INSPIRE Geographic Grid System guidelines. OS-WALK-EU uses this same geography (with a default grid of 500 x 500 meters) as a reference geography for its walkability index (Fina et al., 2022). For amenities, OS-WALK-EU defines six POI groups that input data must comply with: (1) retail, (2) food-related, (3) entertainment, (4) office, (5) civic and institutional, and (6) sports and recreation. By the authors of the assessment tool (Fina et al., 2022), retail shops are described as amenities important for the supply of goods for medium and long-term needs in contrast to food-related stores (e.g. supermarket) that are related to daily food supply and social participation. Entertainment related amenities (e.g. cinema) are meant for enjoyment of leisure time and participation in cultural and social life while office locations consider workplaces in the urban area. Civic and institutional POIs, as instructed by the authors, are objects related to field of education, medicine or civic services and recreation and sport facilities include objects that serve to maintain physical and social well-being. This categorisation imposed by the authors of the assessment tool is mandatory and puts requirement of structure adjustment for user input data, no matter the data source. Green and blue infrastructure data include natural land cover/land use and are an indicator of the degree of urbanisation that has an impact on walkability. Finally, slope data is optional but when used, it indicates the effect of terrain on pedestrian walkability. As required by the developers, digital elevation models should be used for this input data (Fina et al., 2022).

To assess walkability, we combined open data from various sources (Table 1). Additionally, we used administrative boundaries data (from OSM) to limit the assessment results on 11 city districts.

Data	Open data source	Spatial representation and resolution
Residential density	National Bureau of Statistics	/ , city district
Amenities (POIs)	OSM	Point, /
Green and blue infrastructure	Zagreb GeoHUB	Polygon, /
Slope	Copernicus DEM	Raster grid, 30x30m

Table 1. Characteristics and sources of open data for OS-WALK-EU walkability assessment

Of all the data used, residential density data and POIs required significant adjustments to meet the requirements of the assessment tool. The residential density data, provided by the National Bureau of Statistics, was available in tabular form at city district level. This data needed to be disaggregated using a simple areal interpolation method to fit a 500x500m vector grid. POI data was sourced from OpenStreetMap. Despite their source-imposed structure, it had to be reclassified into six POI groups. But however, reclassification process was simplified due to, mostly, preestablished link between OS-WALK-EU and OSM data structure. Ultimately, over 200 amenities were categorized into the six POI groups by OS-WALK-EU.s

3.4 Walkability User Perspectives

Multifaceted nature of walkability concept requires a-priori definition of user perspective that the walkability assessment will reflect upon. In our research we assessed walkability for two user perspectives, one that examines how walkable city is when it comes to enjoying free time and other that looks at walkability related to daily obligations and commitments. The aim of the two perspectives was to illustrate the prevalence of different amenities in various parts of the city and to highlight how some areas are more attractive for living than others.

A clear definition of perspectives is essential to adjust parameters of the assessment tool. For the first user perspective, we focused more on characteristics of the environment we believed had higher impact on walkability, e.g. food-related, retail and entertainment amenities. There we considered that the three closest amenities had the priority over objects located further away (Table 2).

POI category	Object No	Weights per object (closest to furthest)
Retail	3	3, 1, 1
Food-related	3	3, 1, 1
Entertainment	2	3, 1, 0
Office	1	3
Civic & Institutional	1	3
Sport & Recreation	1	3

Table 2. Weighting schema for POIs used in user perspective 'enjoying free time'

For the second scenario, we prioritised office, and civic and institutional amenities as we considered these to be highly positively correlated with proposed walkability perspective. Here, we considered that for Civic and Institutional objects

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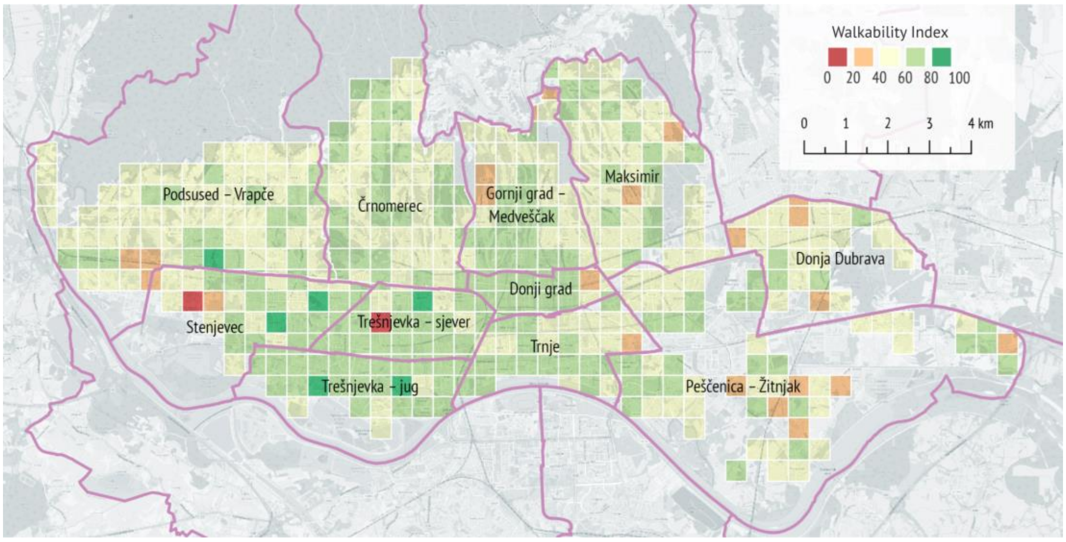

Figure 2. Walkability index for the 'enjoying free time' user perspective across eleven districts in the city of Zagreb, Croatia.

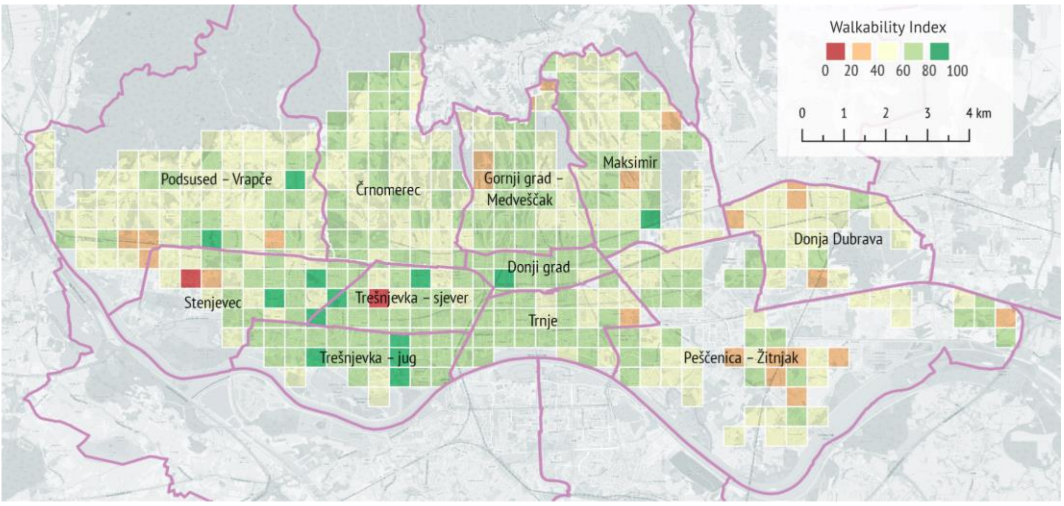

Figure 3. Walkability index for the 'daily obligations and commitments' user perspective across eleven districts in the city of Zagreb, Croatia

again the three closest amenities had the priority over other objects, while for the Office amenities we focused on the first two closest objects and weighted the mostly (Table 3).

POI category	Object No	Weights per object (closest to furthest)
Retail	2	3, 1
Food-related	2	3, 1
Entertainment	2	3, 1
Office	2	3, 1
Civic & Institutional	3	3,1 1
Sport & Recreation	1	3

Table 3. Weighting schema for POIs used in user perspective 'daily obligations and commitments'

For the assessment of both walkability perspectives, we used the same pedestrian radius of activity of 250m and weights assigned to remaining input data (resident density, blue and green infrastructure, pedestrian shed) (Table 4). Also, in both perspectives we excluded some green areas from the assessment in Podsused, Peščenica, Trešnjevka-jug, Stenjevec and Vrbik districts as they did not fall under urban areas and therefore were not within the scope of this assessment.

Environment indicator	Weights
POIs	1
Pedestrian shed	0.9
Resident density	0
Green and blue infrastructure	0.8

Table 4. Environment indicators and corresponding weights in walkability assessment

3.5 Results

Once the setup for both user perspectives was done, the results were obtained (Figure 2 and 3). Unpopulated areas, such as commercial or industrial, were excluded from the analysis and there is no information about walkability index for these areas.
Results show that walkability index ranges from yellow to light green in the city centre (values 40-80) and changes towards

yellow, orange and red as we get away from the centre (values 0-60). Also, Figures 2 and 3 show Donji Grad, Trešnjevka-jug and Trešnjevka-sjever (excluding the red cell – factory plot) districts to have the highest walkability index ranging from 60 to 100 in both user perspectives, while Donja Dubrava and Peščenica – Žitnjak have the lowest walkability indexes (values 20-80). To notice is that, as seen in Figures 2 and 3, no data on walkability is available for majority of Peščenica – Žitnjak, Donja Dubrava and Stenjevec districts.

4. Discussion

The assessment results indicate that Zagreb's geographic position significantly impacts walkability. The slope of the terrain decreases walkability as one moves closer to the Medvednica mountain in the north. In contrast, areas near the Sava River exhibit higher walkability values, likely due to the flat terrain and larger green spaces. Low walkability scores on the periphery of the assessed area could be associated with industrial and commercial land use, which are not designed for residential purposes, so the lack of residents reduces engagement that leads to pedestrian-friendly environment.

The results for the two user perspectives show clear differences in walkability scores, although these differences are not significant. In both cases, the walkability index is highest in the city centre and decreases toward the edges of the city. This is expected, as most public activities occur in the city centre, so high scores indicate an abundance of amenities that contribute to a more walkable area. Furthermore, the similar results for both user perspectives suggest an even distribution of various amenities across city districts, implying that all districts are equally attractive for living. However, slight variations in index scores for the different user perspectives indicate that walkability is strongly dependent on the point of view.

5. CONCLUSION

This study aimed to contribute to the broader discourse on urban planning challenges by presenting a preliminary walkability assessment for the city of Zagreb, Croatia. The results of the assessment using GIS-based OS-WALK-EU walkability index showed that the walkability scores are not consistent and strongly depend on the user's perspective. Variations in walkability scores observed across different prioritisation of amenities in this work suggest that the presence of amenities and green spaces in specific locations does not consistently guarantee high walkability scores for all user perspectives.

However, these different findings hold relevance for urban planners, enabling them to focus on a specific user perspective and identify which parts of the city have the problem of low walkability. The general conclusion for the city of Zagreb is that although the different user perspectives give different walkability scores, these are almost uniform throughout the city.

The findings of the assessment also suggest that data-based approaches to walkability assessment, using GIS environment, have the potential to support policy making. This is based on the adaptability of GIS to process different settings and input data and provide information related to any desired walkability approach or perspective.

Nevertheless, it is crucial to acknowledge potential limitations and challenges associates with the utilisation of open data and technologies in walkability assessment. Factors such as data quality, interoperability, and access to reliable data sources may introduce uncertainties and affect the accuracy and reliability of the study findings. Despite these challenges, the study endeavours to offer valuable insights into the intricate relationship between urban morphology, mobility patterns, and quality of life in Zagreb. The anticipated outcomes of this study are expected to inform urban planning strategies aimed at fostering sustainable urban mobility and enhancing overall urban liveability.

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