Cities 179 (2026) 107505

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

# Uncovering hidden inequities in access to urban public spaces: A multimodal and configurational accessibility in island cities

Chiara Garau [a,1], Mana Dastoum [a,b,*,2], Reza Askarizad [a,3]

[a] Department of Civil and Environmental Engineering and Architecture (DICAAR), University of Cagliari, Via Marengo 2, 09123, Cagliari, Italy
[b] Department of Construction and Architectural Technology, Escuela Técnica Superior de Arquitectura de Madrid (ETSAM), Universidad Politécnica de Madrid, 28040, Madrid, Spain

ARTICLE INFO

*Keywords:*
Socio-spatial equity
Urban mobility
Space syntax
Isochrone spatial analysis
Urban accessibility
Urban squares

ABSTRACT

Ensuring spatial equity and equitable access to public spaces remains a critical challenge in contemporary urban planning, particularly in geographically constrained island cities. This study develops an integrated analytical framework to assess multimodal accessibility and spatial equity in urban public squares by combining configurational accessibility, derived from space syntax analysis, with operational accessibility, evaluated through multimodal isochrone mapping and public transport accessibility. Focusing on three representative Sardinian cities, the research examines how urban spatial configuration and transport infrastructure jointly influence accessibility across walking, cycling, and wheelchair modes, with particular attention to people with reduced mobility (PRM). Space syntax is first employed to identify spatially integrated public squares, which subsequently serve as the basis for multimodal accessibility assessment. By integrating these complementary analyses within a sequential analytical workflow, the framework enables accessibility to be interpreted from both structural and functional perspectives, providing a more comprehensive evaluation of accessibility conditions in urban public spaces. The findings demonstrate that spatial centrality alone does not guarantee inclusive accessibility, as highly integrated locations may still present substantial barriers for wheelchair users owing to infrastructural limitations. By focusing on urban public squares—an important yet comparatively understudied category of public space—the study demonstrates how the complementary interpretation of urban morphology and multimodal accessibility can reveal spatial inequalities that remain overlooked when either approach is applied independently. These findings provide evidence-based insights for promoting more inclusive planning strategies and improving accessibility to public spaces in island and regional urban contexts.

## 1. Introduction

Fair and accessible urban spaces are fundamental to achieving equitable and sustainable urban development (Cetin, 2015; Naya et al., 2023), strengthening the ability of individuals and communities to access essential opportunities, services, and resources that support well-being and quality of life (Santiago Fink, 2016; Selanon & Chuangchai, 2023). Urban planning conceptualises accessibility not solely as physical mobility but as a broader condition that enables equitable participation in urban life through fair access to public spaces, infrastructure, and services (Solá et al., 2018). Such accessibility plays a crucial role in promoting social inclusion and spatial equity (Brussel et al., 2019; Clarke et al., 2023), while also contributing to economic vitality (Carrera, 2023), environmental sustainability (Sretovic Brkovic & Djukic, 2024; Sharifi et al., 2025), and social cohesion (Harris et al., 2023; Zhang et al., 2022). By enabling inclusive participation in urban environments regardless of socioeconomic status, geographic location, or physical ability, accessibility forms a cornerstone of just and resilient cities (Cuthill et al., 2019; Meerow et al., 2019). Nevertheless, persistent spatial disparities in accessibility continue to reinforce social inequalities and disproportionately affect vulnerable populations, including people with reduced mobility (PRM) (Wu & Liu, 2022;

* Corresponding author at: Department of Construction and Architectural Technology, Escuela Técnica Superior de Arquitectura de Madrid (ETSAM), Universidad Politécnica de Madrid, 28040, Madrid, Spain.
*E-mail addresses:* cgarau@unica.it (C. Garau), mana.dastoum@alumnos.upm.es (M. Dastoum), reza.askarizad@unica.it (R. Askarizad).
[1] scholar.google.com/citations?user=KBNYKbsAAAAJ&hl=en.
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https://doi.org/10.1016/j.cities.2026.107505
Received 21 February 2026; Received in revised form 13 July 2026; Accepted 13 August 2026
Available online 20 August 2026

Askarizad, He, & Dastoum, 2025; Xiao et al., 2017).

Social equity is a central principle in urban planning, guiding efforts to create environments that are inclusive, fair, and responsive to diverse population needs (Dempsey et al., 2012; Leach et al., 2018). Unlike equality, which assumes uniform provision, equity emphasises the need to address structural barriers and accommodate differences in mobility, physical ability, and spatial opportunity (Espinoza, 2007; Manaugh et al., 2015; Fitzgibbons & Mitchell, 2021). This requires ensuring that public spaces, transport infrastructure, and urban services are distributed in ways that support accessibility for all population groups, particularly those historically marginalised or excluded (Behbahani et al., 2019; Nicoletti et al., 2023; Taleai et al., 2014; Coni et al., 2020). Equity-oriented planning enhances social participation, strengthens community cohesion, and contributes to broader urban sustainability goals (Meerow et al., 2019; Simões Aelbrecht et al., 2022; Jennings et al., 2016). Conversely, spatial inequities in accessibility may reinforce patterns of exclusion (Cass et al., 2005), limiting opportunities for disadvantaged communities while concentrating resources in already well-served areas (Corburn, 2017; Fincher & Iveson, 2012). Addressing these disparities requires robust spatial analysis methods capable of identifying uneven accessibility patterns and informing targeted planning interventions (Alshuwaikhat & Abubakar, 2008; Bibri, 2021; Hu et al., 2024).

Accessibility and spatial equity have been widely examined across multiple domains, including transport systems (Sharma & Patil, 2024; Cuthill et al., 2019; Cavallaro & Dianin, 2020; Cai et al., 2024; Wan & Titheridge, 2024), green and recreational spaces (He et al., 2024; Iraegui et al., 2020; Wang et al., 2022; Zhao & Gong, 2024), healthcare provision (Chao et al., 2024; Chen et al., 2022; Gu et al., 2023), and educational accessibility (Pizzol et al., 2021; Sharma & Patil, 2022; Wang et al., 2021). However, much of this research has focused on large-scale infrastructure systems or general urban environments, such as transport corridors, residential neighbourhoods, or public facility distribution, with limited attention given to urban public squares as distinct spatial entities. Previous studies addressing accessibility in public space contexts have primarily examined street networks, cycling infrastructure, or residential accessibility patterns (Xu & Wang, 2024; Chang et al., 2023; Zhao et al., 2024). Despite their central role as social, cultural, and functional nodes within cities, urban public squares remain under-examined in accessibility research, particularly in regional and insular urban contexts. This represents a critical gap, as public squares serve as focal points for social interaction, civic engagement, and everyday mobility, and their accessibility is essential for supporting inclusive urban environments. Addressing this gap requires analytical approaches that integrate urban spatial configuration with multimodal accessibility assessment, enabling accessibility to be examined from both configurational and operational perspectives. Such an approach not only improves understanding of how urban form and transport infrastructure jointly shapes equitable access to public spaces, but also provides evidence capable of informing planning decisions aimed at reducing spatial inequalities.

Recent advances in spatial analysis provide valuable tools for evaluating accessibility from both configurational and network-based perspectives (Alam et al., 2026). Space syntax analysis enables the assessment of urban spatial structure by quantifying the configurational integration of street networks and identifying spatially central and accessible locations (Hillier, 2008; Hillier & Hanson, 1984; Yamu & Garau, 2022). Complementing this, multimodal isochrone analysis allows the measurement of travel-time accessibility across different transport modes, providing a dynamic representation of spatial reachability and mobility potential (Moreno, 2024; Moreno et al., 2021). The integration of these complementary approaches enables accessibility to be interpreted from two interconnected dimensions: configurational accessibility, reflecting the movement potential embedded within the urban street network, and operational accessibility, representing the practical reachability of destinations through different transport modes. Examining these dimensions together provides a more holistic perspective of accessibility conditions than either approach can offer independently.

This issue is particularly relevant in insular and peripheral regions, where geographic isolation, uneven infrastructure provision, and constrained transport connectivity may exacerbate spatial disparities in accessibility. Urban development processes, including spatial expansion, land transformation, and urban sprawl, may further reshape spatial continuity and contribute to fragmented urban structures and uneven patterns of connectivity (Hendawy et al., 2019; Nolè et al., 2014; Saganeiti et al., 2018). Sardinia, Italy, represents a particularly relevant case of these combined conditions. As an insular territory characterised by geographic fragmentation and varied urban development patterns, Sardinian cities face distinct accessibility challenges that influence equitable access to urban public spaces. The cities of Cagliari, Sassari, and Olbia provide diverse spatial and infrastructural contexts, reflecting different levels of spatial integration, transport provision, and urban development intensity. Examining accessibility patterns within these cities offers valuable insights into how spatial configuration and multimodal transport networks shape equitable access in regional and island environments. This research also contributes to broader planning objectives aligned with Sustainable Development Goals related to inclusive cities and reduced inequalities (SDG 11 and SDG 10).

Beyond its empirical focus on Sardinian cities, this study makes both theoretical and practical contributions to accessibility research. Theoretically, it advances current approaches by integrating configurational accessibility, represented through Space Syntax analysis, with operational accessibility derived from multimodal isochrone and public transport analyses within a unified analytical framework. Rather than treating these dimensions independently, the framework demonstrates how urban morphology and transport accessibility complement one another in explaining accessibility conditions in urban public spaces. Practically, the framework provides a systematic approach for identifying locations where spatial centrality and functional accessibility converge or diverge, thereby generating evidence that can support context-sensitive planning interventions aimed at improving equitable access to public spaces in regional and insular cities.

Building upon these considerations, the study addresses two complementary challenges. The first is analytical: understanding how urban spatial configuration and multimodal accessibility jointly influence access to urban public squares. The second is practical: demonstrating how the integrated interpretation of these accessibility dimensions can support planning strategies for improving equitable access in insular urban environments. These challenges form the basis of the research questions presented below and provide the conceptual link between the analytical framework and its planning applications.

Accordingly, this study develops an integrated spatial framework combining space syntax analysis and multimodal isochrone mapping to evaluate spatial accessibility and equity in urban public squares. By analysing walking, cycling, wheelchair, and public transport accessibility in relation to spatial configuration, the study investigates how urban form and transport infrastructure jointly influence inclusive access to public spaces. The following research questions guide the investigation:

1) How does spatial configuration influence accessibility to urban public squares in Sardinia's regional cities?
2) To what extent do multimodal accessibility patterns differ across walking, cycling, wheelchair, and public transport modes in these urban contexts?
3) What spatial disparities in accessibility exist among Cagliari, Sassari, and Olbia, and how do these affect inclusive access to urban public squares, particularly for persons with reduced mobility?
4) How can the integrated interpretation of configurational and operational accessibility support planning strategies for improving equitable access to urban public squares in insular urban contexts?

This study hypothesises that urban squares located in highly integrated areas of the street network will demonstrate higher levels of multimodal accessibility due to their structural connectivity within the urban fabric. By identifying where configurational accessibility and operational accessibility either correspond or diverge, the proposed framework provides an evidence base for planning interventions, including improvements to pedestrian connectivity, public transport provision, and barrier-free infrastructure surrounding urban public squares. Consequently, the study not only evaluates existing accessibility conditions but also demonstrates how integrated spatial analysis can inform planning strategies for improving equitable accessibility in regional and insular urban environments, thereby directly addressing the fourth research question. The remainder of the paper is structured as follows. The Material and methods section outlines the integrated analytical framework combining space syntax and multimodal isochrone analysis. The Results section presents the accessibility assessment across selected urban squares in Cagliari, Sassari, and Olbia. The Discussion interprets the findings in relation to spatial accessibility and inclusive urban planning, and the Conclusion summarises the key contributions and implications for improving equitable access to urban public spaces.

## 2. Material and methods

This research adopts an integrated spatial analytical approach combining space syntax analysis with multimodal accessibility mapping to evaluate spatial accessibility to urban public squares in three Sardinian cities. This combined methodology enables the assessment of accessibility from both configurational and network-based perspectives, allowing for a comprehensive examination of how urban spatial structure and transport infrastructure jointly influence access to public spaces. The selected contexts were chosen due to their demographic significance, geographic diversity, and representativeness of insular urban conditions.

The analysis begins with a morphological assessment using space syntax techniques, through which segment maps were generated and global integration (Rn) values were calculated to quantify the configurational accessibility of the urban street network. Areas exhibiting higher integration values were interpreted as structurally central locations within the urban fabric, reflecting their greater potential for accessibility and movement. Based on this analysis, key urban public squares located within highly integrated areas were identified as focal sites for further accessibility assessment, given their importance as social, functional, and spatial nodes within the city.

To evaluate multimodal accessibility to the selected urban public squares, travel-time isochrone analysis was conducted in QGIS 3.40 using the OpenRouteService (ORS) plugin. Isochrones were generated for 5-, 10-, and 15-minute travel times across walking, cycling, and wheelchair modes, reflecting diverse mobility needs and supporting an inclusive assessment of accessibility consistent with the principles of proximity-based urban planning (Moreno, 2024; Moreno et al., 2021). These isochrones represent the spatial extent reachable within defined travel-time thresholds and provide a quantitative basis for comparing accessibility across different mobility modes and urban contexts.

Public transport accessibility was assessed by mapping and analysing the spatial distribution of bus stops obtained from OpenStreetMap data within the generated isochrone areas. The presence and density of bus stops within accessible catchments were used to evaluate the availability and spatial coverage of public transport infrastructure in relation to urban public squares. This approach provides an indication of how well public spaces are connected to the broader urban transport network.

All spatial datasets were processed using a consistent coordinate reference system (EPSG:32632) to ensure spatial accuracy and comparability. Isochrone polygons were used to calculate accessible areas for each mobility mode and time threshold, allowing for direct comparison of spatial reachability. The integration values derived from space syntax analysis were examined alongside multimodal isochrone extents and public transport stop distributions to identify spatial correspondences and disparities between configurational accessibility and transport-based accessibility. This integrated analytical framework enables the systematic evaluation of how spatial configuration and transport infrastructure collectively influence accessibility to urban public spaces, particularly in an insular context. Fig. 1 illustrates the overall methodological workflow adopted in this study.

### 2.1. Morphological analysis using space syntax (configurational accessibility)

This research employed space syntax analysis, originally developed by Hillier and Hanson (1984), to examine the configurational properties of the urban street networks. Space syntax provides a theoretical and analytical framework for quantifying spatial relationships and evaluating how urban configuration influences accessibility, movement patterns, and spatial centrality (Hillier, 2008). Drawing on Natural Movement theory, the approach emphasises that spatial configuration plays a fundamental role in shaping movement behaviour and accessibility patterns within urban environments (Hillier et al., 1993). Consequently, configurational measures derived from space syntax analysis offer valuable insights into the structural accessibility of urban spaces (Garau et al., 2025).

A segment-based space syntax analysis was conducted using DepthmapX software for the cities of Cagliari, Sassari, and Olbia. Street network data were obtained from OpenStreetMap and processed to generate accurate segment maps representing the urban street structure. These maps were created by converting road centreline data into interconnected street segments, enabling the calculation of global integration (Rn) values for each segment.

Integration values quantify the degree to which individual street segments are spatially connected to the overall network (Hillier, 2007). Higher integration values indicate greater spatial accessibility and centrality, as such locations require fewer directional changes to reach other parts of the network and are therefore more likely to support movement and activity (Al-Sayed et al., 2014). By analysing integration patterns across each city, this study identified spatially central areas and key public squares that function as structurally accessible urban nodes. These locations were selected as case study sites for further multimodal accessibility assessment. This approach ensures that the analysis considers both the structural properties of the urban network and the functional accessibility of socially significant public spaces.

### 2.2. Spatial analysis of multimodal accessibility using QGIS (operational accessibility)

Multimodal accessibility to urban public squares was assessed using travel-time isochrone analysis conducted in QGIS 3.40 with the OpenRouteService plugin. Isochrones were generated for walking, cycling, and wheelchair modes at 5-, 10-, and 15-minute travel-time intervals. This multimodal approach enables the evaluation of accessibility for diverse user groups and mobility conditions, providing an inclusive representation of spatial reachability.

Isochrone polygons represent the geographic areas accessible within specified travel times from each public square and serve as quantitative indicators of accessibility extent. The accessible area (in $km^2$) for each mobility mode and time interval was calculated to enable systematic comparison across cities and locations. Table 1 summarises the four accessibility layers analysed in this study: walking, cycling, wheelchair, and public transport accessibility.

Public transport accessibility was incorporated by analysing the spatial distribution of bus stops obtained from OpenStreetMap. As ORS does not directly generate public transport isochrones, bus stop accessibility was evaluated by identifying and counting bus stops located within the walking, cycling, and wheelchair isochrone areas for each

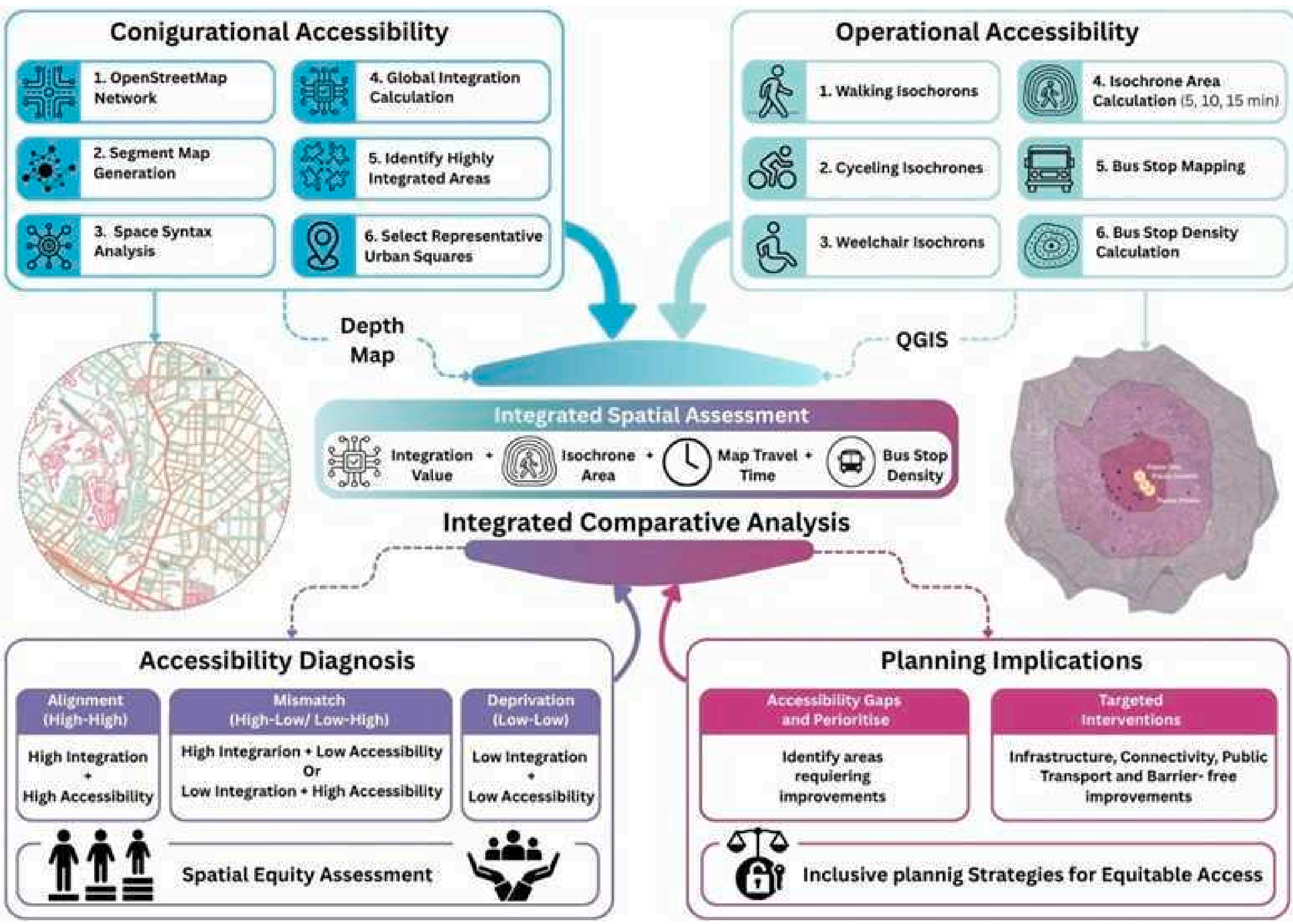


**Fig. 1.** Integrated methodological framework for evaluating equitable accessibility to urban public squares. The framework combines configurational accessibility (space syntax) with operational accessibility (multimodal isochrone mapping and public transport analysis) to identify accessibility alignments and mismatches, supporting spatial equity assessment and planning.

**Table 1**
The four core accessibility layers used in the multimodal spatial analysis.

| | Accessibility layers | Description | Proxy for/role in analysis |
|---|---|---|---|
|  | Walking Accessibility | Isochrone area (km$^2$) by foot, considered default mode for universal access | Reflects baseline urban equity and built environment connectivity] |
|  | Cycling Accessibility | Isochrone area (km$^2$) reachable via cycling infrastructure within specified timeframes | Indicates active mobility infrastructure and spatial coverage |
|  | Wheelchair Accessibility | Isochrone area (km$^2$) accessible by wheelchair in 5, 10, and 15 min using ORS in QGIS | Proxy for accessibility for People with Reduced Mobility (PRM) |
|  | Public Transport Stops | Isochrone area (km$^2$) by foot, considered default mode for universal access | Reflects baseline urban equity and built environment connectivity |

urban square. The "Count Points in Polygon" tool in QGIS was used to quantify the number of bus stops within each isochrone. To ensure comparability, bus stop density was calculated by normalising the number of bus stops by the corresponding isochrone area, expressed as:

$$Bus\ Stop\ Density = \frac{Number\ of\ Bus\ stops}{Area\ \mathrm{km}^2}$$

This density measure provides an indication of the spatial availability and concentration of public transport infrastructure within accessible areas, enabling comparison of transport connectivity across different locations and mobility modes. By examining variations in accessible area and transport stop density, the study identifies spatial differences in multimodal accessibility and infrastructure provision across the selected urban public squares.

### 2.3. Integrated analytical framework for configurational and operational accessibility

To provide an integrated interpretation of the relationship between urban morphology, multimodal accessibility, and public transport provision, the final stage of the analysis synthesised the results obtained from the previous methodological steps into a Configurational–Operational Typology Matrix. Rather than analysing configurational accessibility and operational accessibility independently, this framework combines complementary indicators representing urban structure, inclusive accessibility, and transport service availability within a common analytical space.

The horizontal axis of the framework represents configurational accessibility, quantified using the corresponding integration values derived from space syntax analysis for each city under study. Since integration values are calculated independently for each city's street network and are influenced by their topological characteristics (Hillier, 2008; Hillier & Hanson, 1984), their raw values cannot be directly compared across different urban systems. Direct comparison between cities would therefore introduce systematic bias unrelated to actual accessibility performance. To enable cross-city interpretation while preserving the internal spatial hierarchy of each network, the corresponding integration values were normalized separately for each city using Min–Max normalization (Arora et al., 2021; Mazziotta & Pareto, 2022):

$$I_{norm} = \frac{I - I_{min}}{I_{max} - I_{min}}$$

where $I$ represents the original integration value of each public square, and $I_{min}$ and $I_{max}$ correspond to the minimum and maximum integration values within the respective city. This procedure transforms the values to a common scale ranging from 0 to 1 while maintaining the relative configurational ranking of the public squares inside each urban system.

Operational accessibility was represented by the Modal Catchment Index (MCI), developed to quantify the degree to which accessibility is preserved for people with reduced mobility relative to conventional pedestrian accessibility. The vertical axis of the integrated analytical matrix represents this index which compares the spatial extent of the wheelchair-accessible catchment with the corresponding walking catchment for the same travel time threshold:

$$MCI = \frac{A_{Wheelchair}}{A_{Walking}}$$

The MCI ranges theoretically between 0 and 1. Values approaching 1 indicate that wheelchair users experience accessibility conditions similar to those of pedestrians, suggesting relatively inclusive urban environments. Conversely, lower values indicate a greater reduction in accessible area for wheelchair users, reflecting the presence of physical, topographical, or infrastructural barriers that disproportionately affect inclusive mobility. The 15-minute travel threshold was selected because it represents the largest catchment area analysed in this study and therefore provides the most comprehensive representation of each public square's operational accessibility. Using a single threshold also ensures consistency between the configurational and operational indicators incorporated into the final integrated analysis.

Finally, public transport availability was incorporated using the 15-minute wheelchair Bus Stop Density (BSD), calculated as the number of accessible bus stops divided by the wheelchair-accessible catchment area. BSD was not incorporated into the matrix axes because its role differs conceptually from the previous indicators. Whereas integration represents configurational accessibility and MCI reflects operational accessibility, BSD characterises the availability of supporting public transport infrastructure within the accessible catchment. Consequently, BSD is presented as an accompanying attribute for each public square, allowing simultaneous interpretation of street network configuration, inclusive accessibility, and transport provision without increasing the dimensional complexity of the framework.

#### *2.3.1. Rationale for focusing on wheelchair accessibility in the integrated analysis*

Although multimodal accessibility was evaluated for walking, cycling, and wheelchair users throughout the study, the final integrated analysis focuses exclusively on wheelchair accessibility. This decision reflects the primary objective of the research, namely assessing spatial equity and inclusive accessibility rather than comparing transport modes. Walking and cycling accessibility primarily represent variations in travel efficiency between different mobility options, whereas wheelchair accessibility directly reflects the accessibility conditions experienced by persons with reduced mobility (PRM), one of the population groups most vulnerable to spatial exclusion.

Accordingly, the modal catchment index was formulated by comparing wheelchair and walking accessibility, using pedestrian accessibility as the reference condition against which accessibility loss for PRM can be quantified. This approach transforms the indicator from a conventional accessibility measure into an equity-oriented metric that explicitly captures the extent to which urban environments preserve accessibility for vulnerable users. Similarly, wheelchair-based Bus Stop Density was adopted because it evaluates the availability of public transport services that are realistically accessible under inclusive routing conditions. Including separate integrated analyses for walking and cycling would primarily duplicate the multimodal comparisons already presented in Sections 3.4 and 3.5 without providing additional insight into spatial equity. By focusing on wheelchair accessibility in the final synthesis, the framework directly addresses the study's central objective of identifying hidden inequalities in access to urban public spaces and supporting planning strategies that promote more inclusive urban environments.

### *2.4. Study areas*

The case study is situated within the insular context of Sardinia, Italy (Fig. 2), a region characterised by geographic isolation, uneven infrastructure development, and diverse urban morphologies. Insular regions often experience unique accessibility challenges due to constrained connectivity, spatial fragmentation, and uneven transport provision, making them particularly relevant for accessibility and spatial equity analysis. The study focuses on three Sardinian cities—Cagliari, Sassari, and Olbia, which represent distinct urban, geographic, and infrastructural contexts.

Cagliari, located on the southern coast, serves as Sardinia's primary administrative, economic, and transport hub. It benefits from relatively well-developed infrastructure and an extensive urban transport network. However, accessibility disparities persist between central and peripheral areas. Olbia, situated on the northeastern coast, functions as a key transport gateway due to its airport and port facilities. Despite its strategic importance and recent urban growth, accessibility varies across its urban areas, reflecting uneven infrastructure distribution. Sassari, located inland in the northwest, represents a contrasting urban context characterised by historical urban form and comparatively limited transport infrastructure. These conditions present distinct accessibility challenges relative to coastal cities. By analysing these three cities, the study captures a range of spatial and infrastructural conditions representative of insular urban environments. This comparative approach enables the evaluation of how spatial configuration and multimodal transport accessibility interact to influence access to urban public squares across different urban and geographic contexts.

## 3. Results

In the initial analysis, the integration map of Sardinia (Fig. 3), produced through space syntax analysis, depicts the spatial configuration of the island's road network. Warmer colours (yellow to red) indicate higher integration and therefore stronger configurational connectivity, whereas cooler colours (green to blue) indicate lower integration and more segregated network structures. The map reveals clear spatial differentiation across the island, with Cagliari exhibiting the most extensive and continuous areas of high integration, suggesting a comparatively well-connected urban network. In the north-west, Sassari displays moderate integration patterns, with fewer highly integrated corridors and a greater prevalence of mid-to-low integration values. Olbia, located in the north-east, shows more limited concentrations of highly integrated segments and a generally cooler colour palette, indicating comparatively lower configurational connectivity. Overall, the spatial integration patterns suggest that Cagliari is the most configurationally connected urban system among the three, followed by Sassari, while Olbia shows the lowest relative level of integration within its

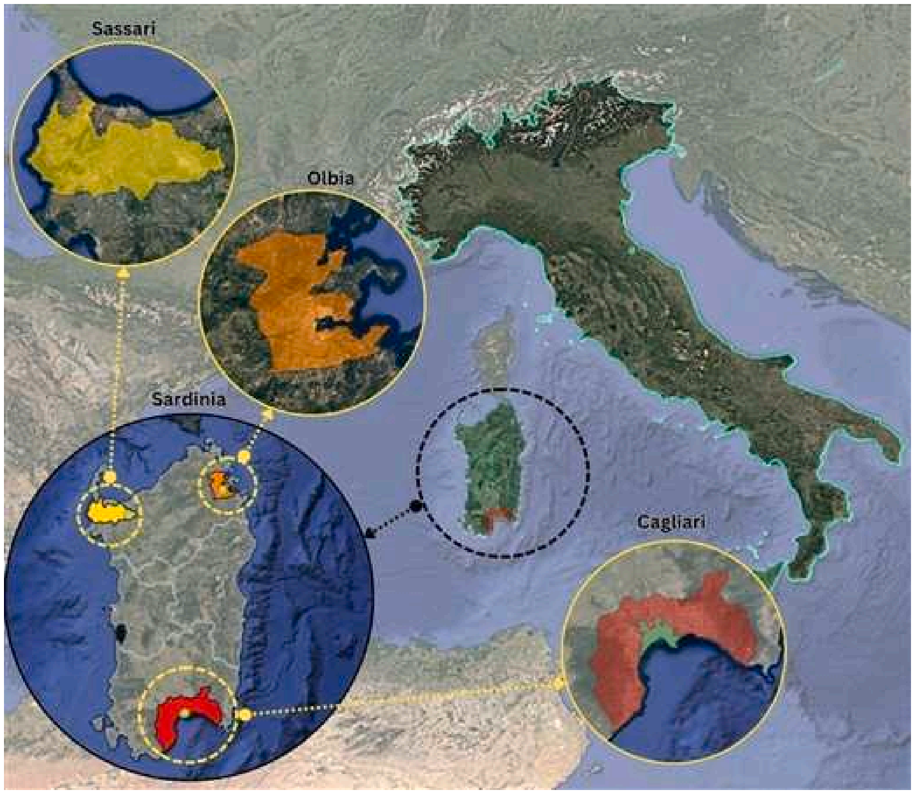


**Fig. 2.** Geographical location of the study areas, three cities of Cagliari, Olbia and Sassari in Sardinia island, Italy.

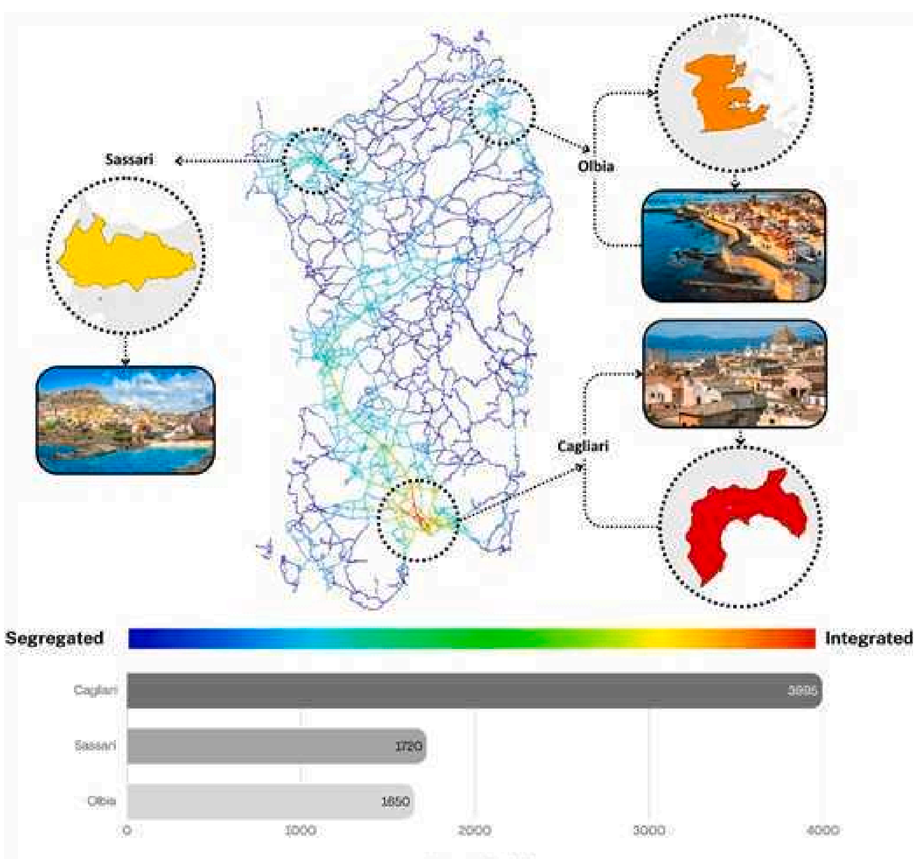


**Fig. 3.** Spatial integration graph of Sardinia using space syntax analysis and the comparative quantitative chart revealing the different levels of integration in the cities of Cagliari, Sassari, and Olbia.

urban network.

The accompanying graphs provide a comparative representation of spatial integration levels across the three Sardinian cities. Integration values, shown by the length of the horizontal bars, reflect the relative ease of movement and configurational accessibility within each urban system. Cagliari records the highest integration value (3995), indicating a highly interconnected street network. Sassari shows an intermediate value (1720), while Olbia exhibits the lowest value (1650), suggesting a comparatively more fragmented network structure. These results corroborate the visual patterns shown in Fig. 3 and provide a quantitative basis for comparing configurational accessibility across the three urban systems.

### *3.1. Detailed spatial analysis of Cagliari using space syntax*

The segment-based analysis of Cagliari's city centre (Fig. 4) highlights variations in spatial integration across the street network. Within the enlarged view of the central area, three public squares—Piazza del Carmine, Piazza Yenne, and Piazza Giuseppe Garibaldi—are located within highly integrated zones and were therefore selected as key sites for subsequent accessibility analysis. Their selection is grounded in their integration values, indicating strong configurational centrality and likely network prominence within the city. The photographs presented alongside the map provide contextual support for interpreting their spatial form and urban function. The comparative chart associated with Fig. 4 ranks the three squares by their integration values. Piazza Giuseppe Garibaldi records the highest integration value (4243), followed by Piazza Yenne (3926), while Piazza del Carmine records a lower value (3273). These results confirm that the selected squares occupy structurally central positions within the urban network, supporting their suitability for multimodal accessibility assessment.

### *3.2. Detailed spatial analysis of Sassari using space syntax*

Fig. 5 presents the space syntax integration analysis of Sassari's urban core, illustrating configurational accessibility using a chromatic scale from blue (lower integration) to red (higher integration). The enlarged map highlights three squares—Piazza Tola (1), Piazza Castello (2), and Piazza d'Italia (3)—selected due to their relatively high integration levels within the street network. These squares are situated within the most integrated areas of Sassari's core, indicating stronger configurational accessibility compared with surrounding streets. Among the selected squares, Piazza d'Italia records the highest integration value (9782), followed by Piazza Castello (9553) and Piazza Tola (9117). The comparative chart below the figure confirms these differences and indicates that, although all three squares are highly integrated, Piazza d'Italia occupies the strongest configurational position within the local network structure.

### *3.3. Detailed spatial analysis of Olbia using space syntax*

Fig. 6 displays the segment-based integration analysis of Olbia's city centre, identifying three public squares—Piazza Crispi, Piazza Matteotti, and Piazza Regina Margherita—located within relatively integrated areas of the urban network. The integration map shows a narrower range of integration variation in comparison with Cagliari and Sassari, suggesting a more uniform configurational structure within Olbia's core. The integration values indicate that Piazza Regina Margherita records the highest integration (5523), followed by Piazza Matteotti (5344), while Piazza Crispi has a lower integration value (5013). Although the differences are modest, the ranking identifies Piazza Regina Margherita as the most configurationally central of the three squares. The accompanying visual and photographic materials support the interpretation of these squares as key public nodes within Olbia's centre.

### *3.4. Operational accessibility: multimodal isochrone analysis*

This section constitutes the first stage of the multimodal accessibility assessment by evaluating the spatial extent of accessibility independently of public transport availability. The objective is to identify the areas that can be reached from each square under different mobility conditions and thereby establish the spatial catchments that form the basis for the subsequent public transport accessibility analysis presented in Section 3.5. Public transport stops are displayed on the maps only to provide spatial context, whereas their quantitative evaluation is undertaken separately in the following section. It should be noted that the multimodal isochrones quantify the operational reachability of each square but do not indicate whether these accessible areas are adequately supported by public transport services.

In this regard, Fig. 7 presents the multimodal isochrone maps generated for the selected urban squares, showing 5-, 10-, and 15-minute catchments for walking (left), cycling (centre), and wheelchair access (right), produced using ORS in QGIS. These maps visualise mode-specific differences in reachable area from each square and enable comparison across cities and mobility conditions. Public transport stops (blue dots), extracted from OpenStreetMap, are overlaid to illustrate their spatial distribution within each travel-time catchment. The calculated spatial extents ($km^2$) of the isochrone areas for each square and mode are reported in Table 2. Across all cities, cycling isochrones consistently produce the largest catchment areas, followed by walking, while wheelchair isochrones generally show smaller spatial coverage, reflecting constraints associated with inclusive routing conditions.

### *3.5. Calculating bus stop density within multimodal catchments*

Building upon the isochrone catchments, this section constitutes the second stage of the multimodal accessibility assessment by evaluating the availability of public transport services within the reachable areas. Rather than measuring accessibility extent, the analysis focuses on the distribution and density of bus stops inside each isochrone, thereby assessing the degree to which operational public transport provision supports the accessibility potential identified in the previous section.

Fig. 8 summarises the distribution of public transport stops within the 5-, 10-, and 15-minute isochrone areas for walking, cycling, and wheelchair modes across the nine selected urban squares in Cagliari (Piazza Yenne, Piazza del Carmine, Piazza Giuseppe Garibaldi), Sassari (Piazza d'Italia, Piazza Castello, Piazza Tola), and Olbia (Piazza Regina Margherita, Piazza Matteotti, Piazza Crispi).

In the walking mode, Piazza Giuseppe Garibaldi in Cagliari shows the highest number of bus stops across all three time thresholds, indicating strong proximity-based access to public transport. By contrast, Piazza Crispi in Olbia exhibits the weakest pedestrian-accessible public transport coverage, with zero stops within the 5-minute walking isochrone and only limited increases at longer thresholds.

For wheelchair accessibility, Piazza Yenne in Cagliari records the highest number of accessible stops within the 5- and 10-minute isochrones, suggesting comparatively stronger transport proximity under inclusive routing constraints. Piazza Crispi again shows the lowest performance, including no accessible stops within 5 min and minimal coverage at 10 and 15 min, indicating limited public transport availability within wheelchair-accessible catchments.

For cycling, the enlarged catchment areas naturally encompass a greater number of stops across all sites. Piazza Giuseppe Garibaldi records the highest number of accessible stops, while Piazza d'Italia in Sassari shows the lowest count, indicating comparatively weaker integration between cycling catchments and stop distribution at that location. These differences highlight spatial variability in how public transport infrastructure aligns with mode-specific catchments across the case study squares.

Fig. 9 reports bus stop density (stops per $km^2$) within the 5-, 10-, and 15-minute isochrone areas for walking, cycling, and wheelchair modes.

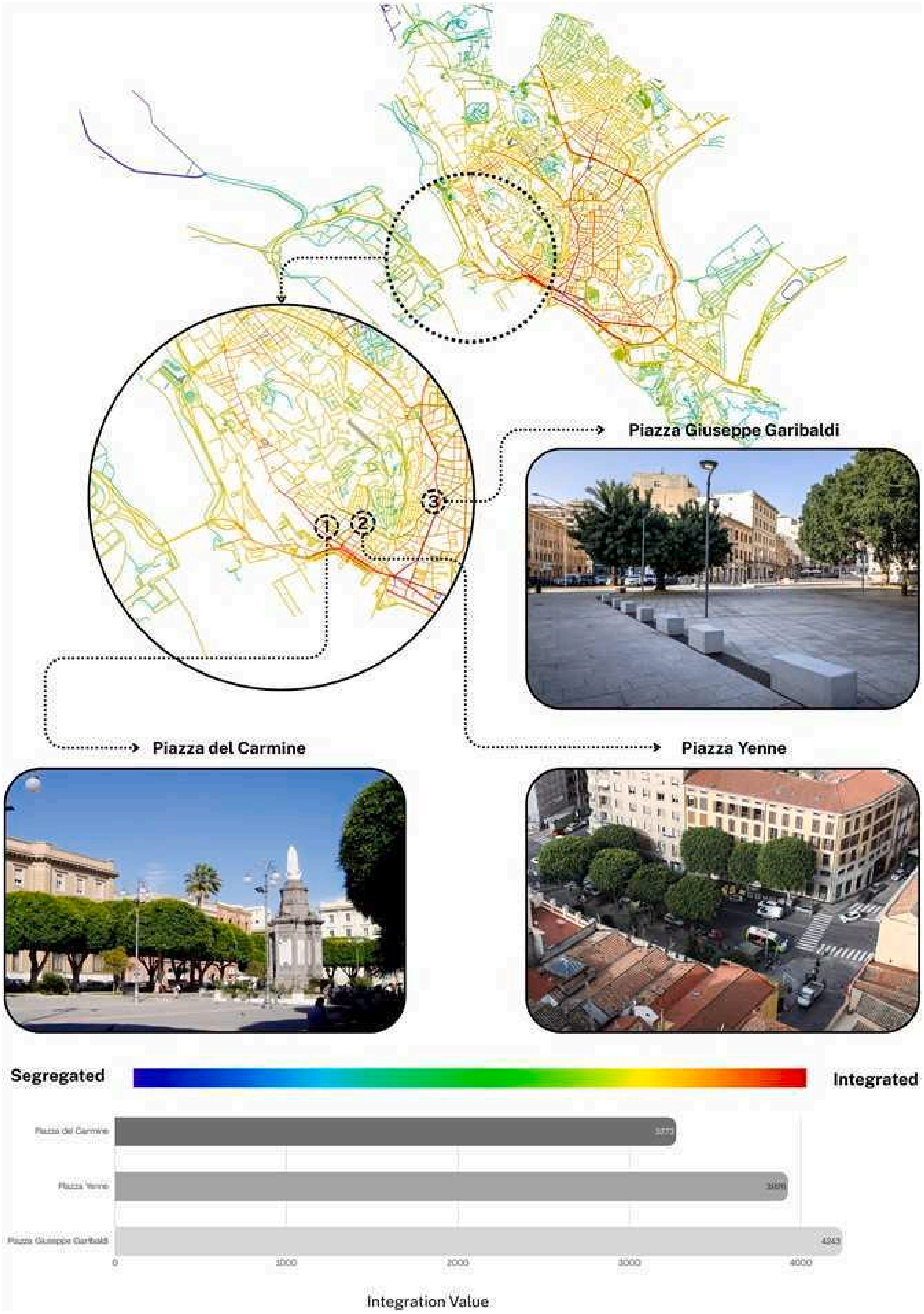


**Fig. 4.** Three identified main urban squares of Cagliari based on the integration graph of spatial analysis using space syntax and the comparative quantitative chart of their integration values.

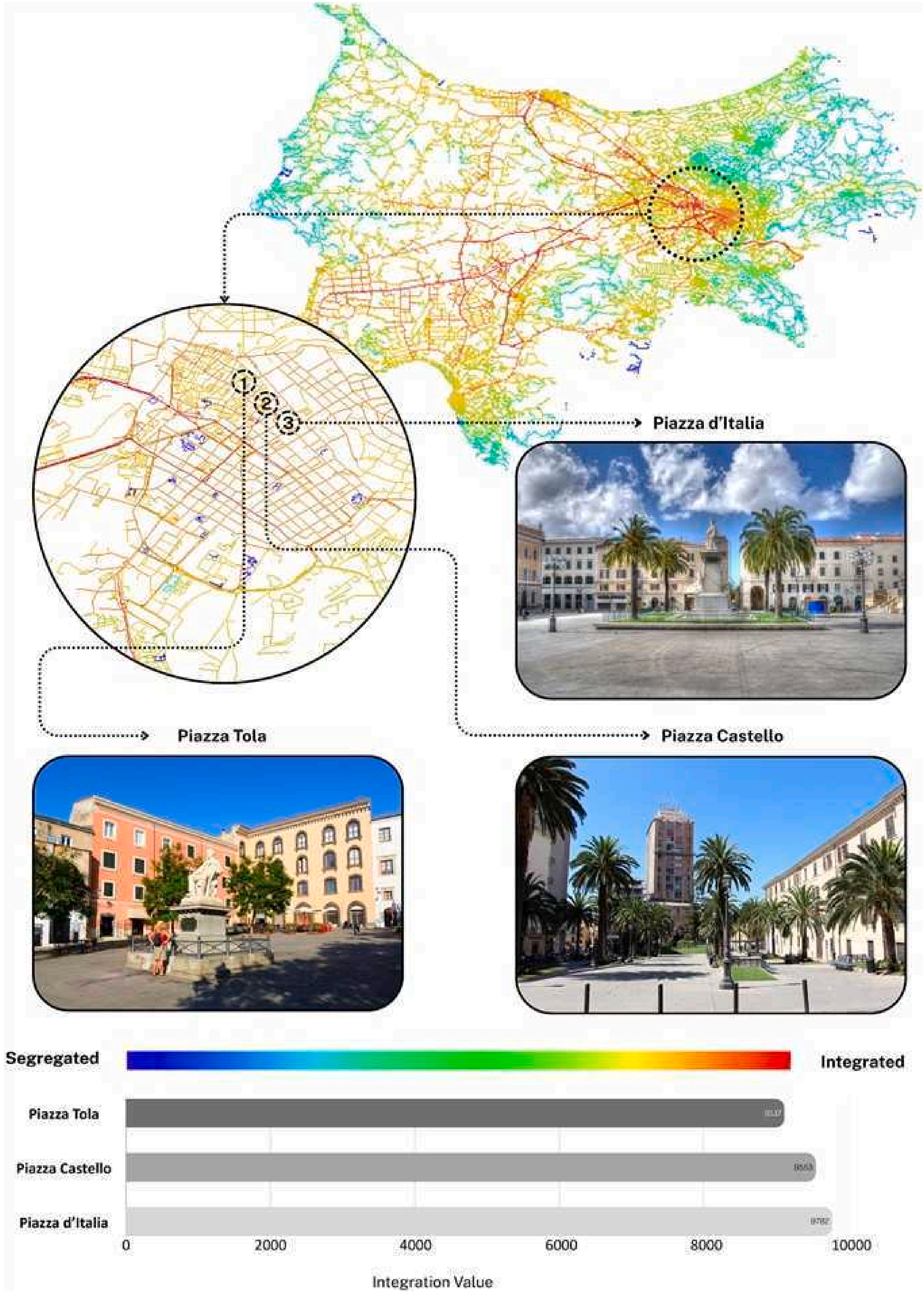


**Fig. 5.** Three identified main urban squares of Sassari based on the integration graph of spatial analysis using space syntax and the comparative quantitative chart of their integration values.

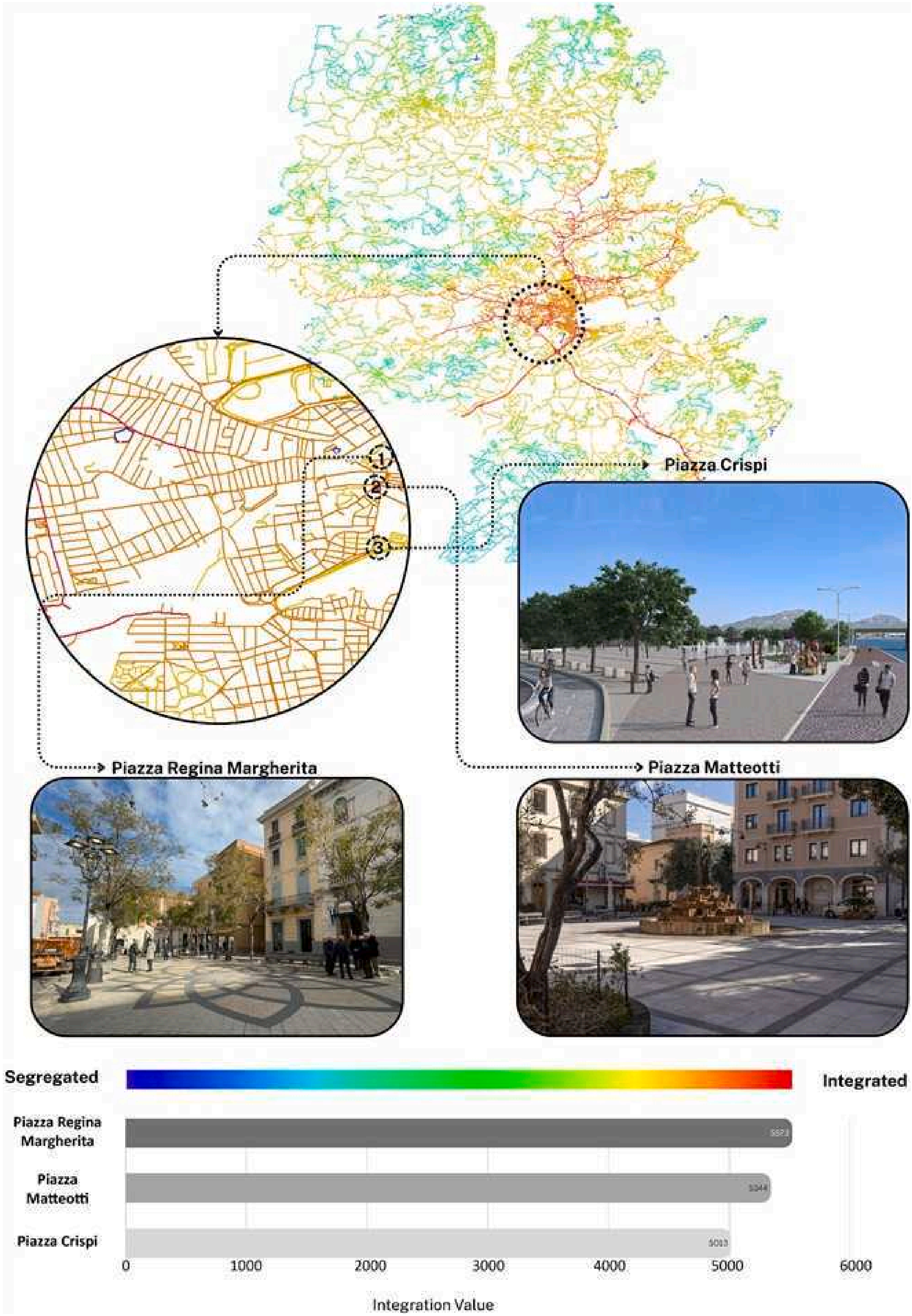


**Fig. 6.** Three identified main urban squares of Olbia based on the integration graph of spatial analysis using space syntax and the comparative quantitative chart of their integration values.

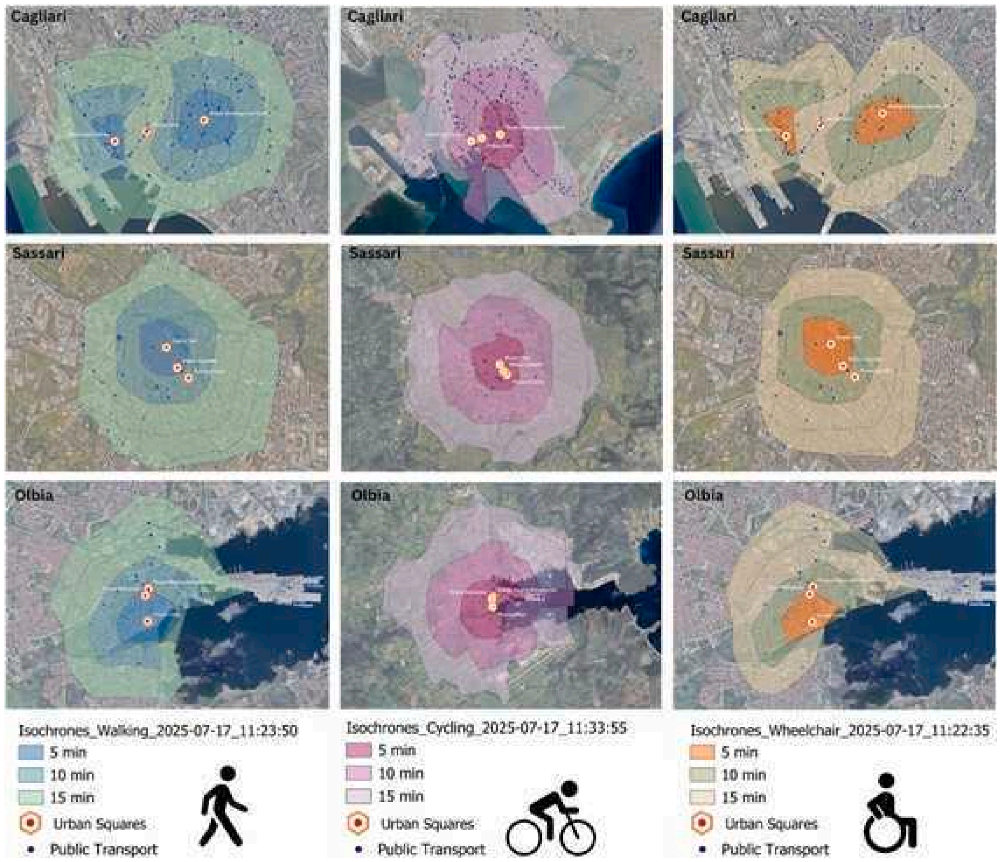


**Fig. 7.** Multimodal isochrone maps for urban squares in Cagliari, Sassari, and Olbia.

**Table 2**
Travel-time isochrone area coverage (km$^2$) across three mobility modes for selected urban squares in Sardinia.

| Urban squares | Travel time | Transport mode | Area (km$^2$) | Transport mode | Area (km$^2$) | Transport mode | Area (km$^2$) |
|---|---|---|---|---|---|---|---|
| Piazza Yenne | 5 | Foot-walking | 0.36 | Cycling-regular | 3.07 | Wheelchair | 0.29 |
| Piazza Yenne | 10 | Foot-walking | 1.01 | Cycling-regular | 14.48 | Wheelchair | 1.18 |
| Piazza Yenne | 15 | Foot-walking | 2.73 | Cycling-regular | 28.56 | Wheelchair | 2.51 |
| Piazza del Carmine | 5 | Foot-walking | 0.18 | Cycling-regular | 1.44 | Wheelchair | 0.15 |
| Piazza del Carmine | 10 | Foot-walking | 1.49 | Cycling-regular | 9.06 | Wheelchair | 0.83 |
| Piazza del Carmine | 15 | Foot-walking | 3.51 | Cycling-regular | 22.06 | Wheelchair | 1.75 |
| Piazza Giuseppe Garibaldi | 5 | Foot-walking | 0.39 | Cycling-regular | 3.14 | Wheelchair | 0.25 |
| Piazza Giuseppe Garibaldi | 10 | Foot-walking | 1.52 | Cycling-regular | 13.57 | Wheelchair | 0.99 |
| Piazza Giuseppe Garibaldi | 15 | Foot-walking | 3.51 | Cycling-regular | 27.85 | Wheelchair | 2.56 |
| Piazza d'Italia | 5 | Foot-walking | 0.35 | Cycling-regular | 4.43 | Wheelchair | 0.25 |
| Piazza d'Italia | 10 | Foot-walking | 1.55 | Cycling-regular | 17.12 | Wheelchair | 1.05 |
| Piazza d'Italia | 15 | Foot-walking | 3.62 | Cycling-regular | 33.94 | Wheelchair | 2.41 |
| Piazza Castello | 5 | Foot-walking | 0.38 | Cycling-regular | 4.48 | Wheelchair | 0.31 |
| Piazza Castello | 10 | Foot-walking | 1.35 | Cycling-regular | 18.3 | Wheelchair | 1.22 |
| Piazza Castello | 15 | Foot-walking | 3.34 | Cycling-regular | 35.89 | Wheelchair | 2.53 |
| Piazza Tola | 5 | Foot-walking | 0.32 | Cycling-regular | 3 | Wheelchair | 0.3 |
| Piazza Tola | 10 | Foot-walking | 1.44 | Cycling-regular | 16.21 | Wheelchair | 1.15 |
| Piazza Tola | 15 | Foot-walking | 2.97 | Cycling-regular | 36.36 | Wheelchair | 2.53 |
| Piazza Regina Margherita | 5 | Foot-walking | 0.4 | Cycling-regular | 3.82 | Wheelchair | 0.35 |
| Piazza Regina Margherita | 10 | Foot-walking | 1.34 | Cycling-regular | 17.92 | Wheelchair | 1.11 |
| Piazza Regina Margherita | 15 | Foot-walking | 2.8 | Cycling-regular | 37.2 | Wheelchair | 2.17 |
| Piazza Matteotti | 5 | Foot-walking | 0.36 | Cycling-regular | 3.83 | Wheelchair | 0.3 |
| Piazza Matteotti | 10 | Foot-walking | 1.16 | Cycling-regular | 17.68 | Wheelchair | 1.02 |
| Piazza Matteotti | 15 | Foot-walking | 2.74 | Cycling-regular | 36.09 | Wheelchair | 2 |
| Piazza Crispi | 5 | Foot-walking | 0.31 | Cycling-regular | 4.08 | Wheelchair | 0.22 |
| Piazza Crispi | 10 | Foot-walking | 1.46 | Cycling-regular | 17.41 | Wheelchair | 0.76 |
| Piazza Crispi | 15 | Foot-walking | 3.48 | Cycling-regular | 35.86 | Wheelchair | 1.77 |

Among walking isochrones, Piazza del Carmine records the highest stop density, particularly at 15 min, followed by Piazza Giuseppe Garibaldi and Piazza Yenne. Conversely, Piazza Crispi records the lowest densities, including no stops within the 5-minute walking catchment. Sassari's squares show generally moderate densities, typically higher than Olbia's but lower than those observed in Cagliari. In cycling mode, stop density values increase across all sites due to expanded catchment areas. Piazza Giuseppe Garibaldi again records the highest density values, followed

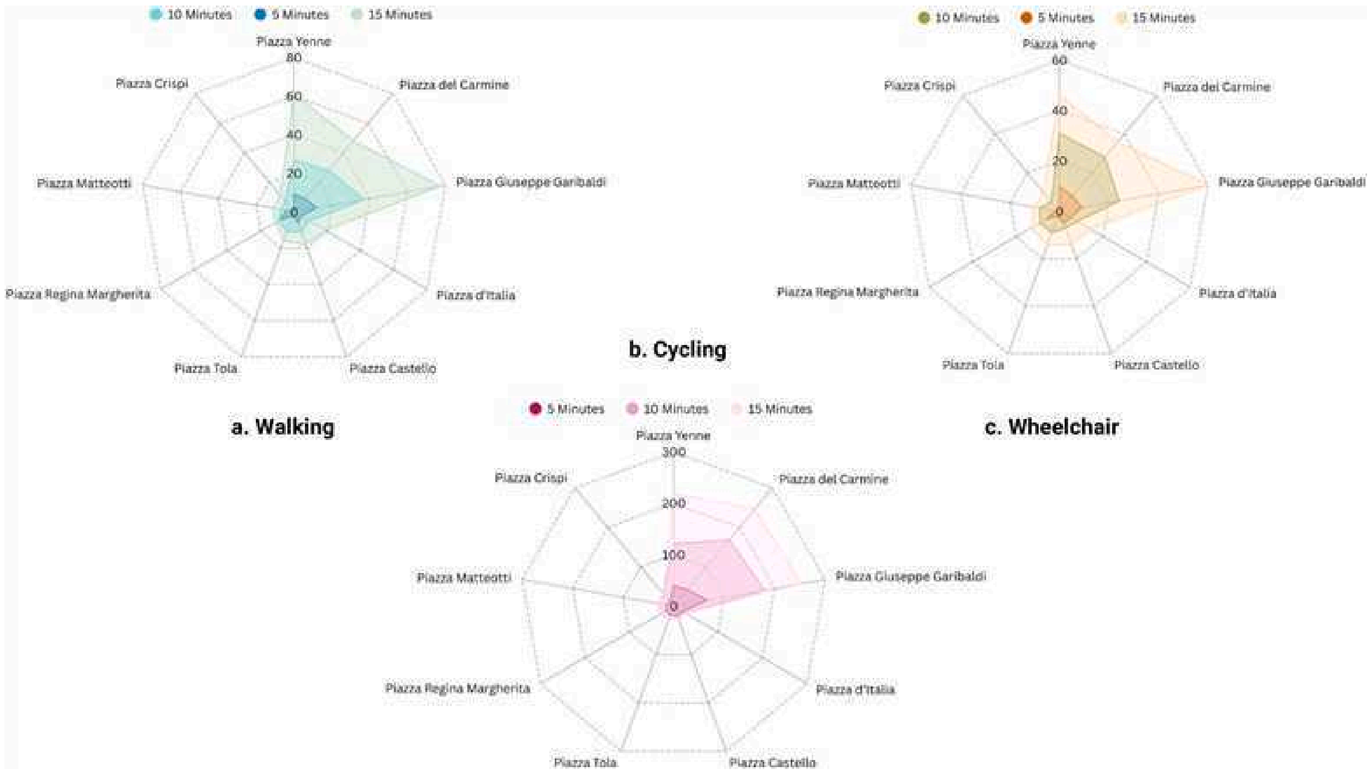


**Fig. 8.** Radar charts comparing number of public transport stops across nine urban squares in three cities at different isochrone thresholds and different modes of transportation (a. Walking, b. Cycling and c. Wheelchair).

closely by Piazza del Carmine and Piazza Yenne. In Sassari, Piazza Castello and Piazza Tola fall within the mid-range, with Piazza d'Italia slightly lower. In Olbia, Piazza Crispi remains the lowest-density site, despite modest increases relative to walking. For wheelchair mode, Piazza del Carmine records the highest bus stop density across time thresholds, with Piazza Yenne and Piazza Giuseppe Garibaldi also showing relatively high values. Sassari's squares display lower density values compared with Cagliari, while Piazza Crispi again records the lowest densities, including no reachable stops at 50 min and limited improvements at longer thresholds. Across the three cities, the density patterns indicate notable spatial differences in public transport availability within accessible catchments, with stronger coverage in Cagliari, moderate conditions in Sassari, and weaker accessibility in Olbia—particularly around Piazza Crispi.

While the preceding analyses describe the operational accessibility of each square, they do not explain whether these accessibility patterns are associated with the underlying spatial configuration of the street network, which is elaborated in the next section.

### 3.6. Integrated analysis of configurational and operational accessibility

The previous sections examined operational accessibility by first quantifying the spatial extent of multimodal catchments and subsequently evaluating the availability of public transport services within those catchments. Building on these findings, this section integrates the configurational accessibility derived from space syntax analysis with the operational accessibility indicators to examine whether structurally integrated urban squares also demonstrate higher levels of operational accessibility. To facilitate the integration of the configurational and operational accessibility analyses, the indicators derived from the previous sections were consolidated into a single analytical dataset (Table 3).

Raw integration values obtained from the space syntax analysis were first normalized independently within each city using Min–Max normalization to preserve the internal configurational hierarchy while allowing comparison across the three urban systems. Operational accessibility was represented by the Modal Catchment Index (MCI), calculated as the ratio between the 15-minute wheelchair and walking isochrone areas, which quantifies the proportion of pedestrian accessibility that remains available to people with reduced mobility. In addition, Bus Stop Density (BSD) values extracted from the 15-minute wheelchair isochrones were included to represent the availability of public transport within the accessible catchment. Together, these indicators provide the quantitative basis for constructing the Morphological–Operational Accessibility Matrix.

Building upon Table 3, Fig. 10 synthesises these indicators by integrating normalized configurational accessibility (X-axis), operational accessibility represented by the Modal Catchment Index (MCI) (Y-axis), and normalized Bus Stop Density (BSD) to classify the accessibility profiles of the selected public squares. To facilitate interpretation, the matrix is divided into four quadrants using the mid-point of the normalized integration values (0.50) and the mean MCI value (0.72), producing four cofigurational–operational typologies representing different relationships between structural accessibility, operational accessibility, and public transport provision.

**Typology 1. High configurational–high operational accessibility:** Public squares located in this quadrant exhibit both strong structural accessibility and high operational accessibility, indicating that favourable street network configuration is generally accompanied by inclusive multimodal accessibility. Piazza Yenne represents the strongest example of this balanced condition, combining high configurational accessibility (0.67), the highest Modal Catchment Index (0.92), and a high level of public transport provision (BSD = 0.84). Piazza Giuseppe Garibaldi similarly demonstrates excellent overall performance, combining maximum configurational accessibility with a relatively high BSD (0.72), indicating that both the street network and transport infrastructure effectively support accessibility.

By contrast, Piazza Regina Margherita (BSD = 0.05), and Piazza

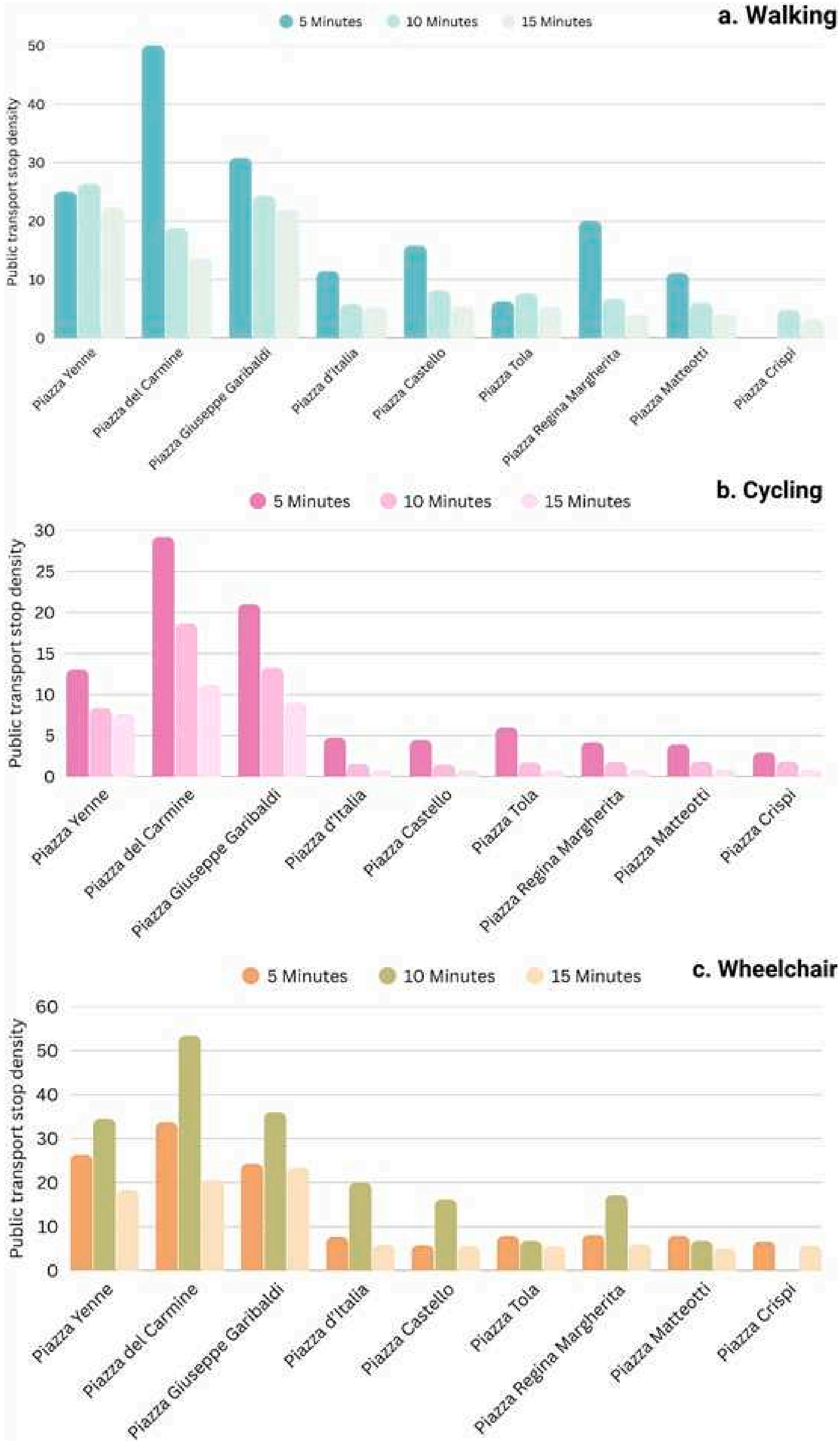


**Fig. 9.** Spatial distribution of transport stops accessible within 5-, 10-, and 15-minute isochrones across Sardinian public squares, grouped by travel mode: (a) walkable, (b) cycle-based, (c) wheelchair-friendly).

**Table 3**
Summary of the derived configurational and operational accessibility indicators used to construct the Configurational–Operational Accessibility Matrix.

| City | Urban square | Raw integration | Normalized integration (X) | MCI (Y) | Raw BSD | Normalized BSD |
|---|---|---|---|---|---|---|
| Cagliari | Piazza Giuseppe Garibaldi | 4243 | 1.000 | 0.729 | 18.33 | 0.722 |
| | Piazza Yenne | 3926 | 0.673 | 0.919 | 20.57 | 0.844 |
| | Piazza del Carmine | 3273 | 0.000 | 0.498 | 23.44 | 1.00 |
| Sassari | Piazza d'Italia | 9782 | 1.000 | 0.665 | 5.81 | 0.043 |
| | Piazza Castello | 9553 | 0.656 | 0.757 | 5.53 | 0.028 |
| | Piazza Tola | 9117 | 0.000 | 0.851 | 5.53 | 0.028 |
| Olbia | Piazza Regina Margherita | 5523 | 1.000 | 0.775 | 5.99 | 0.053 |
| | Piazza Matteotti | 5344 | 0.649 | 0.729 | 5.00 | 0.000 |
| | Piazza Crispi | 5013 | 0.000 | 0.508 | 5.65 | 0.035 |

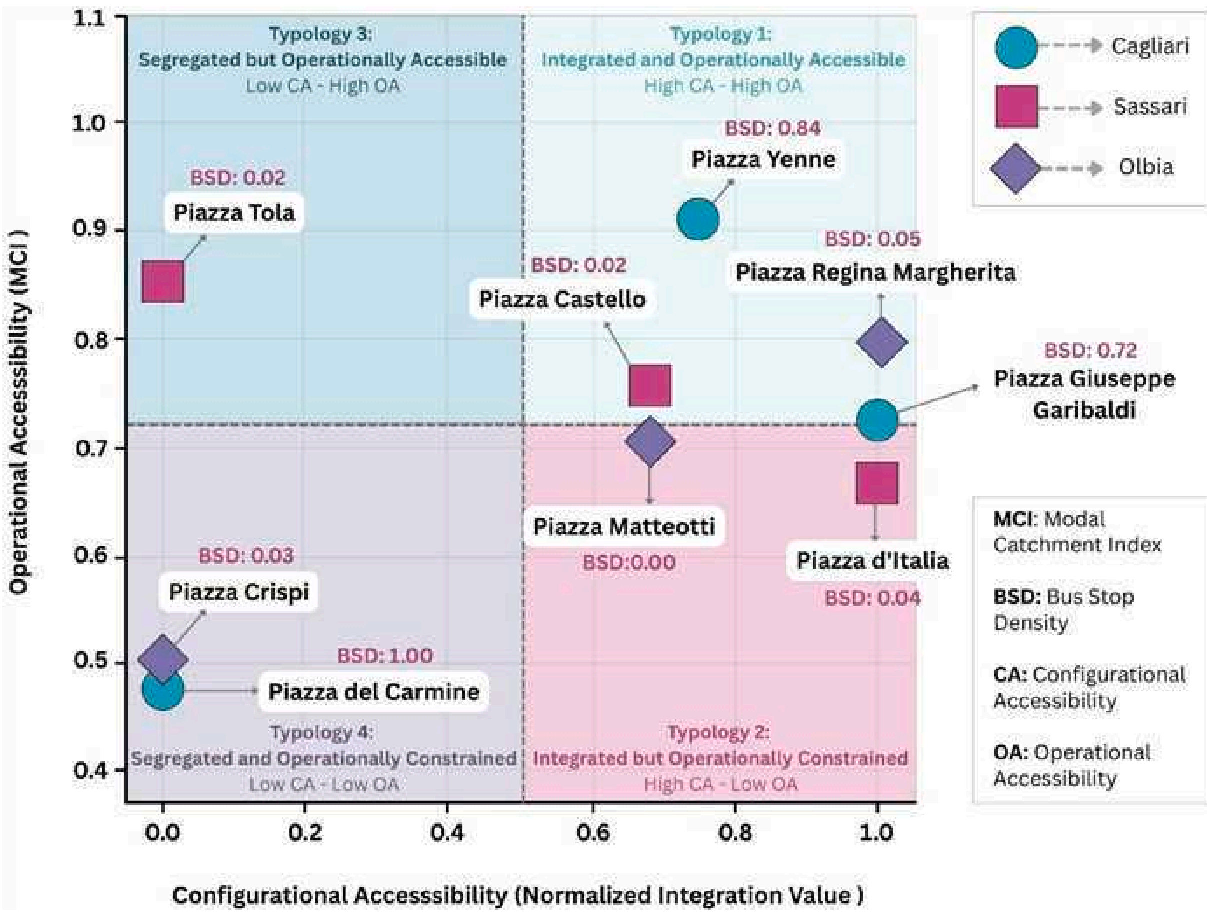


**Fig. 10.** Configurational–Operational Typology Matrix integrating normalized configurational accessibility (Space Syntax), Modal Catchment Index (MCI), and normalized wheelchair Bus Stop Density (BSD) for the selected urban public squares.

Castello (BSD = 0.02), although classified within the same typology because of their favourable MCI values, exhibit substantially lower public transport provision. These findings suggest that their overall accessibility is primarily supported by the street network and pedestrian routing rather than by dense public transport infrastructure. Consequently, increasing the availability of public transport services within their accessible catchment areas could further strengthen operational accessibility and improve multimodal access, particularly for users who depend on public transport.

**Typology 2. High configurational–low operational accessibility:** This quadrant contains public squares that are structurally well integrated within the urban street network but demonstrate comparatively weaker operational accessibility. Piazza d'Italia represents this condition. Although it records the highest configurational accessibility within Sassari, its Modal Catchment Index remains below the operational threshold (0.665), indicating that favourable urban configuration alone is insufficient to ensure inclusive accessibility. Furthermore, its low BSD value (0.04) suggests that public transport provision is present but not sufficiently extensive to compensate for the reduced wheelchair accessibility. These findings indicate that improving pedestrian infrastructure and expanding public transport accessibility within the surrounding catchment could help transform structural accessibility into effective operational accessibility.

**Typology 3. Low configurational–high operational accessibility:** This quadrant includes public squares that display relatively limited configurational accessibility but comparatively favourable operational accessibility. Piazza Tola represents this condition, achieving one of the highest Modal Catchment Index values (0.85) despite recording the lowest configurational accessibility within Sassari. Nevertheless, its BSD remains substantially low (0.02), indicating that the observed operational performance is primarily supported by favourable routing conditions rather than by strong public transport provision. Improving the density and distribution of nearby bus stops could therefore enhance multimodal accessibility while compensating for the square's structurally less integrated urban location.

**Typology 4. Low configurational–low operational accessibility:** This category represents locations where both configurational accessibility and operational accessibility are limited. Piazza Crispi shows the weakest overall accessibility performance, combining the lowest configurational integration with a low Modal Catchment Index (0.51) and the lowest wheelchair Bus Stop Density in the study (BSD = 0.03). This convergence of poor street network integration, limited inclusive accessibility, and very weak public transport provision identifies Piazza Crispi as the most disadvantaged public square within the analysed cases.

Piazza del Carmine also falls within this typology. Although it benefits from the highest Bus Stop Density in the study (BSD = 1.00), its low configurational accessibility and reduced Modal Catchment Index (0.50) indicate that abundant public transport infrastructure alone cannot fully overcome deficiencies in the surrounding street network or local accessibility conditions. This finding illustrates that improvements in transport provision should be accompanied by interventions that enhance spatial accessibility and inclusive pedestrian movement.

Overall, the typology matrix demonstrates that configurational accessibility, operational accessibility, and public transport provision represent complementary but independent dimensions of urban accessibility. While highly integrated public squares generally tend to exhibit stronger operational accessibility, the variation in Bus Stop Density reveals that similar configurational and operational performance may still be supported by markedly different levels of public transport provision. Likewise, abundant transport infrastructure alone does not necessarily compensate for poor spatial configuration or limited inclusive routing, as illustrated by Piazza del Carmine. These findings demonstrate that equitable accessibility depends on the combined performance of urban morphology, multimodal movement conditions, and public transport availability. Evaluating public spaces through only one of these dimensions risks overlooking hidden accessibility inequalities. Integrating configurational, operational, and transport-based indicators therefore provides a more holistic framework for identifying priority intervention areas and supporting evidence-based planning strategies aimed at improving equitable access to urban public spaces.

## 4. Discussion

This study advances the understanding of accessibility to urban public spaces (Hansen, 1959) by demonstrating that accessibility is not solely a function of urban spatial configuration or transport provision individually but rather emerges from the interaction between configurational accessibility and operational accessibility. While previous studies have generally assessed these dimensions independently, the proposed Configurational–Operational Accessibility Framework integrates them into a unified analytical approach capable of distinguishing different accessibility profiles and revealing spatial mismatches that would remain hidden when applying either method in isolation.

Unlike conventional accessibility assessments that primarily identify where accessibility is high or low, the proposed framework explains why accessibility deficiencies occur. By combining normalized configurational accessibility derived from space syntax, the Modal Catchment Index (MCI), and Bus Stop Density (BSD), the framework classifies public squares into four planning-oriented typologies (Fig. 10). The corresponding planning implications of each typology are summarized in Table 4, transforming the analytical results into a practical decision-support tool for urban planning.

The typological analysis clearly demonstrates that high configurational accessibility alone is insufficient to guarantee inclusive accessibility. Squares classified within Typology 2 ("Integrated but Operationally Constrained") illustrate this structural paradox. Although these locations occupy highly integrated positions within the street network, their operational accessibility remains comparatively low because inclusive routes fail to fully exploit their structural advantages. This finding suggests that movement potential embedded within urban morphology does not automatically translate into equitable accessibility outcomes, particularly for people with reduced mobility. Consequently, improving accessibility in these locations requires interventions targeting pedestrian infrastructure and barrier-free mobility rather than solely increasing transport services (Table 4).

This integrated analytical approach addresses a critical gap in the literature, as urban public squares have received comparatively limited attention in accessibility research despite their important social and functional roles. Previous studies have primarily focused on accessibility to transport infrastructure (Sharma & Patil, 2024; Cai et al., 2024; Wan

**Table 4**
Planning interpretation of the Configurational–Operational Typology Matrix, summarising the accessibility characteristics, principal constraints, and priority planning interventions for each typology identified across the selected urban squares.

| Typology | Public squares | Accessibility characteristics | Main accessibility challenge | Recommended planning response |
|---|---|---|---|---|
| **Typology 1** Integrated and Operationally Accessible | Piazza Yenne, Piazza Regina Margherita | Strong spatial integration and high operational accessibility. Users can reach the square through relatively inclusive routes. | Although structurally successful, some squares (e.g., Piazza Regina Margherita) exhibit relatively low Bus Stop Density (BSD), indicating that public transport provision has not fully matched their accessibility potential. | Preserve existing spatial connectivity while strengthening public transport services, increasing bus stop provision where appropriate, and maintaining barrier-free pedestrian infrastructure. |
| **Typology 2** Integrated but Operationally Constrained | Piazza Giuseppe Garibaldi, Piazza d'Italia, Piazza Matteotti | Highly integrated within the street network but wheelchair accessibility remains limited because operational accessibility is reduced. | Spatial centrality is not translated into inclusive accessibility. Physical barriers, inaccessible pedestrian routes and insufficient inclusive infrastructure reduce operational performance. Increasing bus stops alone cannot resolve the problem. | Prioritise removal of physical barriers, improve sidewalks, crossings, ramps and accessible routes. Transport improvements should complement—not replace—infrastructure upgrades. |
| **Typology 3** Segregated but Operationally Accessible | Piazza Castello, Piazza Tola | Despite relatively weak configurational accessibility, inclusive operational accessibility remains relatively high. | The main limitation is structural segregation within the urban network rather than local accessibility conditions. Piazza Castello also exhibits relatively low BSD, suggesting that transport services could still be improved. | Improve strategic pedestrian and cycling connections linking these squares to the wider urban network, while selectively increasing public transport provision where service coverage remains limited. |
| **Typology 4** Segregated and Operationally Constrained | Piazza del Carmine, Piazza Crispi | Poor performance in both configurational and operational accessibility. | Piazza Crispi suffers from deficiencies across all dimensions. Piazza del Carmine demonstrates that even very high BSD cannot compensate for poor configurational accessibility and limited inclusive routes. | Apply comprehensive regeneration strategies combining public realm redesign, accessible route improvements, enhanced multimodal connectivity and urban integration. Additional bus stops alone are unlikely to substantially improve accessibility. |

& Titheridge, 2024), green spaces (He et al., 2024; Wang et al., 2021; Zhao & Gong, 2024; Sun et al., 2025), healthcare services (Chao et al., 2024; Gu et al., 2023; Su et al., 2024), and educational facilities (Pizzol et al., 2021; Sharma & Patil, 2022; Wang et al., 2021). Only a limited number of studies focus on how social behaviours unfold within the spatial configuration of urban squares through empirical validation (Askarizad, Lamíquiz-Daudén, et al., 2025; Dastoum, Alam, et al., 2026). In contrast, this study specifically examines accessibility to urban public squares as distinct spatial entities, recognising their role as focal points for social interaction, civic activity, and everyday mobility. By applying space syntax analysis alongside multimodal isochrone mapping, the research provides a spatially explicit framework for evaluating how urban form and transport accessibility interact to shape access to these socially significant public spaces.

The findings reinforce the established consensus that urban accessibility depends on both the spatial distribution of opportunities and the effort required to reach them (Garau et al., 2026; Mouratidis, 2026; Tomasiello et al., 2023; Verma & Ukkusuri, 2025). From the methodological standpoint, prior studies mostly applied isochrone analysis within the framework of 15-minute city concept (Kłos et al., 2026; Rodrigues et al., 2026; Surmiková & Džupka, 2026). On the other hand, this study complements the particular focus on configurational accessibility as the primary stimulator of efficient urban accessibility (Askarizad et al., 2024; Lamíquiz & López-Domínguez, 2015; Torrisi et al., 2026). Although very limited studies have attempted to combine isochrone analysis with space syntax (Megahed et al., 2025), the present study extends this concept by demonstrating that configurational accessibility and operational accessibility function as complementary rather than interchangeable dimensions. It contributes to the literature by showing that urban spaces displaying similar levels of configurational accessibility may experience substantially different levels of operational accessibility because of differences in infrastructure quality, transport provision, and barrier-free routing conditions.

From an international perspective, the proposed framework contributes to the growing body of research advocating multidimensional accessibility assessment in contemporary cities (Bittencourt & Giannotti, 2021; Chang & Liao, 2011; Van Heerden et al., 2022). Although developed using Sardinian case studies, the methodology itself is not context-dependent. Because it relies on commonly available spatial datasets, space syntax analysis, network-based isochrones, and public transport information, it can be readily transferred to other cities where planners seek to evaluate accessibility to public spaces from both structural and operational perspectives. The normalization procedures introduced in this study further facilitate comparative analyses across urban systems with different morphological characteristics while preserving their internal spatial hierarchies.

The insular context of Sardinia provides an especially valuable testing ground because island cities frequently experience fragmented transport networks, uneven infrastructure investment, and geographical constraints that intensify accessibility inequalities (Caschili et al., 2015; Gambacurta, 2026; Dastoum et al., 2026). Nevertheless, the structural relationships identified through the proposed framework are not unique to insular environments. Similar mismatches between configurational accessibility and operational accessibility are likely to occur in many medium-sized cities where urban morphology and transport investment have evolved independently. Consequently, the framework offers wider relevance for supporting equitable accessibility planning beyond the specific context of Sardinia.

From a planning perspective, the principal contribution of the study lies in demonstrating that different accessibility problems require different planning responses rather than uniform interventions. As summarized in Table 4, Typology 1 primarily requires preservation of existing accessibility conditions together with targeted improvements to public transport provision. Typology 2 should prioritise barrier removal, pedestrian infrastructure upgrades, and improvements to inclusive mobility rather than simply increasing the number of bus stops. Typology 3 requires stronger integration with the wider street network while maintaining existing operational accessibility. Finally, Typology 4 demands comprehensive regeneration strategies combining improvements to urban connectivity, inclusive infrastructure, and multimodal transport accessibility. This typology-based interpretation therefore provides planners with a practical framework for prioritising interventions according to the underlying causes of accessibility deficiencies rather than their symptoms.

Overall, the study demonstrates that equitable accessibility cannot be understood through configurational analysis or transport accessibility assessment alone. Instead, accessibility should be interpreted as the product of interactions between urban morphology, mobility infrastructure, and inclusive routing conditions. By translating these interactions into a planning-oriented typological framework (Fig. 10 and Table 4), the study moves beyond methodological integration to provide an operational decision-support approach capable of identifying not only where accessibility inequalities exist, but also why they occur and how they can be addressed through targeted planning interventions.

### 4.1. Implications for policy and planning

Building upon the integrated analytical framework developed in this study, the following planning recommendations translate the identified accessibility patterns into practical interventions for regional and insular cities. The findings of this study demonstrate the importance of adopting multidimensional accessibility assessments when planning urban public spaces. Rather than relying solely on measures of spatial centrality or transport provision, planners should evaluate accessibility through the combined consideration of urban configuration, inclusive mobility, and public transport accessibility. Such an approach enables a more comprehensive understanding of accessibility inequalities and supports the identification of interventions that address their underlying causes rather than their observable symptoms. Beyond spatial and infrastructural assessment, participatory processes can further support the identification of context-specific barriers and priorities, contributing to the development of more responsive strategies for improving urban walkability (Scorza et al., 2021).

The proposed Configurational–Operational Accessibility Framework offers a practical decision-support tool that can assist municipalities in prioritising investments according to the specific accessibility challenges of individual public spaces. By distinguishing between configurational and operational accessibility, the framework enables planners to determine whether accessibility improvements should focus on barrier-free infrastructure, pedestrian and cycling connectivity, public transport provision, or broader urban regeneration strategies. This targeted approach can improve the efficiency of public investment while supporting more equitable and inclusive urban environments.

The methodology is particularly relevant for regional and insular cities, where fragmented transport networks and uneven infrastructure provision frequently create spatial disparities in access to public spaces. However, because the framework relies on widely available spatial datasets and open-source analytical tools, it is readily transferable to other urban contexts. Its application can support evidence-based planning, accessibility auditing, and the development of inclusive mobility policies aligned with broader sustainable urban development objectives, including the Sustainable Development Goals, the New Urban Agenda, and the European Union's accessibility and social inclusion strategies.

### 4.2. Research limitation and future research orientation

Despite its contributions, this study has several limitations that should be acknowledged. First, the proposed Configurational–Operational Accessibility Framework evaluates accessibility from a spatial perspective and therefore does not capture how public spaces are actually used by different population groups. Future studies could complement the present framework with behavioural observations, such as gate counts, behaviour mapping, GPS tracking or digital twin platforms, to examine how the identified accessibility typologies relate to patterns of public life and social interaction. Second, the operational accessibility assessment was intentionally centred on wheelchair accessibility through the Modal Catchment Index (MCI), as this mode is likely to represent the most significant mobility constraints and may therefore provide a highly rigorous test of inclusive accessibility. Future research may extend the framework by incorporating additional mobility indicators or multimodal composite indices to examine accessibility from a broader range of user perspectives.

Furthermore, the public transport analysis was limited to the spatial distribution and density of bus stops and did not account for service frequency, timetable reliability, or network performance due to the lack of general transit feed specification data. In addition, although intra-city Min–Max normalization enabled comparison of configurational accessibility across independent urban systems, future research should validate the proposed framework using larger datasets and additional cities with different urban morphologies. Finally, while this study focused on urban public squares, the methodology is transferable and could be applied to other public facilities, such as parks, schools, healthcare centres, and transport hubs, to further evaluate its applicability in diverse planning contexts.

## 5. Conclusion

This study investigated the accessibility of urban public squares in three Sardinian cities by examining the relationship between urban spatial configuration, multimodal accessibility, and public transport provision. Rather than considering accessibility as a purely spatial or transport-based attribute, the research demonstrated that equitable access emerges from the interaction between configurational conditions, mobility constraints, and infrastructural support. By integrating Space Syntax analysis, multimodal isochrone mapping, and public transport accessibility assessment, the study developed a Configurational–Operational Accessibility Framework capable of revealing accessibility disparities that may remain hidden when individual indicators are considered separately.

The findings demonstrate that spatial configuration provides important structural advantages for accessibility, as highly integrated squares generally benefit from wider catchment areas and stronger connectivity within the urban network. However, the results also challenge the assumption that spatial centrality automatically produces inclusive accessibility. The identified mismatches between configurational accessibility, wheelchair accessibility, and public transport availability reveal that central locations may still exclude vulnerable users when inclusive infrastructure and mobility conditions are insufficient. This highlights the need to move beyond conventional accessibility assessments based solely on proximity or network centrality and to consider whether accessibility advantages are equally experienced by different user groups.

The proposed Configurational–Operational Accessibility Framework contributes to accessibility research by providing a diagnostic approach for identifying the underlying causes of accessibility inequality. Instead of prescribing universal solutions, the framework enables planners to distinguish whether accessibility limitations originate from spatial configuration, mobility barriers, or insufficient transport provision. This distinction is particularly important because improving accessibility does not always require increasing transport infrastructure; in some contexts, targeted improvements to pedestrian connectivity, barrier-free design, or spatial integration may provide more effective solutions. Therefore, accessibility interventions should be tailored to the specific characteristics of each urban context rather than relying on standardized strategies.

From a planning perspective, the findings demonstrate the importance of integrating spatial analysis into inclusive urban decision-making processes. In regional and insular cities, where geographical constraints and uneven infrastructure investment can intensify accessibility disparities, understanding the relationship between urban morphology and mobility systems is essential for promoting equitable public spaces. The proposed framework offers a transferable basis for identifying priority areas, evaluating accessibility conditions, and supporting evidence-based interventions aimed at improving access for diverse population groups.

Although this research focuses on Sardinian cities, its implications extend to other regional, peripheral, and geographically constrained urban environments facing similar challenges of fragmented mobility and unequal accessibility. By demonstrating that inclusive accessibility depends not only on where public spaces are located but also on how different users can reach and experience them, this study contributes to a broader understanding of spatial equity and supports the development of more inclusive and socially sustainable urban planning practices.

## CRediT authorship contribution statement

**Chiara Garau:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition. **Mana Dastoum:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Reza Askarizad:** Writing – review & editing, Validation, Software, Methodology, Investigation, Formal analysis, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This study was supported by the project "RAMÉ RegCITY: spatial analyses foR A sMartest and happiEst Region/CITY". This study was also partially supported by the MUR through two projects, (1) SMART3R-FLITS: SMART Transport for Travellers and Freight Logistics Integration Towards Sustainability" (Project protocol: 2022J38SR9; CUP Code: F53D23005630006) and (2) MOVING StEPS: MOVING from Street Experiments to adaptive Planned Solutions (Project protocol: 2022BLK9TS; CUP Code: F53D23005550006), both financed by the PRIN 2022 (Research Projects of National Relevance) program, funded by the European Union—NextGenerationEU. This study was also partially supported by the Ecosystem of Innovation for Next Generation Sardinia (e.INS) and received funding from the European Union NextGenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.5 – ECS00000038). In particular, the 'Materials and methods' was funded by eINS. This study reflects only the authors' views and opinions, and neither the European Union nor the European Commission can be considered responsible for them. **Authors' Contribution:** This paper is the result of the joint work of the authors. The 'Abstract', 'Results' (with sub-paragraphs), and 'Discussion' (with sub-paragraphs) were written jointly by the authors. CG wrote 'Introduction', MD wrote Section 2.2 'Spatial analysis of multimodal accessibility using QGIS (operational accessibility)', Section 2.3 'Integrated analytical framework for configurational and operational accessibility', and 'Conclusion'. RA wrote the introductory part of the 'Material and Methods' section, together with Section 2.1 'Morphological analysis using space syntax (configurational accessibility)' and Section 2.4 'Study areas'. The paper was coordinated and supervised by CG.

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

## Data availability

Data will be made available on request.

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