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Urban Green Infrastructure Accessibility: Investigating Environmental Justice in a European and Global Green Capital

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Abstract: Access to green spaces offers numerous benefits to citizens and is key to achieving environmental justice. This article explores accessibility to green infrastructure (GI) in Vitoria-Gasteiz, Spain, the European and Global Green Capital in 2012 and 2019. Vitoria-Gasteiz was selected as a case study because it combines actions aimed at promoting green infrastructure in the city along with an urban model that in recent years has favored more expansive urbanism. Manhattan distance and configurational analysis is used to investigate accessibility to the most relevant elements of the GI system and their integration in the urban tissue. Considering the actual pedestrian mobility network, configurational accessibility is examined globally and locally with 1 km and 300 m radii. The analysis reveals great differences both in global and local configurational accessibility across fifty components of the GI system that are greater than 0.5 ha and open for public use. It also shows that, while almost all inhabitants (97.9%) reside within 1 km from these green areas, 27.7% of the population live more than 300 m away. The investigation demonstrates the need to improve the city's GI to provide universal accessibility to green spaces. It offers useful methods that planning professionals and local administrations can use to assess residents' access to green areas and guide future GI transformation and development towards environmental justice.

Keywords: urban green infrastructure; space syntax; environmental justice; accessibility; 3-30-300 rule; spatial configuration

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1. Introduction

The concept of green infrastructure (GI) is gaining prominence in public policies and is becoming consolidated as a recurring theme within city and regional planning theory and practice [1,2]. GI can be defined as a planned network of natural and semi-natural spaces that, in combination with other environmental elements, provide ecosystem services and protect both urban and rural biodiversity [3]. Their typologies are multiple (urban green areas, peri-urban green areas, ecological corridors, and natural areas of special protection) and so are their functionalities [4].

GI contributes to maintaining the integrity of habitats and supports broader ecological networks [5]. By increasing vegetation cover (natural, semi-natural, and artificial), GI promotes biodiversity and more sustainable landscapes [6]. It also expands the availability of natural resources, aids in preventing natural disasters, and improves water management, among other benefits [7,8]. GI increases the resilience of urban areas to climate change by improving flood management, reducing heat stress, favoring greater coastal protection, improving water management, favoring carbon sequestration and storage, reducing energy use, or providing renewable energy, among other factors [9,10]. GI also yields economic and social advantages [5,8,10,11]. It can boost investments, revalue nearby real estate, generate employment, and promote economic activities related to leisure and tourism [8].

Access to green spaces has also been linked to favorable public health outcomes [12]. Studies have found significant associations between green space exposure and various health indicators, including cortisol levels, heart rate, blood pressure, cholesterol, heart rate variability, diabetes, mortality rates, and pregnancy outcomes. GI provides a wide range of ecosystem services that sustain and promote public health, such as improving water quality, supporting local agriculture, and providing adequate spaces for greater physical activity and social interaction, with a positive impact on physical and mental health [5,11]. GI also brings benefits in terms of population well-being and crime reduction [13]. The benefits of green space are more pronounced among groups with low socioeconomic status and in deprived areas [12]. Strategies and interventions should be developed to maximize green space advantages for those most in need.

Mechanisms explaining the positive impacts of green spaces on life expectancy and mortality include the inherent qualities of natural environments, a salubrious setting with reduced air pollutants, temperature and noise, opportunities for physical activity, and enhanced social interactions [14]. Both surrounding greenery and access to green areas contribute to these effects. Moreover, planning that maximizes accessible green space promotes public health, especially given that extensive evidence suggests that exposure to natural environments reduces stress and chronic diseases [15].

In this vein, Louv [16] introduced the concept of Nature Deficit Disorder, highlighting the adverse impacts of reduced outdoor time for children and linking it to behavioral problems and health issues. This speaks to the concerning disconnection from nature in modern society, which contributes to global ecosystem degradation. Efforts must promote direct experiences in nature to foster environmental awareness and reverse this trend. However, some critique the emphasis on individual responsibility, arguing it distracts from underlying political and economic drivers of ecological decline [17]. A political ecology perspective challenges the concept of nature and explores alternative ways of understanding human–nature relationships. As Dickinson [18] argues, addressing root causes is crucial, since attributing child–nature alienation to insufficient exposure and technology overlooks deeper contributing factors and disregards individual nature choices.

Accessible urban green infrastructure is essential for equitable cities, providing health and community benefits that should extend to all residents [19]. Shared parks, gardens, and nature spaces enable recreation, relaxation, and social connection while promoting mental and physical well-being. These numerous benefits highlight the need to ensure equity of access to GI among the population [7,20,21]. However, inequitable access excludes and isolates vulnerable populations, deepening environmental injustice [15,22]. Cities must ensure green spaces are reasonably accessible in all neighborhoods, regardless of income level. Doing so enhances quality of life for all while enabling inclusive development where everyone can access urban amenities. Thus, it is important to promote and ultimately provide greater GI accessibility, especially for pedestrians, as walking is the most inclusive and sustainable transportation mode.

However, it is worth questioning what we consider accessibility. Thus, accessibility to urban green spaces is often measured by distance, with standards recommending access within a 5–15 min walk [7]. In the field of urban planning, two concepts advocating for proximity and accessibility to amenities have emerged in recent years: the 15 min city and the 3-30-300 rule. The 15-min city concept, originally proposed by Carlos Moreno [23], advocates for urban areas where residents can access daily necessities within a 15 min walk or bike ride. This model utilizes the principles of chrono-urbanism and chronotopia to reimagine neighborhood-level urban planning, aiming to organize infrastructure and environments for greater accessibility, proximity, and human-centric design. By maximizing proximity, diversity, density, and ubiquity, it allows residents to prioritize time for social activities rather than lengthy commutes while weaving neighborhoods into a cohesive urban fabric. This approach constructs livable and sustainable communities where essentials are accessible through active mobility. Advocates present this adaptable framework as optimizing land use and balancing livability with ecology [24]. However, critics like

Glaeser [25] argue it restricts the diversity of interactions and exchanges within cities, hindering social mobility and economic dynamism and confining advantages mainly to already privileged areas.

To ensure a fair and accessible distribution of trees and green spaces, urban planners are increasingly advocating for the implementation of the 3-30-300 rule, which was first proposed in early 2021 by Cecil Konijnendijk, a professor of urban forestry at the University of British Columbia [26]. Konijnendijk introduced the rule as a simple, evidence-based target to guide the planning and expansion of urban forests and green spaces. Since its introduction, the rule has gained support from cities and organizations as an impactful, evidence-based target to expand urban forests and green infrastructure [27].

This rule sets specific thresholds aimed at maximizing the benefits of proximity to nature. It entails ensuring that every home has a minimum of three trees within view, that a minimum tree canopy coverage of 30% is achieved in each district, and that no residence is located more than 300 m away from the nearest park or green space. The promotion of this rule aims to create a more equitable environment with enhanced access to nature for all residents [28,29]. Evidence also shows that adherence to the rule is associated with improved mental health, especially for women and young people [28,29].

Along with this, the 3-30-300 rule is, at the same time and thanks to its simplicity, a powerful communication tool and a straightforward instrument that local administrations can implement and adapt to each territorial context, bringing visibility to the importance of urban greening. Implementation requires adjustments to context. The rule provides clear greening targets, enabling progress tracking. Its memorable format galvanizes stakeholder support. Both evidence-based and adaptable, this straightforward guideline can drive strategic urban greening to enhance well-being [29].

However, green space availability differs geographically, with more access for higher compared to lower socioeconomic groups. This constitutes an environmental justice issue [7]. Moreover, urban greening projects intended to increase access can paradoxically lead to "green gentrification" by displacing lower-income original residents who lose access. Evaluating and addressing these accessibility inequities is crucial for cities to provide green space benefits to all. Research must examine how conditions and redevelopment contexts can promote or obstruct access to quality green spaces regardless of housing or income. Identifying the specific qualities of green spaces that meet community needs is key, as is uncovering any exclusion or displacement from new amenities. Analyses of how diverse residents' use and value of urban nature is should inform the planning of inclusive, responsive infrastructure available to all. The goal should be maximizing equitable access, not enabling gentrification [30].

Our study aims to investigate whether the design of the urban layout, influenced by the city's morphology and the choice of a compact urban model, can affect accessibility to green areas. We will propose a methodology based on space syntax to measure accessibility to green infrastructure, selecting Vitoria-Gasteiz as our case study due to its characteristics as a medium-sized city that has recently prioritized the enhancement of its green infrastructure. Moreover, over the past two decades, the city has experienced significant expansion, giving rise to new peripheral neighborhoods that adhere to a less dense urban development model in contrast to the traditional compact urbanism that characterized its historical evolution. By applying this methodology, we seek to uncover how the urban model may influence accessibility to green spaces, potentially leading to unequal access for the entire population. The city of Vitoria-Gasteiz, in Spain has stood out for its actions in favor of sustainable development, which has earned it international recognition for its good practices (2012 European Green Capital and 2019 Global Green Capital). One of its most emblematic projects is the so-called green belt, intended as the backbone of the city's GI network. It aims to connect with (a) most of the green areas within the city, (b) the so-called yellow belt that includes the agricultural lands around the city, and (c) the currently paused highlands belt project, which would have linked more peripheral natural spaces via ecological corridors [31,32]. The highlands belt project was halted due to insufficient political will for implementation.

The aim of this investigation is to analyze pedestrian accessibility to the green belt and the most relevant components of the urban GI within the whole city of Vitoria-Gasteiz by focusing both on the spatial configuration of the walkable street and public space network to identify differences in GI accessibility across the municipality, with the further aim of examining potential disparities in access among the population. We address those objectives from environmental justice approaches [33], considering that the entire population has the right to live in areas with a sufficient degree of accessibility to GI given the benefits it brings.

The paper is structured following the Introduction, Methods, Results, and Discussion model (IMRaD model) with a further conclusive section. After the introduction that includes the abovementioned research objectives, in the next section we describe the case study, the research methods and tools, as well as our sources of information. Next, we present the results derived from the analysis. In the Section 4, we thoroughly discuss the results and identify the main limitations of the research. Lastly, in the Section 5, we synthesize the key contributions of the Space Syntax methodology and propose future research directions.

2. Materials and Methods

2.1. Case Study: The GI of Vitoria-Gasteiz, a European and Global Green Capital

Vitoria-Gasteiz is the capital of the Basque Country region in Spain (Figure 1). It has a population of 248,087 inhabitants and a population density of 898 inhabitants/km^2. It is a high-income city with a Gross Domestic Product per capita of EUR 36,268. Vitoria-Gasteiz has a dynamic service-based economy, though manufacturing remains relevant, comprising 27.3% of industrial Gross Value Added. [34].

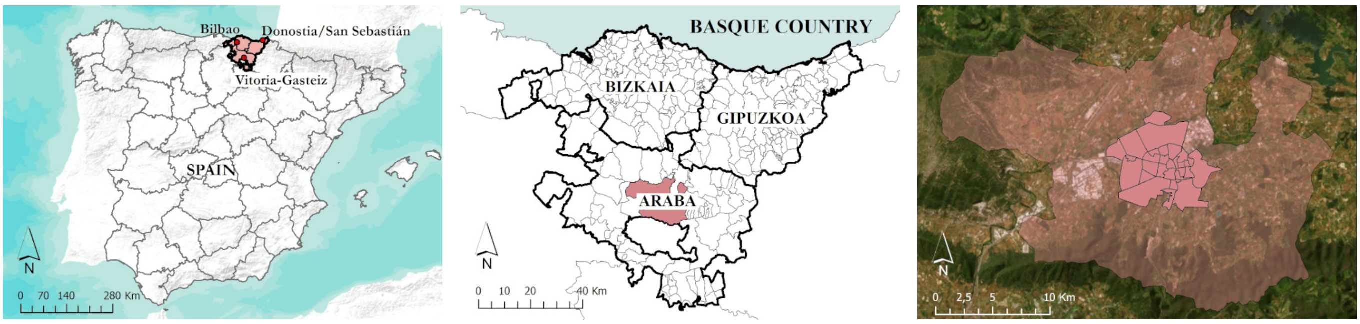

Figure 1. Location of the municipality of Vitoria-Gasteiz (**right**), capital of the Basque Country, in the Araba province (**middle**), which is one of the smaller peninsular provinces of Spain (**left**).

The Basque capital is in the center of a large plain, which is also the largest region in the province of Alava. Framed by the Vitoria-Gasteiz Sierra to the south and the Badaia Sierra and Arrato Sierra to the northwest, the municipality encompasses the central urban area and 63 local entities—very small rural settlements within the municipality limits that possess full administrative and management autonomy. Vitoria-Gasteiz is surrounded by a green belt beyond which most of the land is agricultural, except for a large industrial state to the west. This means that 73.6% of its total surface area (27,630 hectares) corresponds to undeveloped rustic land [35]. The Zadorra River crosses the city from northeast to west, but numerous streams and brooks also flow through the municipality, some of them underground [36] (Figure 2).

The Old Town district (01) sits atop a hill as Vitoria-Gasteiz's core. It has a distinctive almond shape with a street network that has its main and longest streets in the north–south direction, where the slope is gentler. They are perpendicularly crossed by narrower alleys in the Ensanche district (02). Vitoria-Gasteiz did not expand beyond the Old Town district

(01) until the late 18th century, when unplanned extensions began tentatively. Over the next century, more planned growth occurred through a 19th century Ensanche common to many Spanish provincial capitals. In the early 20th century, an upper-middle class garden suburb was built [37]. It was not until the 1950s that accelerated industrialization led to exponential population growth [38], spurring new working-class districts. The first comprehensive city plan was approved in 1956, and it quickly became obsolete in the face of what was the greatest relative population growth in the whole country.

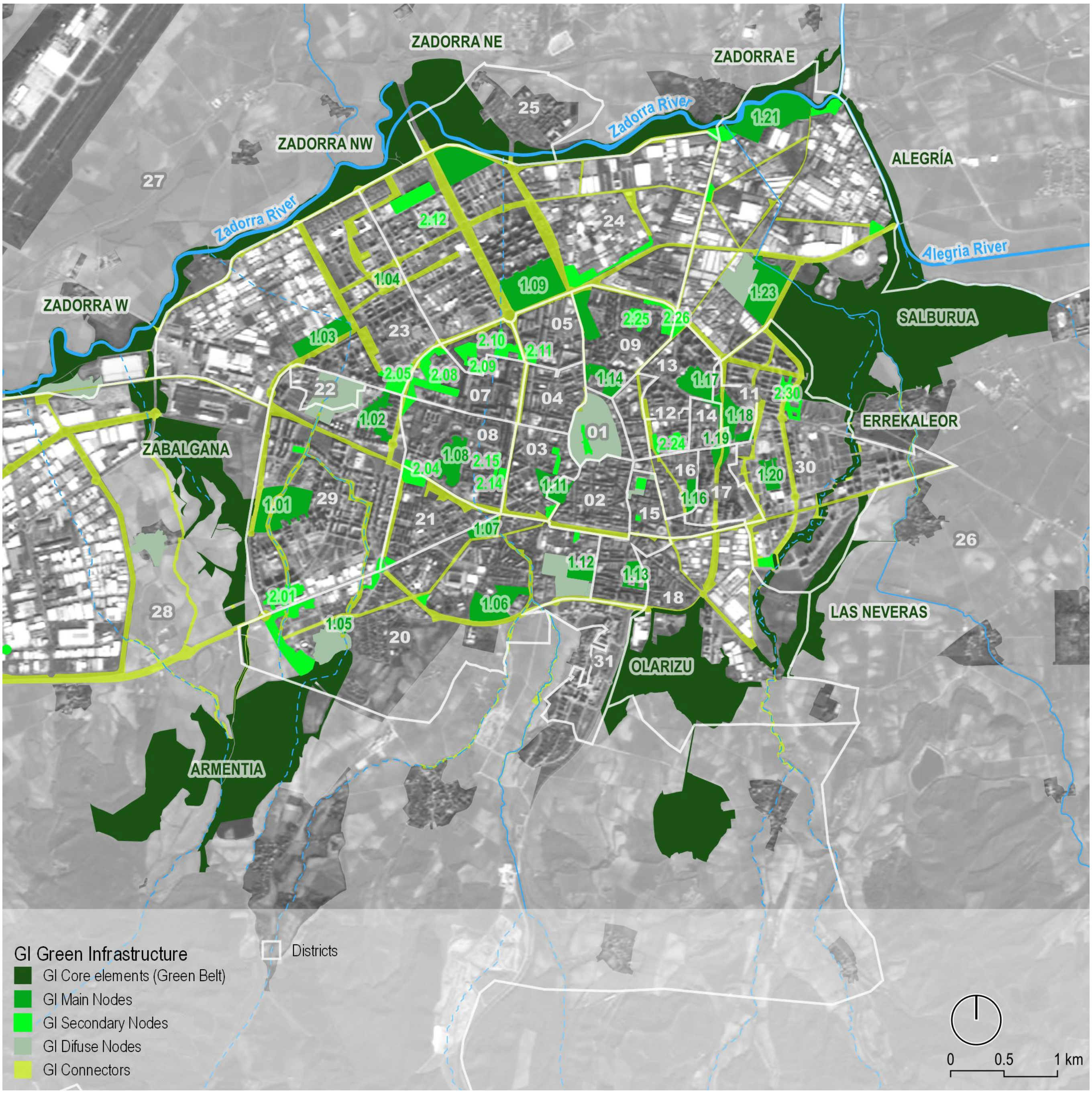

Figure 2. Orthophoto of Vitoria-Gasteiz with district distribution and limits (numbered from 01 to 30), as well as GI components. Core elements are labeled and main nodes and secondary nodes greater than 0.5 hectares and open to public use are numbered as 1.NN and 2.NN, respectively, according to their GI code.

Besides the garden suburb, Vitoria-Gasteiz's expansions remained relatively compact until the construction of the Arriaga-Lakua district (24) in the 1970s. It was not until the 21st century real estate boom that the city sprawled at a much lower density and occupied a disproportionate amount of land due to the construction of the new suburbs of Zabalgana (29), Salburua (30), and Goikolarra (31). These extensions well surpassed population growth. Due to this sprawl, even the city's acclaimed sustainability policies of the 2010s, including sustainable mobility and GI policies, have come into question.

The city, however, continues to stand out for its abundant urban green areas, cycle-oriented mobility, and sustainability leadership from agencies like the Center for Environmental Studies. The green belt remains the city's flagship green infrastructure project, which was originally proposed in the 1986 city plan. This pioneering plan aimed to complete the urban green space system by incorporating nearly 300 hectares of bordering forests and natural reserves [31].

The green belt comprises four parks (Armentia, Olarizu, Salburua, and Zabalgana), two linear parks along the Alegría River and Zadorra River (divisible into four sections by length), and the Las Neveras hills (Figure 2). This perimetral green strip remains incomplete. Since its formalization in 1992, specific actions in each park have improved natural values and public usage suitability, restoring degraded areas closer to the city and developing environmental education activities. Designed to encourage ecological connectivity and ecosystem services, efforts have focused on adapting the Zadorra River's passage through the city to mitigate recurrent flooding in the industrial northeast district (26).

Over the years, it expanded to include the late 1990s restoration of the Salburua wetlands and the subsequent incorporation of the Zadorra River Linear Park, along with hydraulic adjustments to mitigate frequent flooding (Figure 3). Connections between parks were also established. The project primarily focuses on conserving and restoring peri-urban spaces, integrating them into the urban landscape, and linking them to the natural environment. It encompasses ecological, social, and economic objectives, including promoting public use of the spaces to improve environmental awareness and education among residents [31,39]. Recent additions include the Olarizu Botanical Garden and the Basaldea ecological agriculture project. Currently, the project has nearly completed its original proposal, covering over 830 hectares and a perimeter of 35 km.

Despite the project's achievements, challenges remain, particularly regarding ongoing pressure for urbanization in the southern region, which threatens valuable land within the project area. However, its success stems from an innovative socio-ecological planning approach, aiming to preserve and restore natural spaces while creating new functions benefiting the city and inhabitants. This includes restoring ecological connectivity, managing urban growth, and promoting compactness. The project is conceived as a complex socio-ecological system transcending traditional urban planning that advocates for new approaches, mechanisms, and frameworks that facilitate city–nature integration and ensure harmonious coexistence and sustainability [33].

Over the past decades, accessibility to the Green Belt has markedly improved thanks to the ongoing incorporation of new spaces and expanded interconnections between its core elements. Municipal policies promoting sustainable mobility have played a pivotal role in this progress. Initiatives like expanding the bicycle lane network, fostering pedestrian routes, and implementing measures for pedestrianization and traffic calming across the city have helped enhance access to the Green Belt. These efforts have cultivated a more sustainable and accessible environment for residents and visitors alike. However, the city's GI encompasses more than just the green belt. The set of green areas, parks and gardens, tree coverage, urban orchards, and other semi-natural areas now account for 33% of the urban area, which has allowed for a ratio of 45 m^2 of green spaces per inhabitant to be achieved [40].

Figure 3. Some examples of the evolution of the green belt: (**a**) Olarizu Park in 1991; (**b**) Olarizu Park in 2022 with the botanical garden and arboretum built; (**c**) Salburua Park in 1991; (**d**) Salburua Park in 2022 with the wetland restored; (**e**) Zabalgana Park in 1991; (**f**) Zabalgana Park in 2022 with the gravel pits restored; (**g**) Zadorra River Linear Park in 1991; (**h**) Zadorra River Linear Park in 2022 with hydraulic adaptation of the Zadorra River.

The received funding has also been an important aspect in the development and ongoing expansion of the green infrastructure in the city. Over the years, the project has been able to take advantage of different funding opportunities. One of the first actions, the 1998 restoration of the Arcaute pond in Salburua Park, was made possible thanks to European Union financing. In 2002, funding was obtained from the Ebro River Basin Authority for the execution of the first phase of the Hydraulic Adaptation and Environmental Restoration Project of the Zadorra River as it passes through Vitoria-Gasteiz. The Biodiversity Foundation of the Government of Spain financed the INBIOS project to increase biodiversity in the Salburua wetlands.

In 2006, through the IZARTU program of the Basque government, a program dedicated to financing urban rehabilitation projects, the expansion of an ecological orchard facility was financed in the Zadorra River Linear Park [41]. The European Commission, through the LIFE programme 2014–2019, financed a project for the conservation of European mink. Most recently, funds have been received from the Basque government, as well as from the Recovery, Transformation, and Resilience Plan, to carry out various actions in the green ring within the framework of the Tourism Sustainability Plan in Vitoria-Gasteiz.

Vitoria-Gasteiz's GI system and development strategy [40] is divided into three types of elements: cores, nodes, and connectors (Figures 3 and 4). The green belt parks comprise the core elements. Nodes are interior open spaces with significant vegetation, like district parks, smaller green areas, vacant plots, and other facilities serving GI functions, such as cemeteries, school yards, sports facilities, or parking lots. Nodes have three types: main, secondary, and diffuse (discontinuous). Connectors are linear elements providing ecological connectivity (either fluvial or non-fluvial) totaling 100 km. Of all the elements, we will investigate the most relevant ones, namely publicly accessible cores and main and secondary nodes over 0.5 hectares which thus meet the minimum size recommended by the WHO Regional Office [42].

Table 1 lists and provides basic characteristics of these elements of the GI system. A coding system identifies the various elements comprising Vitoria-Gasteiz's green infrastructure network. Elements starting with 0 designate core components of the green belt. Elements starting with 1 indicate main nodes, the key public green spaces. Elements starting with 2 are secondary nodes, additional accessible green spaces. This coding categorizes the green belt parks, primary urban green spaces, and supplementary urban green spaces that make up the overall green infrastructure system.

2.2. Space Syntax, Spatial Accessibility, and Residents' Proximity to Green Areas

Space syntax is a set of theories and tools, created by Hillier and Hanson in the 1970s, that seeks to analyze the influence of the configuration of space in the creation of higher quality, better connected, and more utilized architectural and urban spaces, thus seeking to understand the relationship between the built environment and the social activity in it [43]. It can be applied at different scales, from a building space to the urban-territorial scale [44]. The starting point is that societies use the environment as an essential and necessary resource for their organization, but that the relationship between the two is dynamic as one changes and restructures the other [45,46]. Thus, the configuration of space is directly related to how people perceive and use it [47]. This, in turn, can provide insight into the effects that spatial configuration presents on various social variables [46,48]. However, it can be applied to any environment as it is not influenced by the social, political, or cultural context, instead only influenced by the spatial configuration.

The analysis utilizes a graphic model representing streets and the public space network available for pedestrians (two figures after Figure 5). The model consists of straight lines denoting potential pedestrian movement paths. They all constitute a network of spatial elements that can be analyzed quantitatively. Thus, the role of each space in the configuration of the system can be determined either through global analysis that examines the whole system or through local analysis that studies each component in relation to segments within a given distance [47,49]. A key concept in space syntax analysis is integration, which is a measurement of the degree of spatial accessibility of a given space in the whole or part of the network. This configurational analysis allows us to identify the spatial accessibility of each space in relation to movement patterns [50].

Table 1. Most relevant elements of Vitoria-Gasteiz's GI system.

GI Code	GI Name	GI Type	Green Area (ha)
0.01	Zabalgana	Core (Green Belt)	71.6
0.02	Armentia	Core (Green Belt)	157.8
0.03	Olarizu	Core (Green Belt)	124.1
0.04	Las Neveras	Core (Green Belt)	29.3
0.05	Errekaleor	Core (Green Belt)	17.7
0.06	Salburua	Core (Green Belt)	218.8
0.07	Alegría	Core (Green Belt)	11.8
0.08	Zadorra East	Core (Green Belt)	39.1
0.09	Zadorra Northeast	Core (Green Belt)	87.4
0.10	Zadorra Northwest	Core (Green Belt)	38.5
0.11	Zadorra West	Core (Green Belt)	23.9
1.01	Salinillas de Buradon	Main Node	14.5
1.02	Borinbizkarra	Main Node	6.1
1.03	Lakuabizkarra	Main Node	8.1
1.04	Lakua Ibaiondo	Main Node	1.6
1.05	Armentia Fields	Main Node	1.8
1.06	Mendizabala	Main Node	11.2
1.07	El Prado	Main Node	3.6
1.08	San Martín	Main Node	8.1
1.09	Arriaga	Main Node	17.7
1.11	La Florida & Cathedral	Main Node	5.4
1.12	María de Maeztu	Main Node	3.3
1.13	Maurice Ravel Gardens	Main Node	3.5
1.14	Molinuevo	Main Node	4.5
1.16	Judimendi	Main Node	2.5
1.17	Aranbizkarra	Main Node	6.7
1.18	Arana	Main Node	4.3
1.19	Santa Lucía	Main Node	6.2
1.20	East	Main Node	3.9
1.21	Gamarra	Main Node	19.4
1.23	Michelín	Main Node	14.1
2.01	Mariturri	Secondary Node	3.5
2.04	Etxezarra	Secondary Node	2.7
2.05	Los Goros	Secondary Node	3.5
2.07	Donantes de Sangre Square	Secondary Node	2.6
2.08	Txagorritxu	Secondary Node	3.2
2.09	Gazalbide	Secondary Node	3.1
2.10	Conservatorio	Secondary Node	2.6
2.11	Constitución	Secondary Node	1.1
2.12	Catalunya Square	Secondary Node	1.5
2.14	Gerardo Armesto	Secondary Node	0.5
2.15	Bulevar Abendaño	Secondary Node	0.8
2.24	Simón Bolívar	Secondary Node	1.2
2.25	Llodio Square	Secondary Node	2.4
2.26	Zaramaga	Secondary Node	2.7
2.30	Aeropuerto Viejo	Secondary Node	2.1

Figure 4. Some examples of the core elements and main nodes of the Vitoria-Gasteiz GI network: (**a**) core element 0.06, Salburua wetlands; (**b**) core element 0.06, Salburua Park Interpretation Center; (**c**) core element 0.03, Olarizu Park; (**d**) core element 0.02, the Armentia Park entrance; (**e**) main node 1.11, Florida Park; (**f**) main node 1.11, secret water garden in Florida Park; (**g**) main node 1.15, Judimendi Park; (**h**) main node 1.05, Armentia Fields.

To carry out the spatial accessibility analysis, a segment map was prepared that includes all the routes open for pedestrian movement in Vitoria-Gasteiz (Figures 5 and 6). The cartographic information was obtained from OpenStreetMap, and the model was built from it. It was necessary to simplify and complete the geometry to represent the real movement possibilities available to be taken by pedestrians considering pedestrian crossings, walkways, pedestrian paths, and the like. The model was then analyzed using the Space Syntax Toolkit QGIS plugin and DepthmapXnet software (version 0.35). The former allows for a set of spatial network analyses to be performed to understand social processes within a built environment. It operates at various scales, from the level of a single building to that of entire cities. Using the segment map model, which in our case represents the pedestrian network, the software creates a map composed of nodes and connectors, relates these elements, and performs a graphical analysis of the model network, subsequently providing the values of syntactical variables to each segment [51]. We only consider the variable called integration, which evaluates how accessible a given segment is within the network when considering its spatial configuration. The higher the integration of a segment, the more spatially accessible it is.

Two types of integration analysis were carried out: global and local. Global integration (I_G) analysis examines each segment in relation to all model segments, while local integration evaluates segments by considering only those within a specified radius. We performed two local integration analyses for radii of 1 km and 300 m. These two distances were set considering the 15 min city proposal [23] and the 3-30-300 m rule [29]. The former considers that everyone should have a park within a 15 min walk from their home, while the latter advocates for a green area greater than 0.5 ha within 300 m. The results of these analyses are presented in the first two subsections of the following section.

Based on these three integration analyses, we then characterize and investigate the level of integration of each one of the GI elements presented in Table 1. Researchers have used different methods to investigate this matter, but no methodology is commonly accepted nor established. To characterize the accessibility of each GI element, we calculated the sum of the lengths and integration values of each segment of the pedestrian network within the area of influence around a given green area and divided it by the extension of its buffer. We refer to this measure as the integration coefficient (i_r) of a green area, which is calculated as follows:

$$i_\mathrm{r} = \frac{\sum_n (I_\mathrm{r} l)}{A_{0.3}} \tag{1}$$

where

i_r is the radius 'r' integration index of a given urban element (e.g., a park);

$A_{0.3}$ [m^2] is the extension of the 300 m area of influence of the same element (meausured along the pedestrian network);

n is the number of segments within the area of influence;

I_r is the integration (radius 'r') of a segment 'n' within the area of influence;

and l [m] is the length of a segment 'n' within the area of influence.

We have calculated the global integration coefficient as well as the two local integration coefficients for r = 300 m and r = 1 km to investigate how integrated every considered GI element is at these three scales. The area of influence of a given GI element is determined by the 300 m Manhattan distance measured along the pedestrian network. Using the latter and the most recent available population density map from 2016, we have also calculated the residents within the catchment area of each relevant GI component (Figure 7). Once the population served by each green area has been determined, we have divided it by (a) the area of the given CI element, (b) its area of influence, and (c) the residential land within the area of influence. These results in three different residential densities allow us to explore the ratio of people to green areas, as well as the residential densities in the immediate surroundings.

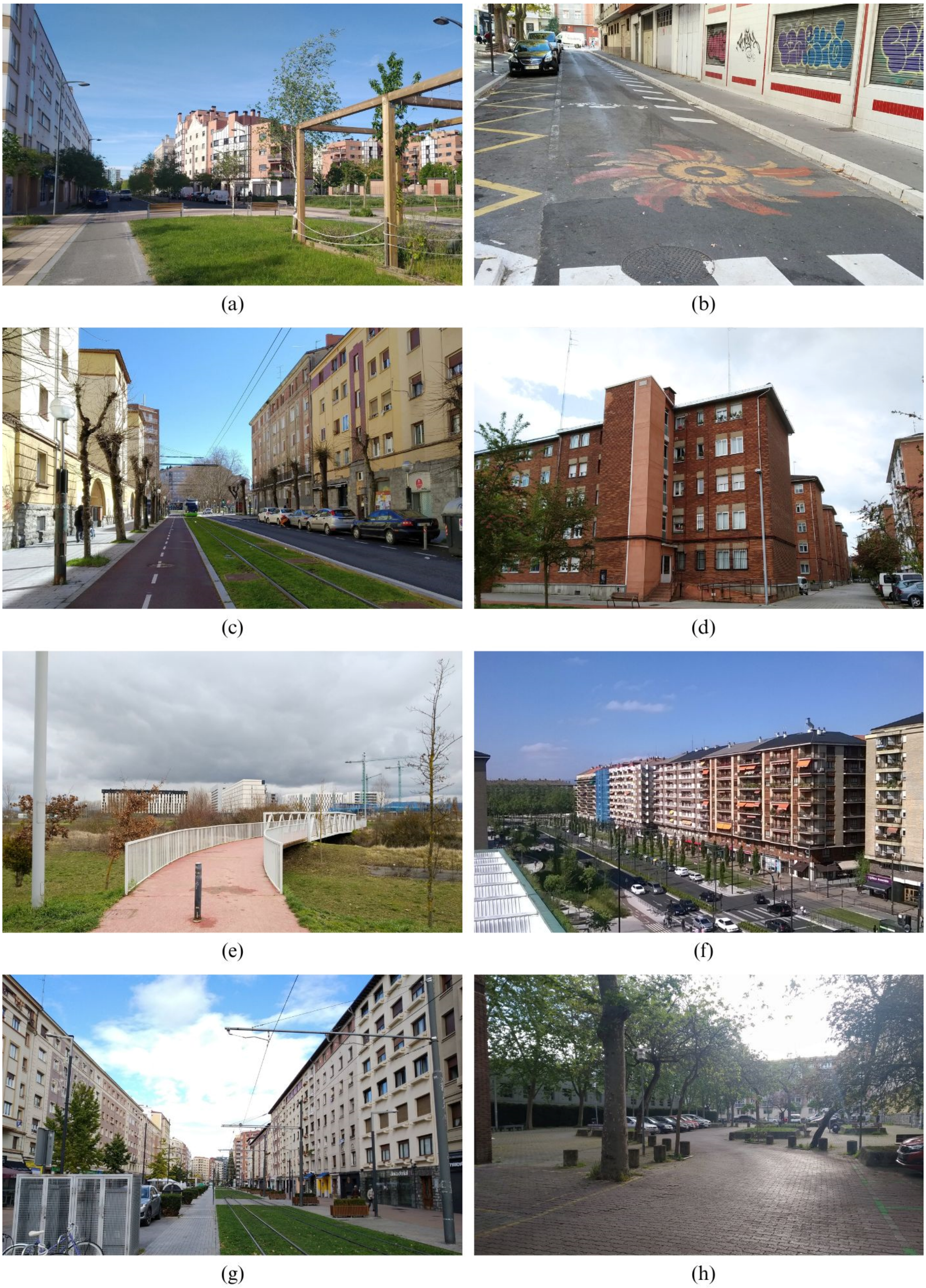

Figure 5. Some examples of the elements included as part of the Vitoria-Gasteiz pedestrian network: (**a**) superblock-type street, Zabalgana neighborhood; (**b**) traffic-calming street, Eguzkilore Street; (**c**) single platform street, Nieves Cano Street; (**d**) pedestrianized spaces, Zaramaga neighborhood; (**e**) pedestrian itinerary in a green area, Arkaiate sector; (**f**) renaturalized street, Avenida Gasteiz Street; (**g**) urban path, Sancho el Sabio Street; (**h**) woonerf-style street, Flandes Street.

Last, we investigate inhabitant accessibility and inaccessibility to Vitoria-Gasteiz green areas and reflect on the differences between the 300 m and 1 km areas of influence and the role played by the different kinds of elements in the urban GI. To do so, we determined the corresponding areas of influence in the same way as was explained for the case of the 300-m radius. Once obtained, we calculated the number of people without convenient access to green areas for different GI element types.

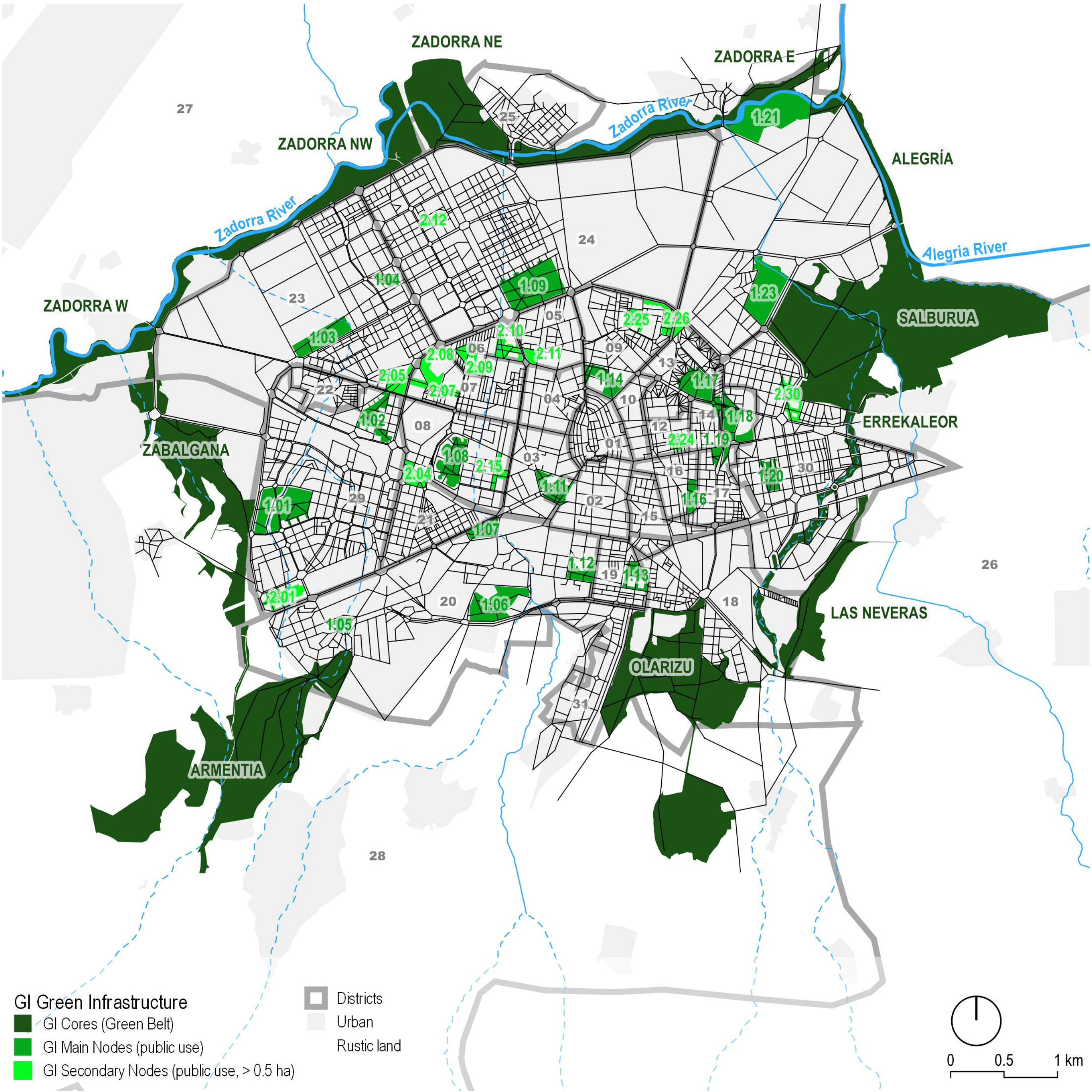

Figure 6. Vitoria-Gasteiz pedestrian network model (black lines) showing the most relevant elements of the GI system (cores, main nodes for public use, and secondary nodes for public use that are greater than 0.5 hectares), including district limits and urban and rustic land.

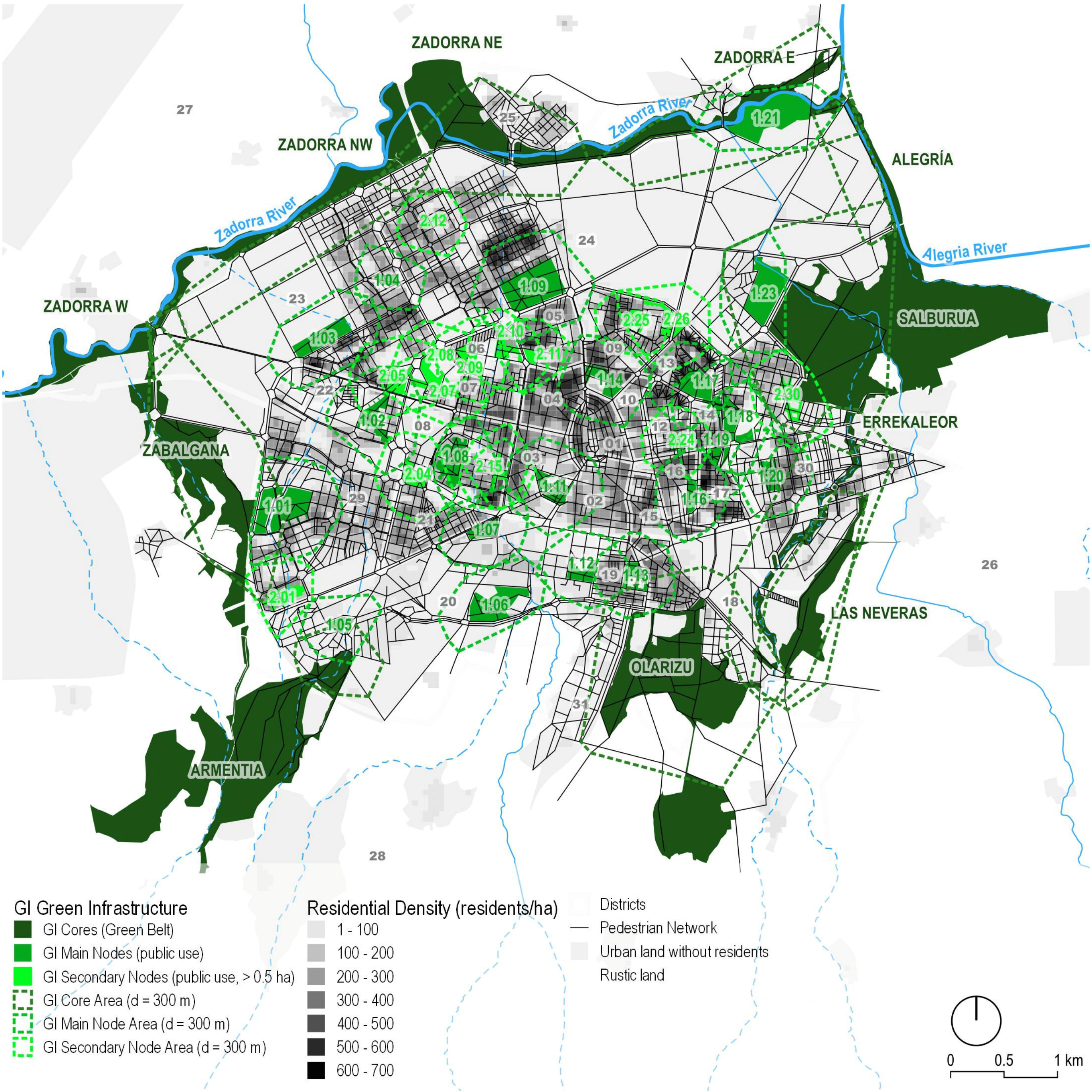

Figure 7. Vitoria-Gasteiz residential density, the pedestrian network model (black lines), the most relevant elements of the GI system (cores, main nodes for public use, and secondary nodes for public use that are greater than 0.5 hectares), and their 300 m influence areas, with district limits and urban and rustic land also shown.

2.3. Cartographic Sources

The Open Data service of Vitoria-Gasteiz was used to identify complementary information and the location of the components of the urban GI network. Digital base maps with administrative boundaries and land uses were downloaded from the Geoeuskadi GIS server. Building shapefiles were obtained from the official cadastre of Alava. The central axis of the street network was obtained from OpenStreetMap using the QGIS OSMDownloader plugin. All the cartographic information was processed in the ESRI shapefile format using the ETRS89 UTM 30N reference system. The pedestrian-accessible street network model was built from the OSM street network base, which was modified according to the 2019 orthophoto obtained from the Geoeuskadi WMS service. When aerial photos provided insufficient detail on pedestrian access, Google Street View images or site visits offered clarification.

3. Results

3.1. Global Integration of the Pedestrian Network

Once the global integration of each element of the pedestrian network of Vitoria-Gasteiz had been analyzed, the elements were grouped into five categories (high, mid-high, medium, mid-low, and low), which correspond to quintiles based on their degree of global integration. Figure 8 shows those with higher values (higher spatial accessibility) in red and those with lower values (lower spatial accessibility) in blue. Generally, central areas show the most integration, while peripheral zones exhibit lower global integration. However, some notable exceptions exist. The main radial arteries along which Vitoria-Gasteiz expanded demonstrate high or mid-high values, indicating greater integration than adjacent segments even in peripheral areas. The industrial areas in the northeast and southeast parts of the city show low integration, but higher than the residential districts in the western and northwestern areas.

While the central part has high global integration, Old Town's core (02) does not.Part of the historic district has medium integration, and several segments appear in white. The medieval city was founded on top of a hill in the style of the French bastides with three almost parallel longitudinal north–south streets. Over the following centuries, it expanded first towards the west through the construction of three new streets and later towards the eastern slope with the addition of three more streets. The east–west connections made through the narrow alleys are limited and have a great distance between them, resulting in low accessibility in this part of the Old Town. The lower presence of cantons on the eastern side of the hill leads to even lower integration.

In the analysis of global integration, some wide streets or large avenues that function as articulators of the city's road network show a high level of integration. This is the case of Avenida de Vitoria-Gasteiz, which marks the division between the districts of El Pilar (05) and Gazalbide (06), Coronación (04) and Txagorritxu (07), and Lovaina (03) and San Martín (08). In the periphery, the districts with the lowest global integration are Arriaga-Lakua (24), Ali Gobeo (22), Zabalgana (29), Goikolarra (31), and the outermost area of Salburua (30). On the contrary, the adjacent part of Salburua (30) to the Santa Lucía district (17) shows a good level of integration.

Furthermore, it can be observed that the major avenues that have served as articulating axes for the city's growth exhibit a high level of integration. This is evident, for instance, in the case of Avenida de Santiago, which acts as the northern boundary of the Santa Lucía district (17) and extends into the Salburua district (30).

The smaller local entities on the periphery also show very low integration. In the case of the northern ones, their location on the other side of the Zadorra River, which constitutes a geographical barrier with very few crossing points, diminishes their spatial accessibility. In the case of those in the east (such as Ali-Gobeo (22)), the most recent developments in the Zabalgana district (29), adjacent to the previous urban fabric of the historic original settlement, are quite disconnected. While Ali-Gobeo preserves the formal characteristics of a small rural settlement with a series of housing developments built during the expansion period of Vitoria-Gasteiz in the 1960s, the contemporary developments present a low-density urban fabric with open blocks of medium-height buildings and large unconsolidated interstitial spaces.

The Errekaleor area, situated within the Adurza district (18), has remarkable characteristics. This old residential zone between the Errekaleor River and Las Neveras was originally built in the 1960s with the purpose of accommodating the immigrant population. A narrow access road also connects it to the Uritiasolo Industrial Park. Errekaleor is now Spain's largest squatted district, comprised of elongated, narrow, three-story freestanding blocks aligned and separated by small open spaces. It also features a central square and a minor green area and borders a small southern boulevard. Due to its configuration and morphology, Errekaleor has poor global integration.

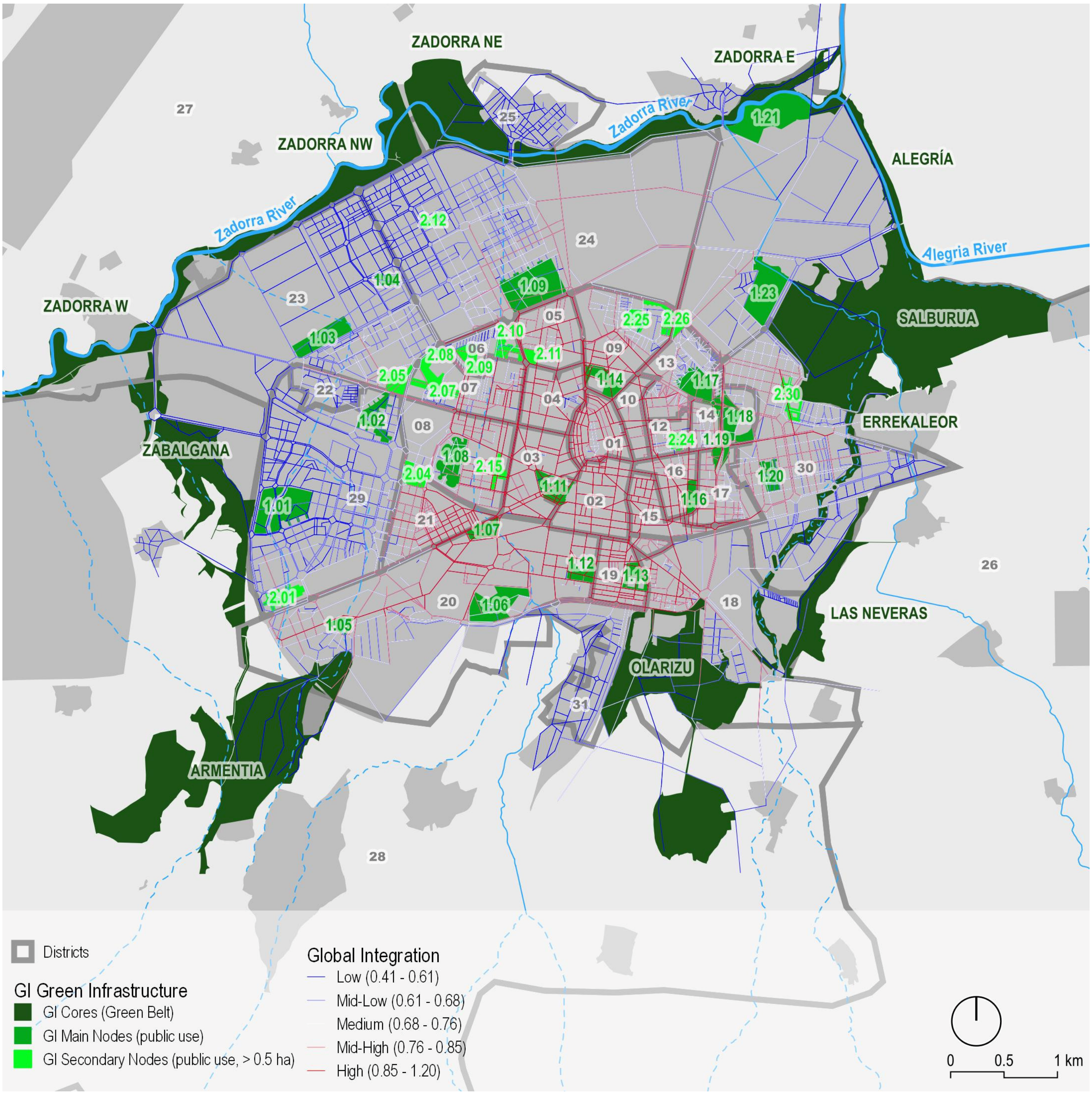

Figure 8. Global integration (I_G) of the segments of the pedestrian network of Vitoria-Gasteiz and the most relevant elements of the GI system (cores, main nodes for public use, and secondary nodes for public use that are greater than 0.5 hectares), with district limits and urban and rustic land also shown. Low, mid-low, medium, mid-high, and high classifications of global integration values are included according to quintiles.

3.2. Local Integration of the Pedestrian Network

The analysis of local integration (which includes the elements within 1 km of each element of the network, as described in the Section 2) shows, in general, that the eastern part of the city is more integrated than the western part (Figure 9). The western districts (e.g., Desamparadas (15), El Anglo (10), Judimendi (16), Santiago (12), Arana (14), and Santa Lucía (17)) are comparatively more compact, which allows for a greater number of street intersections and a more accessible configuration. In contrast, the more peripheral areas and, especially, the industrial parks, which showed low global integration, also show low levels of local accessibility. In contrast, the residential areas of the new districts (also peripheral) are more accessible at the local level. This is especially visible in the Zabalgana district (29), where there are areas with very low global integration but very high local integration. Something similar occurs in Salburua and Arriaga-Lakua (24), where several areas with high local integration are identified.

The analysis of local integration in Arriaga-Lakua (24) highlights the contrasts between its eastern and western parts. The eastern part, characterized by older constructions, a higher density of houses, and taller rationalist blocks, differs from the western part, which was built more recently and features a greater abundance of open spaces and houses arranged in blocks.

Notably, the Errekaleor sector stands out due to a significant disparity between local and global integration, with local integration surpassing global integration. As previously mentioned, this discrepancy can be attributed to the aligned arrangement of housing blocks and the layout of streets and interior open spaces, which facilitates the attainment of these elevated levels of local integration.

Around the Old Town, the western streets present a low local of accessibility, while the eastern ones show greater integration. The heart of the Old Town, which presents low global integration, also turns out to be barely accessible from a local perspective. In the western part of the Ensanche, a housing state known as Las Conchas (1.08) at the end of the San Martín district (21) also shows a lower level of local accessibility than global accessibility. This area of the city has a rather unique configuration, with a set of open blocks that form a semicircle in the San Martín Park.

Other areas, such as Errekaleor, Abetxuko, the San Prudencio housing group in Armentia, and the IMOSA workers colony in Ali-Gobeo (a local entity that has been absorbed by the Zabalgana district (29)), which emerged as marginal enclaves on the outskirts of Vitoria-Gasteiz in the 1950s and 1960s [52], have very low global and local accessibility. These urban developments were located in poorly connected and distant areas from the city, with planners seeking cheap land prices to enable the construction of affordable housing for the new immigrant workers arriving in the city. Even today, they all still share this poor integration despite the notable differences in their urban fabric, which ranges from garden suburbs dominated by semi-detached houses to modernist residential districts where blocks prevail.

In this case, the Abetxuko district (25), which emerged in the 1960s on the other side of the Zadorra River with the intention of accommodating the immigrants welcomed by the city, demonstrates relatively better local integration compared to global integration. Specifically, El Cristo Street, one of the widest streets in the district and the route taken by the tram, plays a significant role in achieving a high level of local integration.

Aside from this exception, the analysis of local integration shows that the configurations of the street and pedestrian networks are interconnected in terms of the types and forms of the buildings and blocks; thus, there is a relationship between the latter and the spatial accessibility of different urban patterns. In general, the areas with greater integration show enclosed city blocks and higher buildings, while in the areas with lower local integration, single-family dwellings and building blocks of less than five floors predominate. The industrial areas on the periphery, i.e., districts 18, 22, 23, and 24, have worse local accessibility than the residential areas in the same districts, mainly due to the higher density of streets and pedestrian pathways in the residential areas.

In sum, considering the results of the integration analysis both at a global and local level, the most integrated areas are the districts that occupy central locations, especially those to the east. These districts have gradually grown from their more central part towards the periphery during the second half of the 20th century. They are dominated by closed blocks of mid-rise buildings, although there are also higher modernist blocks in those districts that were built in the 1980s.

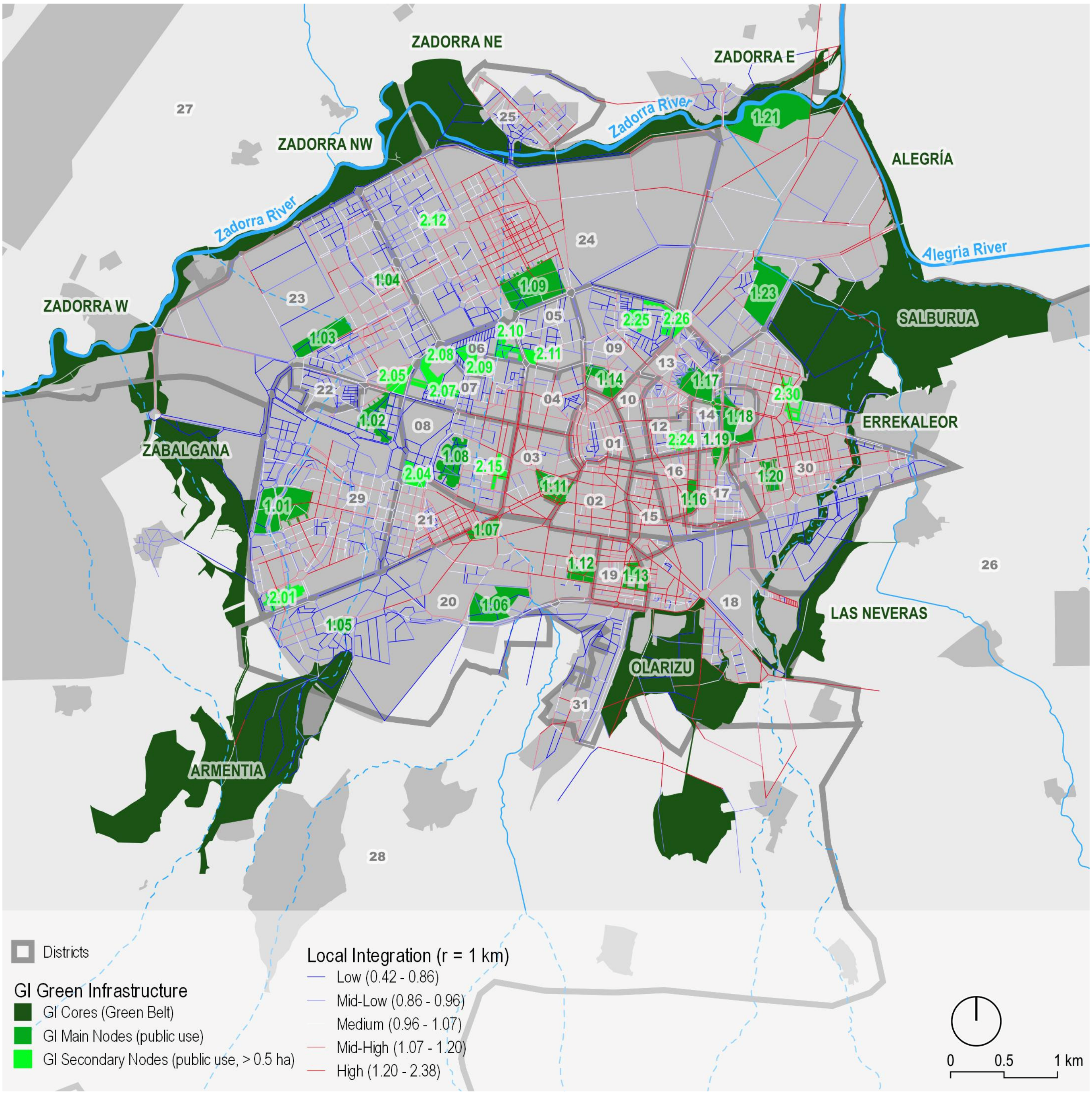

Figure 9. Local integration for 1 km radius ($I_{1.0}$) segments of the pedestrian network of Vitoria-Gasteiz and the most relevant elements of the GI system (cores, main nodes for public use, and secondary nodes for public use that are greater than 0.5 hectares), with district limits and urban and rustic land also shown. Low, mid-low, medium, mid-high, and high classifications of local integration values are included according to quintiles.

In contrast, the least integrated areas, locally and globally, are the most recent suburbs and those settlements with lower housing density. Many of these areas have abundant public housing, such as in Sansomendi (23) and Zabalgana (29), where a significant number of social housing units are concentrated in the farthest and adjacent ends of both neighborhoods. However, the borders between Zabalgana and Sansomendi and the outer edges of the city in those neighborhoods have the lowest integration. The garden suburb of Armentia in the Mendizorrotza district (20), home of the upper classes, is a significant exception.

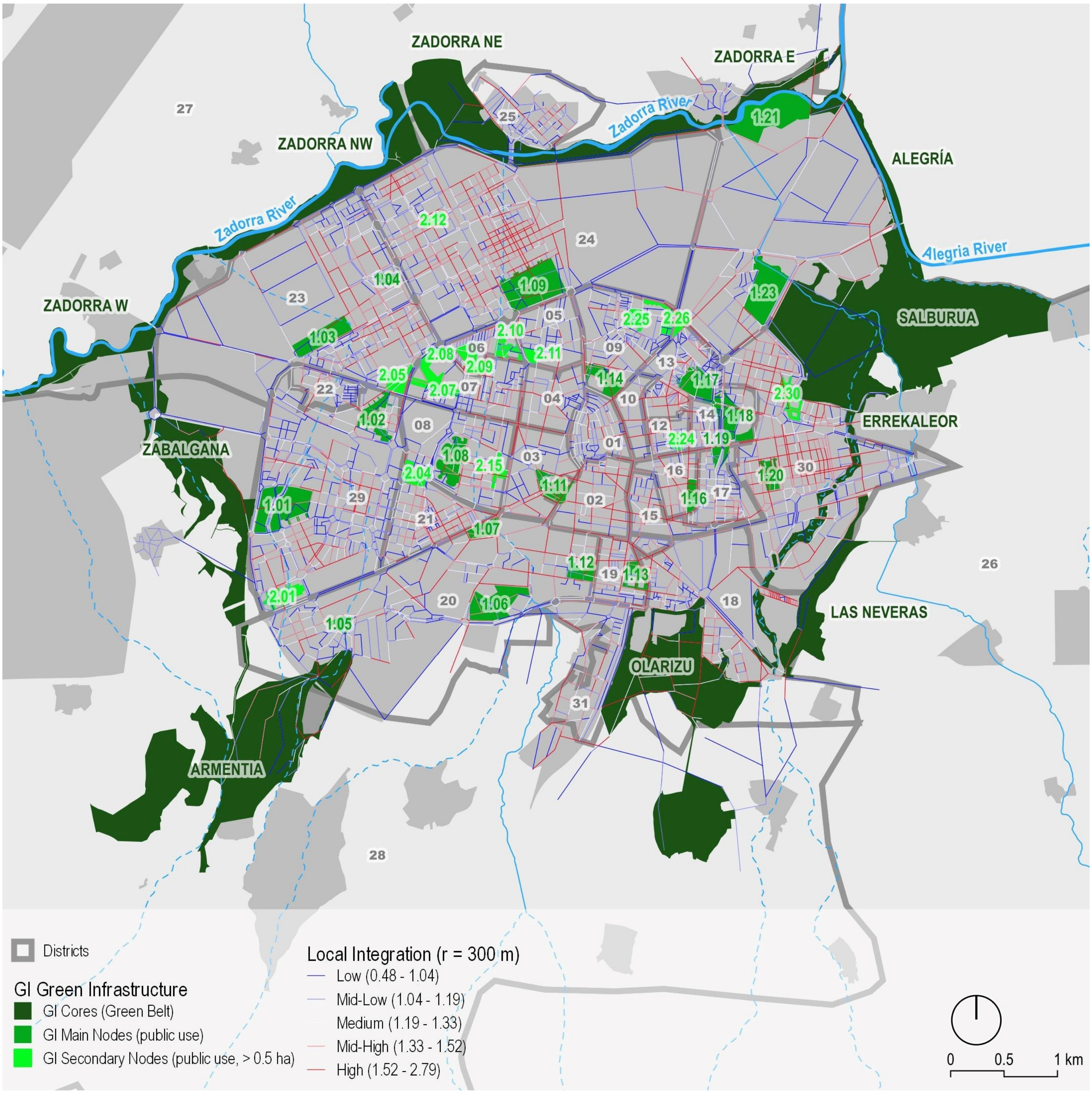

Figure 10. Local integration in terms of a 300 m radius ($I_{0.3}$) for the pedestrian network of Vitoria-Gasteiz and the most relevant elements of the GI system (cores, main nodes for public use, and secondary nodes for public use that are greater than 0.5 hectares), with district limits and urban and rustic land also shown. Low, mid-low, medium, mid-high, and high classifications of local integration values are included according to quintiles.

When we analyze local integration with a 300 m radius (Figure 10), the importance of the density and connectivity of the pedestrian network in enhancing configurational accessibility shows its relevance. This is particularly notable in the densely populated inner areas. In this sense, districts like the Old Town (01) yield lower local integration with a 300 m radius than with a 1 km radius. Conversely, districts like Arriaga-Lakua (24) and Sansomendi (23), situated in the northern part of the city, show better results with a 300 m radius than with a 1 km radius. However, in general, there is a decrease in integration when considering the 300 m radius. In addition, a more detailed analysis can be conducted under the 300 m criterion, revealing that different sections of the same street can exhibit varying levels of integration.

3.3. Spatial Accessibility of the Cores, Main Nodes,, and Secondary Nodes of Vitoria-Gasteiz's GI

Table 2 provides the dimensions of the 300 m areas of influence around each considered element of the urban GI system of Vitoria-Gasteiz, as well as their global and local (for 1 km and 300 m radii) spatial accessibility. Data analysis shows that the main nodes and secondary nodes have higher integration coefficients compared to the core elements. This finding suggests that these nodes are more extensively connected and integrated within the network.

Table 2. GI elements, 300 m areas of influence, and integration coefficients: global, i_G; local $i_{1.0}$ (r = 1 km); and local $i_{0.3}$ (r = 300 m). Color-coded classification indicates **high**, mid-high, medium, mid-low, and **low** values according to quintiles.

GI Code	GI Name	Area of Influence (ha)	Integration Coefficient		
			Global i_G	Local $i_{1.0}$ (r = 1 km)	Local $i_{0.3}$ (r = 300 m)
0.01	Zabalgana	169.3	**0.43**	**0.67**	**0.86**
0.02	Armentia	41.8	1.02	**1.19**	**1.72**
0.03	Olarizu	279.2	**0.83**	**1.25**	**1.47**
0.04	Las Neveras	117.7	**0.54**	**0.77**	**1.14**
0.05	Errekaleor River	235.9	0.99	1.45	1.97
0.06	Salburua	277.8	**0.75**	**1.13**	**1.41**
0.07	Alegria	48.2	**0.51**	**0.98**	**1.08**
0.08	Zadorra East	176.1	**0.46**	**0.80**	**0.90**
0.09	Zadorra Northeast	139.0	0.99	1.58	2.05
0.10	Zadorra Northwest	112.6	**0.85**	1.38	1.83
0.11	Zadorra West	14.7	**0.71**	**1.31**	**1.22**
1.01	Salinillas de Buradon	66.2	1.47	2.53	3.02
1.02	Borinbizkarra	61.1	1.57	2.04	2.69
1.03	Lakuabizkarra	62.3	1.29	1.87	2.45
1.04	Lakua Ibaiondo	29.8	1.46	2.44	3.03
1.05	Armentia Fields	33.7	1.33	1.47	2.11
1.06	Mendizabala	53.5	1.19	1.49	1.98
1.07	El Prado	46.4	**2.19**	**2.85**	3.14
1.08	San Martin	37.8	1.95	2.33	3.18
1.09	Arriaga	83.2	1.77	2.41	3.09
1.11	La Florida and Cathedral	59.0	**2.12**	2.66	2.92
1.12	Maria de Maeztu	43.5	1.87	2.63	2.87
1.13	Maurice Ravel	44.5	**2.40**	**3.63**	**3.76**
1.14	Molinuevo	52.9	2.05	2.45	2.93
1.16	Judimendi	43.5	**2.31**	**3.15**	**3.57**
1.17	Aranbizkarra	46.1	**2.76**	**3.65**	**4.46**
1.18	Arana	48.8	1.99	**2.84**	**3.23**
1.19	Santa Lucia	86.5	**2.24**	**3.08**	**3.53**
1.20	Este	45.6	1.96	**3.07**	**3.82**
1.21	Gamarra	63.0	**0.42**	**0.72**	**0.87**
1.23	Michelin	58.2	0.97	1.39	1.81

Table 2. *Cont.*

GI Code	GI Name	Area of Influence (ha)	Integration Coefficient		
			Global i_G	**Local $i_{1.0}$ (r = 1 km)**	**Local $i_{0.3}$ (r = 300 m)**
2.01	Mariturri	31.4	1.61	2.36	2.86
2.04	Etxezarra	43.9	1.93	2.38	2.99
2.05	Los Goros	50.8	1.66	2.20	2.77
2.07	Donantes de Sangre	46.2	1.80	2.15	2.73
2.08	Txagorritxu	40.7	1.61	1.99	2.69
2.09	Gazalbide	40.6	1.96	2.23	3.15
2.10	Conservatorio	40.4	2.09	2.30	3.12
2.11	Constitución	31.7	**2.11**	2.24	2.88
2.12	Catalunya	29.1	1.56	2.42	3.21
2.14	Gerardo Armesto	27.0	2.07	2.63	2.95
2.15	Bulevar Abendanho	37.6	1.99	2.56	2.94
2.24	Simón Bolivar	32.0	**2.22**	**3.05**	**3.55**
2.25	Llodio	32.3	**2.17**	2.51	**3.32**
2.26	Zaramaga	51.9	1.91	2.34	3.06
2.30	Aeropuerto Viejo	47.6	1.96	**3.09**	**3.60**

Overall, the data suggest varying levels of integration for the different green areas, with some areas exhibiting higher integration at both local scales (1 km and 300 m). The comparison between main nodes and core elements reveals that the former, which include parks and primary green areas within the urban fabric, exhibit higher levels of integration compared to the latter, which are the most relevant parks and green areas that constitute the green belt. This higher integration is observed at both a global and local scale. The mean global and local integration values of the cores (i_G = 0.73; $i_{1.0}$ = 1.13; $i_{0.3}$ = 1.42) are considerably lower than those of the main nodes (i_G = 1.77; $i_{1.0}$ = 2.43; $i_{0.3}$ = 2.92).

However, Armentia Park (i_G = 1.02; $i_{1.0}$ = 1.19; $i_{0.3}$ = 1.72) and the central sections of the Zadorra River Linear Park (Zadora NE: i_G = 0.99; $i_{1.0}$ = 1.58; $i_{0.3}$ = 2.05 and Zadorra NW: i_G = 0.85; $i_{1.0}$ = 1.38; $i_{0.3}$ = 1.83) demonstrate a notable level of integration both globally and locally. In contrast, Zabalgana Park (i_G = 0.43; $i_{1.0}$ = 0.67; $i_{0.3}$ = 0.86) exhibits the weakest integration at both the global and local level. These findings are attributed to the limited local integration of Zabalgana on a global scale, as well as the inadequate integration of the residential areas situated west of the Old Town in the analysis of local accessibility. Additionally, the less compact configuration and form of the Zabalgana district (29) can play an important role in conditioning its accessibility,

The main nodes consistently exhibit higher integration levels compared to the core elements. When examining the main nodes, Aranbizkarra (i_G = 2.76), Maurice Ravel Gardens (i_G = 2.40), Judimendi Park (i_G = 2.31), Santa Lucía (i_G = 2.24), and El Prado Park (i_G = 2.19) stand out as the nodes with the highest global integration. Conversely, Gamarra (i_G = 0.42), Michelin (i_G = 0.97), Mendizabala (i_G = 1.19), Lakuabizkarra (i_G = 1.29), and Armentia Fields (i_G = 1.33) are the main nodes with the lowest global accessibility, with these areas mainly located in peripheral areas.

The integration levels of the secondary nodes reliably surpass those of the core elements. Their global integration values range from 1.56 to 2.22, indicating further increased integration in the local analysis measures.

In sum, the analysis reveals that parks and green areas situated in the southeastern and eastern parts of the city, along with those in central locations, exhibit higher levels of integration, both on a global and local scale. Additionally, the accessibility of these elements is influenced by their configuration. Larger surface areas in contact with the urban fabric result in greater accessibility. This is exemplified by the Zadorra River Linear Park (0.08–0.11), which borders the northern part of the city. Conversely, elements with a smaller contact area demonstrate lower accessibility, as observed for Armentia Fields (1.05) located in the southwestern region of the city.

3.4. Accessibility to Vitoria-Gasteiz GI

Based on the geographic and demographic data in Figure 7, Table 3 provides comprehensive information on GI elements, including details on green areas, 300 m areas of influence, residents served, and residential density. The data are categorized based on different green areas and areas of influence, offering insights into the residential land within each influence area. The color-coded classification further aids in visualizing the distribution of values, classifying them into high, mid-high, medium, mid-low, and low categories based on quintiles.

Analysis of the data reveals significant variations in the characteristics of the GI elements. The range of green areas spans from 0.01 to 218.82 ha, displaying the diversity in size among the green spaces. The 300 m areas of influence also exhibit considerable variability, ranging from 14.7 to 277.8 ha, providing valuable insights into the extent of impact surrounding each GI element. Moreover, the number of residents served by the GI elements shows substantial variation, with a range of 0 to 14,510 individuals, highlighting the varying levels of population impact. The observed differences in residential density further contribute to the overall variations, reflecting distinct values for green areas, influence areas, and residential areas, thereby indicating the varying concentration of residents in relation to these parameters. These findings underscore the complexity and diversity of the GI elements within the studied area, emphasizing the need for a nuanced understanding of their characteristics and implications.

Regarding the secondary nodes, Gerardo Armesto Park (2.14) stands out as the one with the highest residential density in various categories. Notably, it exhibits the highest residential density by green area, with a substantial value of 14,484. Furthermore, it also attains the highest residential density by influence area, recording a notable value of 280. Moreover, in terms of residential density by residential area, Simón Bolivar Square (2.24) emerges as the frontrunner, boasting a significant value of 299. These findings shed light on the concentrated population and the presence of high residential density within these specific secondary nodes.

Finally, when considering the influence areas of the cores and main nodes (Figure 11), it becomes apparent that most of the city enjoys accessibility within a fifteen-minute distance. Upon closer examination of the influence areas of various GI elements, it is evident that a 1 km radius, adhering to the principles of the 15 min city, would ensure extensive coverage and accessibility to the key features of the green belt throughout most of the city. Nevertheless, there are specific areas that lie beyond this coverage. These include a small portion of the Arkaiate sector located on the outskirts of the Salburua district (30), a significant segment of the recently developed Goikolarra district (31), and a minor section of the Abetxuko district (25).

When considering a closer level of accessibility, specifically within a 300 m radius, the coverage significantly decreases, highlighting the importance of secondary and primary nodes in ensuring proximity to GI within the city. These nodes play a critical role in providing residents with access to green spaces within a shorter distance, thereby contributing to a more sustainable and livable urban environment.

In this case, a substantial portion of the Ariznabarra (21) and Zabalgana (29) districts, as well as sections of the Old Town (01) and Ensanche (02), lack convenient access to nearby green spaces. Furthermore, specific areas within the Coronación (04), Arriaga-Lakua (24), and Sansomendi (23) districts exhibit below-average levels of accessibility to green areas.

Table 4 provides valuable insights into the level of integration within the Vitoria-Gasteiz urban area by examining the proximity of residents to different types of GI nodes. It provides the areas and the amount of the population that are not within 300 m and 1 km from the most relevant elements of the GI, both in absolute numbers and in the percentage they represent over the total urban area and total population, respectively.

Table 3. GI elements, green areas, 300 m areas of influence, residents served, and residential density by green area, area of influence, and residential land within each influence area according to Figure 7. Color-coded classifications indicate **high**, mid-high, medium, mid-low, and **low** values according to quintiles.

GI Code	Green Area (ha)	300 m Area of Influence (ha)	Residents within 300 m	Residential Density by		
				Green Area	Influence Area	Residential Area
0.01	**71.57**	169.3	1657	**23**	**10**	112
0.02	**157.76**	41.8	**88**	**1**	**2**	**15**
0.03	**124.11**	279.2	5434	**44**	19	143
0.04	**29.34**	117.7	**1162**	**40**	**10**	**74**
0.05	17.68	235.9	6450	365	27	115
0.06	**218.82**	277.8	4917	**22**	18	94
0.07	11.84	48.2	**0**	**0**	**0**	**0**
0.08	**39.10**	176.1	**185**	**5**	**1**	**28**
0.09	**87.36**	139.0	4566	52	33	83
0.10	**38.47**	112.6	2799	73	25	77
0.11	**23.94**	14.7	**1**	**0**	**0**	**11**
1.01	14.46	66.2	5880	407	89	135
1.02	6.15	61.1	5095	829	83	135
1.03	8.12	62.3	5449	671	87	186
1.04	**1.61**	29.8	4250	**2643**	143	149
1.05	**1.82**	33.7	**180**	99	**5**	**17**
1.06	11.16	53.5	**1109**	99	21	**74**
1.07	3.55	46.4	5384	1515	116	129
1.08	8.14	37.8	5255	646	139	162
1.09	17.66	83.2	**13,431**	760	161	**221**
1.11	5.40	59.0	**9221**	1707	156	174
1.12	3.33	43.5	3104	931	71	119
1.13	3.47	44.5	**8748**	2521	**197**	**216**
1.14	4.51	52.9	**14,510**	**3217**	**274**	**281**
1.16	2.47	43.5	**11,640**	**4704**	**268**	**271**
1.17	6.69	46.1	**10,020**	1499	**217**	**244**
1.18	4.27	48.8	5068	1188	104	153
1.19	6.18	86.5	**14,415**	2334	167	210
1.20	3.88	45.6	5954	1534	131	160
1.21	19.37	63.0	**112**	**6**	**2**	**37**
1.23	14.12	58.2	**950**	67	**16**	**52**
2.01	3.53	31.4	3013	854	96	126
2.04	2.72	43.9	4085	1504	93	130
2.05	3.45	50.8	5988	1734	118	188
2.07	2.64	46.2	4663	1765	101	166
2.08	3.16	40.7	2520	797	62	114
2.09	3.10	40.6	3834	1238	94	137
2.10	2.60	40.4	6437	2474	159	189
2.11	**1.08**	31.7	8272	**7694**	**261**	**266**
2.12	**1.46**	29.1	4851	**3314**	167	173
2.14	**0.52**	27.0	7553	**14,484**	**280**	**280**
2.15	**0.75**	37.6	**10,003**	**13,260**	**266**	**276**
2.24	**1.24**	32.0	**9427**	**7607**	**294**	**299**
2.25	**2.42**	32.3	6192	2562	**192**	201
2.26	2.69	51.9	7447	**2764**	143	209
2.30	**2.12**	47.6	4533	2138	95	124

Regarding population, the analysis revealed that 89.2% of the population lives more than 300 m away from a core element, indicating limited proximity to the green belt parks for most residents. Conversely, almost half of the people (47.6%) live close to a GI main node, making them one of the most accessible GI elements. The secondary nodes, which are within close reach of only 28.5% of the residents, do complement the main nodes quite well, as only one third of the population (33.7%) does not live within 300 m of any of them. The core elements do not work as effectively in combination with the main nodes, as almost half of the people (44.8%) are not close enough to any of them. Actually, the peripheral condition of the green belt means that when added to the main and secondary nodes, the population that is not close enough to a green area is not significantly diminished, being reduced from 33.7% to 27.7%, i.e., only five percentage points.

These statistics serve as a valuable tool to evaluate the actual proximity of residents to the different elements of the GI (cores, main nodes, and secondary nodes), thereby indicating their effectiveness in serving the people. It is relevant to compare the percentage of the population without access to green infrastructure within a distance of less than 300 m or 1 km, and the percentage of areas located at a distance greater than 300 m or 1 km from green infrastructure. The discrepancies are significant in most cases, showing differences ranging from 15 to 27 percentage points. Conversely, both the areas and the amount of the population that are not within 300 m of a GI core/main node (42.2% and 44.8%, respectively) and the areas and population not within 300 m from a GI core/main/secondary node (33.6% and 27.7%, respectively) show relatively similar percentages. However, these generally significant differences between the percentages of underserved areas and the underserved population stress the importance of considering the distribution of residents to evaluate their actual accessibility to green areas.

The generation of maps such as the one shown in Figure 11 is very useful to orientate future planning and development of the GI. It not only identifies the urban areas that are not within 300 m from a relevant GI element, but also, thanks to the residential densities displayed, allows planners and decision makers to anticipate where would be more relevant to introduce new green areas or expand or intensify already existing ones, such as central and densely populated districts like the Old Town (01), Ensanche (02), Coronación (04), and Desamparadas (15).

Table 4. Areas and residents not within 1 km of GI main nodes and 300 m from GI cores/main nodes/secondary nodes in the Vitoria-Gasteiz urban area.

	Area (ha)	**%**	**Population**	**%**
Vitoria-Gasteiz urban area	3238	100.0%	238,422	100.0%
Not within 1 km from a GI main node	662	20.4%	5003	2.1%
Not within 300 m from a GI core (green belt)	2138	66.0%	212,774	89.2%
Not within 300 m from a GI main node	2287	70.6%	124,940	52.4%
Not within 300 m from a GI secondary node	2805	86.6%	170,582	71.5%
Not within 300 m from a GI main/secondary node	1968	60.8%	80,348	33.7%
Not within 300 m from a GI core/main node	1365	42.2%	106,714	44.8%
Not within 300 m from a GI core/main/secondary node	1089	33.6%	65,969	27.7%

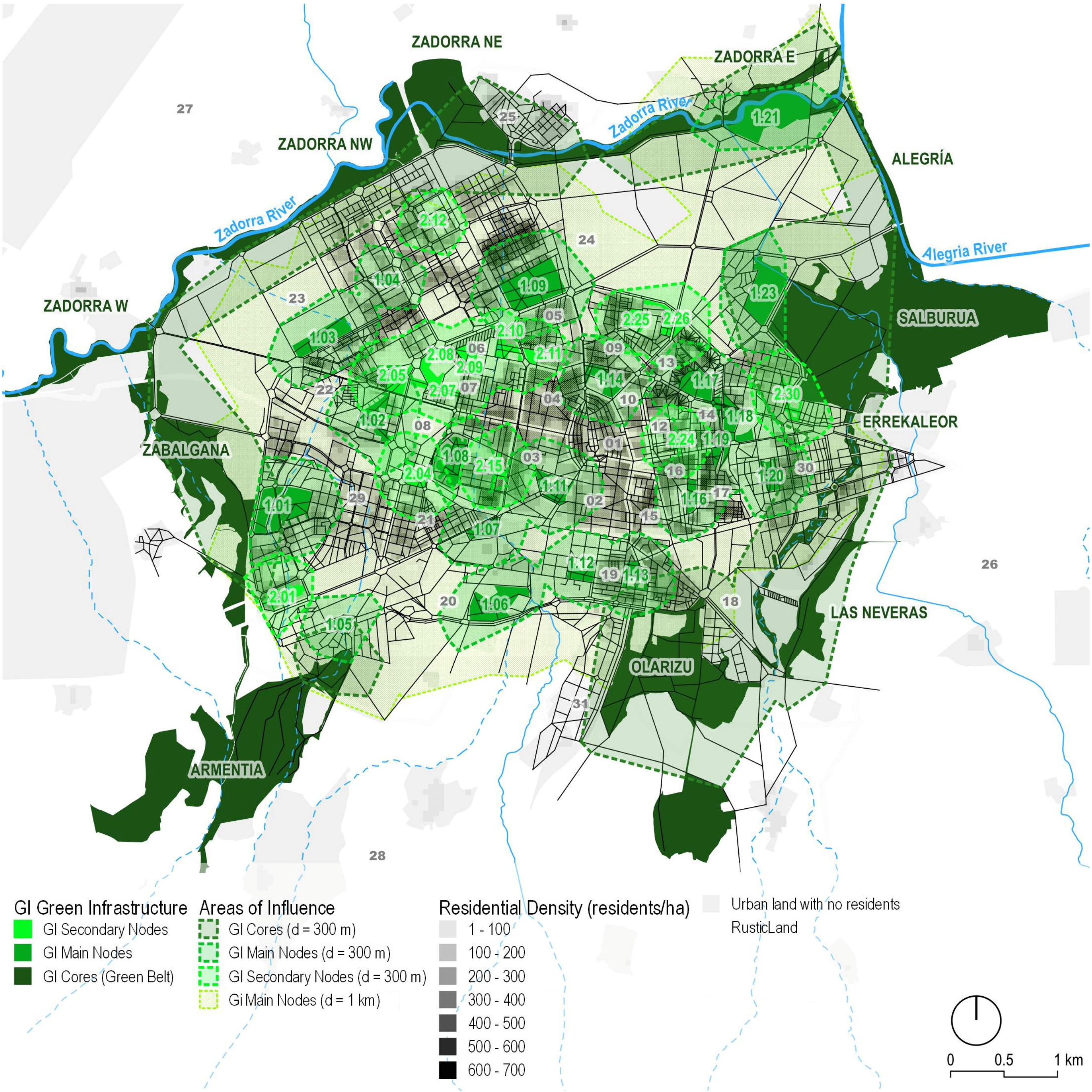

Figure 11. Areas of influence around the most relevant elements of Vitoria-Gasteiz GI: 300 m around cores, main nodes with public access, and secondary nodes with public access that are greater than 0.5 ha and 1 km around main modes with public access. A pedestrian network model (black lines) with district limits (white lines), residential density, and urban and rustic land is also included.

4. Discussion

The primary objective of this study was to examine the accessibility of Vitoria-Gasteiz's GI network by focusing on its key elements, such as cores and main nodes. By employing quantitative and cartographic analysis based on the pedestrian mobility network, the study investigated configurational accessibility at both global and local scales, as well as distance-based accessibility. The identification of green area accessibility in different parts of the city, along with variations in the level of accessibility, provides valuable insights for future city planning. Given the direct impact of access to green spaces on citizens' quality of life, proper planning and development of this infrastructure and of public spaces is crucial for achieving greater spatial justice.

The analysis highlights the influence of urban form on the accessibility of the GI system, particularly the configuration of the pedestrian network. Generally, on a global scale, the city center demonstrates higher integration (except for the core of the medieval Old Town) compared to the peripheral districts, as expected. However, the analysis reveals the relative inaccessibility of the medieval Old Town core and the greater integration of the eastern part of the city compared to the west side. This disparity can be attributed to the denser and more connected urban fabric in the east, as well as the presence of large urban blocks and areas that impede pedestrian flow, such as the Seminary and Txagorritxu Hospital, and the network configuration of certain western parts, including the C-shaped blocks in polygon 8 of San Martín (08) and the design of San Martín Park (1.08) itself.

The substantial number of main nodes distributed evenly throughout the city ensures that almost every resident of Vitoria-Gasteiz lives within less than 1 km of an urban green area. However, when considering their local integration, significant differences arise. It is essential to understand these spatial accessibility variations because spaces located at the same distance can differ significantly in terms of their actual reachability to people.

The analysis has identified two peripheral residential areas in the city, namely the Arkaiate sector in the Salburua district (30) and the more exterior district of Goikolarra (31), which face limited pedestrian accessibility to nearby green spaces. To address this issue, it is recommended that future development plans take into consideration the establishment of the green belt or the creation of new green areas near these locations. The findings of this analysis provide valuable guidance for public decision makers to optimize the design of the GI network. For instance, the planned Larragorri Park, located in the southern part of the city and adjacent to the recently developed Goikolarra district (31), is expected to mitigate limitations in GI access within that area. However, it is important to acknowledge that the Arkaiate sector, located farther away from the center within the Salburua neighborhood (30), will still require the provision of nearby green areas.

It is noteworthy that the green areas with lower integration are typically concentrated in districts with lower incomes, except for the Mendizorrotza district (20) in the southwest. This district primarily consists of single-family homes with gardens and gated communities that cater to the upper classes. Despite the income disparity, evaluation of GI accessibility reveals that the district has high accessibility to both the green belt and other main nodes. Furthermore, it is essential to consider that the study does not account for the private gardens of homes in the area or the concentration of sports centers, which further contribute to residents' access to green spaces and recreational areas.

The distribution of green spaces in Vitoria-Gasteiz is not equitable, resulting in unequal opportunities for the population to access and enjoy these spaces, as happens in other cities [7,15,19]. Access to services plays a crucial role in understanding equity from a social perspective, and the level of accessibility to GI serves as an important indicator of its effectiveness [53]. To address the potential degradation and marginalization of lower-income districts, it is essential to focus on areas with lower integration, as spatial segregation often reinforces barriers to accessing public spaces [54]. Moreover, considering the benefits offered by GI [5,8,11,20], ensuring equitable access to these green spaces is crucial due to their direct impact on the quality of life of the population [55].

While areas with poorer street integration have been identified, such as industrial estates or peripheral residential sectors, Vitoria-Gasteiz overall provides adequate accessibility to its GI. In fact, despite some imbalances, nearly all residential areas have access to green spaces. Spatial syntax tools can be employed to address these imbalances and offer recommendations or guidelines for urban design [56]. In certain areas, interventions can be made in the street network to create new intersections or improve pedestrian passage where it is currently limited. The implementation of traffic-calming measures, the introduction of additional crosswalks, and the implementation of planned superblocks are measures that can reconfigure the street grid and enhance the integration of GI elements.

Furthermore, considering the impact of the urban fabric configuration on accessibility, it is essential to acknowledge that future urban developments in the city may lead to transformations in street integration and, consequently, accessibility. In fact, future urban planning actions that reshape the accessibility model can result in functional, social, and economic changes in the short, medium, or long term. Therefore, incorporating spatial syntax analysis as a preliminary step in urban planning is a perspective that should be considered [42].

One limitation of this study is the omission of sociodemographic variables that would have allowed us to not only investigate the number of residents with and without access to relevant green areas, but also to better characterize those groups. The pedestrian network model includes all segments that are available to pedestrian movement but does not consider characteristics that might affect their walkability, such as slope or surface conditions. Walkability to a green area, and thus its actual accessibility for each person, might also depend on individual personal factors like feelings of insecurity or comfort that can contribute to lower visitation rates. Future research could incorporate these perspectives to gain a better understanding of the accessibility and utilization of different elements within the GI system.

5. Conclusions

This study analyzed the accessibility of Vitoria-Gasteiz's GI network and key components through quantitative and cartographic analysis focusing on pedestrian mobility. Disparities in green area distribution were identified, highlighting the need for equitable access. Urban design recommendations were proposed to improve GI integration in areas with limited accessibility.

Overall, Vitoria-Gasteiz provides adequate GI access, though imbalances exist, particularly in industrial and peripheral residential areas. The analysis provided here demonstrates how the layout of the urban environment, especially the pedestrian network, affects GI accessibility. Reconfiguring the street network and promoting greater integration of GI elements through spatial syntax tools and urban design interventions can address these disparities.

Although most residents live within 1 km of green areas, variations in local integration were observed. Two peripheral residential areas were identified as lacking pedestrian accessibility, highlighting the need for new green areas nearby. It is crucial to ensure equitable access to GI to prevent the degradation and marginalization of lower-income districts. Future urban planning should recognize the transformative potential of accessibility models in order to realize functional, social, and economic changes. Further research incorporating sociodemographic factors and sustainable transportation modes could deepen understanding of GI accessibility and guide future development.

This study underscores the significance of considering GI accessibility in urban planning processes. Access to green areas directly affects residents' quality of life and well-being, emphasizing the need for proper infrastructure planning and design. The findings reveal variations in accessibility across different areas of Vitoria-Gasteiz, with the city center demonstrating higher integration and the medieval Old Town core presenting challenges. This research provides valuable insights towards achieving spatial justice by guiding future planning initiatives to improve accessibility to green spaces and ensure equitable distribution throughout the city. Furthermore, the study highlights the importance of incorporating sociodemographic variables, analyzing all elements of the GI network, and exploring alternative modes of sustainable transportation in future research.

Future research could explore the significance of considering impervious space alongside green space when assessing urban environmental needs. Additionally, investigating the diverse types of green spaces (including private gardens) and their respective impacts is crucial. Understanding how subjective factors such as feelings of insecurity or unfamiliarity influence green space accessibility is also an important area for further investigation. Investigating green space accessibility from both a physical distance perspective and the perceived safety aspect is another avenue for future research. Moreover, examining how sociodemographic characteristics such as age, income, and race/ethnicity influence the perception and use of green space can contribute to a more comprehensive understanding of urban environmental dynamics. To achieve these goals, utilization of ArcGIS Network Analyst to incorporate demographic, economic, and road/path quality factors in green space studies could provide valuable insights.

Finally, to complement this study, another potential research direction could explore other sustainable modes of transportation, such as public transportation and bicycles. Vitoria-Gasteiz boasts a dense network of bicycle paths that connect the parks of the green belt. Analyzing the integration of this network of routes and paths within the parks would provide valuable insights for future development and retrofitting initiatives. To promote sustainable mobility in Alava and encourage recreational and active tourism activities in rural areas, it is important to consider the broader-scale connection of the GI.

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