Urban Planning
2025 • Volume 10 • Article 9703
https://doi.org/10.17645/up.9703

ARTICLE

Open Access Journal

Reclaiming Urban Spaces: A Systemic Approach to Integrated Pedestrian-Centric City Design in Rio de Janeiro

Carlo Andrea Biraghi [1], Hadi Mohammad Zadeh [1], Andrea Bruschi [2], and Massimo Tadi [1]

[1] Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Italy
[2] Sistemi per la Mobilità, MM, Italy

Correspondence: Carlo Andrea Biraghi (carloandrea.biraghi@polimi.it)

Submitted: 25 November 2024 **Accepted:** 13 February 2025 **Published:** 4 June 2025

Issue: This article is part of the issue "Walkability: From Spatial Analytics to Urban Coding and Actual Walking" edited by Elek Pafka (University of Melbourne) and Carlo Andrea Biraghi (Politecnico di Milano), fully open access at https://doi.org/10.17645/up.i427

Abstract

Quality public spaces, especially pedestrian areas, play an essential role in cities. Communities gather in these spaces and benefit from the proximity to activities in a safe and car-free environment. Pedestrian areas can have greenery, which helps address the issues raised by climate change. Repurposing existing roads is a priority in many cities worldwide whose aim is to improve their social and environmental performance. This study presents a systemic, data-based approach that supports the transition from the current pervasive car-based mobility model to a people-centric, pedestrian-based one. This transformative model leverages the structural properties of urban systems to reconfigure streets as integral components of a comprehensive strategy aimed at mitigating the effects of climate change. Image segmentation is used to assess the presence of people in the streets. The numerical evidence provided by metrics and indicators is complemented by visual evidence from local-scale maps. The proposed method is tested on a portion of Bairro Cidade Nova in Rio de Janeiro within the framework of the Integrated and Sustainable Urban Regeneration Milan–Rio (REMIRIO) project, a city-to-city cooperation project between Milan (Italy) and Rio de Janeiro (Brazil) funded by the European Union which aims to implement pilot nature-based solutions to address local environmental issues such as flooding and overheating. In particular, five North–South streets are compared to define customised pedestrianisation interventions within a more comprehensive super-block strategy with the aim of improving the continuity of the existing green system and the ecosystem services. This precise network diagnostic process can be easily transferred to any urban system.

Keywords

pedestrian-centric design; Rio de Janeiro; space syntax; urban mobility

1. Introduction

As climate change intensifies, cities play a critical role in addressing its challenges. Urban life significantly contributes to the global carbon footprint, and phenomena like the urban heat island effect exacerbate environmental risks such as flooding, air pollution, and extreme temperatures (Oke et al., 2017; Santamouris, 2015). At the same time, cities hold great potential to develop sustainable, climate-responsive solutions. Through thoughtful planning and design, urban centres can reduce emissions, manage risks, and foster resilient ecosystems, positioning themselves as both frontlines of climate adaptation and testing grounds for innovative environmental strategies.

A critical component of this transformation lies in the design and use of public spaces, especially walkways. As urbanisation accelerates globally, the importance of these spaces has become increasingly evident, not only as connectors between places but as fundamental elements for the creation of sustainable, vibrant urban environments (Forsyth & Southworth, 2008; Gehl, 2011). Walkability has emerged as a key factor in fostering cities that are both liveable and resilient. Well-designed pedestrian areas promote non-motorised mobility while reducing reliance on private vehicles, the social cost (Gössling et al., 2019), and the environmental impacts of urban sprawl. These spaces offer multiple benefits, from enhancing public health and encouraging social interaction to supporting local economies and strengthening civic engagement. The built environment in walkable neighbourhoods encourages movement, interaction with surroundings, and community life, contributing to a stronger sense of place and identity.

Beyond their social and economic value, walkways and public spaces are also critical for a sustainable environment. They can help mitigate urban heat islands when designed with greenery and trees, while also improving air quality and facilitating better management of stormwater (Bowler et al., 2010; Nowak & Dwyer, 2007). When integrated with green infrastructure such as parks, greenways, and tree-lined streets, pedestrian areas provide not only aesthetic and recreational value but also ecological benefits that help cities adapt to climate change. As the recognition of these benefits grows, cities are increasingly prioritising pedestrian-friendly planning. However, achieving walkability requires strategic thinking, thoughtful design, and a commitment to ensuring that these spaces are accessible, interconnected, and inclusive for all urban residents.

The transition to more pedestrian-friendly cities involves rethinking urban mobility and the spaces that support it. Pedestrianisation—converting streets and areas to prioritise pedestrian use, often alongside other forms of non-motorised mobility—has emerged as a key strategy for cities aiming to reduce their environmental impact, improve public health, and foster vibrant, equitable communities (Litman, 2003). This concept encompasses varying degrees of pedestrian priority, from fully car-free zones to shared spaces where pedestrians coexist with limited vehicular access. Beyond spatial configuration, the success of pedestrianisation often hinges on land use planning, as the activities and amenities present in these spaces significantly influence their vibrancy and utility. However, the decision of when and where to prioritise pedestrianisation requires a nuanced understanding of urban dynamics, such as the density of urban areas, existing infrastructure, and socio-economic conditions. In areas with overwhelming traffic congestion or pollution, pedestrianisation can be transformative, but its success depends on a balanced approach that addresses competing needs such as maintaining access to services, supporting local businesses, and improving public transportation links to mention a few.

This article situates itself within the Integrated and Sustainable Urban Regeneration Milan–Rio (REMIRIO) project in Rio de Janeiro, which seeks to transform a local area into a more pedestrian-friendly environment. As part of the European Union's Partnership for Sustainable Cities programme, REMIRIO represents the cooperation between the municipalities of Milan and Rio de Janeiro. This initiative seeks to establish common visions and strategies to address the 2030 Agenda for Sustainable Development and the goals outlined by the C40 Cities Climate Leadership Group. The project aims to develop an Integrated Sustainable Urban Regeneration Plan (ISURP) for the Vila Operária Salvador de Sá area, emphasising environmental sustainability, social inclusion, and economic growth. Vila Operária is a historic housing district where architectural charm is coupled with maintenance and preservation issues. The neighbourhood is vulnerable to the urban heat island effect (de Faria Peres et al., 2018) and to flooding (Nunes et al., 2020). Therefore it presents an opportunity to explore strategies to mitigate these challenges through urban design interventions and green infrastructure. Moreover, its socio-economic complexity underscores the importance of addressing equity concerns in urban regeneration initiatives.

The project follows a diagnosis-based approach adopting the integrated modification methodology (IMM) to identify malfunctioning subsystems within the local urban structure. IMM (Mohammad Zadeh et al., 2024) is a comprehensive procedure that uses various scientific techniques to analyse and evaluate the built environment at multiple scales. IMM is characterised by an integrative and system-oriented approach, a focus on sustainability, the use of data-driven methods, and alignment with global sustainable development goals (SDGs). The methodology is structured in phases, starting with a diagnostic phase based on geospatial data, leading to the design and optimisation of solutions.

The aim of this article is to explore the challenges and opportunities of pedestrianisation in urban contexts, using the REMIRIO project as a lens to investigate how different urban dimensions interplay to influence walkability and environmental resilience. Specifically, the article proposes a simplified, flexible, and data-based multi-criteria approach to evaluate the suitability of a street link to various types of pedestrianisation interventions. The determination of a set of monitoring and evaluating criteria with an impact on the quality of urban space aligns with the work of Ewing and Clemente (2013). This article introduces measures obtained with GIS-based simulations on urban systems linked to vegetation and public transport. As a result, this study contributes to the broader discourse on sustainable urban design and its role in fostering liveable, resilient cities. The proposed approach has been tested on five neighbouring streets involved in a larger strategy that aims at improving the continuity of the green system in the area. This study is part of a participatory process based on a continuous feedback mechanism for the iterative refinement of proposed interventions based on community input, gathered during workshops and consultations.

2. Literature Review

Although pedestrianisation has gained recent prominence as an urban design strategy, historical evidence proves that cities were inherently pedestrian-oriented before the advent of automobiles. In classical antiquity and pre-industrial urban contexts, streets were primarily designed for walking and for transportation with carts, carriages, and other modes of transport (Fruin, 1971; Hass-Klau, 2014). This indicates that non-motorised mobility is not a merely contemporary environmental strategy to control traffic and reduce pollution. Rather, the natural flow of pedestrians within urban spaces is a fundamental aspect of the human–environment relationship, offering numerous benefits (Diaconu, 2011). In their 2016 review, Nikhil and Neetishree Soni classified these benefits into five categories: transportation, society, environment, economics, and health (Soni & Soni, 2016). However, to fully harness the potential of pedestrianisation in urban planning, transition strategies must be designed to engage the structural parameters that influence non-motorised mobility (Blaga, 2013); most significantly, carefully considering these parameters across different scales of urban form. Pedestrianisation, defined as the removal or restriction of vehicular traffic in favour of pedestrian use (Monheim, 1980), involves numerous overlapping criteria that can be broadly categorised into two phases: The first is the identification of areas with the highest potential for car limitation at the intermediate scale; the second is the application of encouraging design principles and supportive policies at the local scale (Nassar et al., 2018).

The literature reveals key factors promoting non-motorised mobility on meso and local scales. Among these, a minimal population density is widely recognised as essential for fostering a walkable environment at the intermediate urban scale. In one of the most influential studies of the 20th century, Newman and Kenworthy demonstrated a strong inverse relationship between population density and fuel consumption in urban areas (Newman & Kenworthy, 1989). Numerous other scholars have emphasised high density as a prerequisite for encouraging walking as a mode of travel (Kott & Eells, 2016; Oakes et al., 2007; Tanishita & van Wee, 2017). Dense areas naturally facilitate the concentration of diverse land uses within shorter distances, thereby increasing the likelihood of walking. Consequently, mixed-use development is frequently cited alongside density as a structural parameter critical to the success of pedestrianisation efforts (Carmona, 2015; Ewing et al., 2018; Mehta, 2014; Nakamura, 2016; Soni & Soni, 2016).

Although a dense urban fabric at the neighbourhood scale is essential for facilitating the transition to non-motorised mobility, it is not sufficient on its own. Over the past three decades, it has been well established that spatial configuration and network connectivity have direct and measurable effects on the dynamics of pedestrian movement and land-use patterns (Al-Sayed et al., 2014). In this context, space syntax is a widely referenced theoretical framework that enables the study of network qualities by providing measures for the evaluation of integration, metric distances, and angular choice (Hillier, 1996). While it is widely accepted that the metric distance between points of interest (POIs) significantly influences foot traffic (Sheng et al., 2021), numerous studies emphasise that the underlying topological structure of street patterns, rather than solely the scale of movement, plays a crucial role in determining pedestrian flow. Accordingly, Hillier and Lida (2005) advocate for synthetic methods that combine the evaluation of metric distance with topological distance, which is characterised by directional changes.

In their 2008 study, Peponis et al. (2008) examined the combined influence of geometric and topological properties on pedestrian movement. They confirmed that spatial cognition and function are fundamentally shaped by the topological interpretation of the network at intermediate scales, thus offering a more nuanced perspective than the traditional space syntax on metric and directional connectivity. As well as revealing movement patterns, they argued that these measures also help explain other attributes, such as density distribution and block size, which enhance the morphological understanding of street layouts and facilitate comparisons between different urban areas (Peponis et al., 2008).

In a more recent study, Duarte and Celani (2019) utilised topological measures to develop a framework aimed at enhancing walkability in urban streets through retrofitting. The authors integrated space syntax with shape grammar to create a design support method that facilitates the generation of urban street retrofitting scenarios.

While they affirm the importance of metric accessibility for ease of walking within specific distances, their proposed framework employs angular choice analyses conducted at varying radii to establish a hierarchical approach to identify which streets should be prioritised as non-motorised links.

Many scholars, including Jabbari et al. (2021), Jayasinghe et al. (2016), and Kubat et al. (2013), have emphasised the importance of considering both metric and directional accessibility in walking behaviour and their crucial roles in shaping pedestrianisation scenarios. Kubat et al. (2013) employ both metric and directional assessments to critique the official pedestrianisation choices in three historical zones in Istanbul. Their study provides valuable insights into effective pedestrianisation strategies, balancing urban design with functional needs to create more walkable environments.

While network configuration and overall connectivity at the neighbourhood scale provide the structural foundation for a successful non-motorised urban context, the execution of pedestrianisation on individual links is equally critical. As previously discussed, the second phase of an effective pedestrianisation project involves the implementation of policies, design principles, and strategies that encourage walking at both local and intermediate scales. Parajuli and Pojani (2018) concluded that, especially at the local level, the most persistent barriers to pedestrianisation tend to be political, institutional, and social, rather than technical or financial. Yassin (2019) advocates for tactical urbanism to address these barriers, especially in city centres. According to Lydon and Garcia (2015), tactical urbanism employs short-term actions for long-term change, using low-cost, scalable interventions to activate neighbourhoods. Analysing various global examples, Yassin (2019) highlights effective tactics such as temporary street closures and pop-up parks, arguing that tactical urbanism facilitates both top-down and bottom-up transitions. This dual approach engages many stakeholders, fostering greater community involvement.

Regarding the structural environment of pedestrian links, Gehl (2006) suggests that the ideal street that attracts pedestrian traffic is one with a "soft edge." He describes such streets as being lined with shops and large windows at ground level, offering numerous openings and notable interruptions. However, these attributes appear to be typological outcomes of larger-scale urban characteristics, such as high-density layouts, optimal block sizes, well-functioning public space systems, and connected street networks. These desirable morphological properties at larger scales have already been partially discussed.

Greenways can be considered a cross-scale strategy that can be implemented not only independently on selected links but has the potential to unify a larger network as well. In a recent study, Dostal and Eisenman (2022) explored how pedestrianised streets can unlock underutilised road spaces in dense urban areas, transforming them into greenways. Through a systematic review of the available literature concerning pedestrian zones and greenways, they identified shared characteristics and the benefits of integrating these urban interventions. Greenways enhance urban liveability by providing various advantages, such as noise reduction, air filtration, additional shade, and mental health benefits. Additionally, they address urban challenges such as flooding when positioned near waterways and create safer, car-free environments that benefit both pedestrians and local wildlife. The study emphasises the synergy between pedestrian zones and greenways when planned together.

Pedestrianisation is gaining popularity in Brazilian cities as well as in many other countries. The city of Curitiba introduced car-limited links in the 1970s. In the 1980s the largest pedestrian area in the country was developed in São Paulo (Rodriguez et al., 2012). Today, pedestrianisation initiatives are also being implemented in major cities like Rio de Janeiro and Salvador. In most cases, designers leverage the existing density of urban blocks and rich street networks to define revitalisation projects by enhancing structural elements. One key aspect to be considered in similar initiatives, as well as in many contemporary planning activities, relates to the involvement of citizens and relevant stakeholders. In a 2016 study, Sala Minucci and Righi (2016) examined the revitalization of Oscar Freire Street, one of São Paulo's most prominent commercial streets, known for high-end shopping. This project, initiated by local retailers and implemented in cooperation with the municipal government, included upgrades to the existing infrastructure such as burying electrical wires, installing street furniture, improving lighting, and landscaping to enhance pedestrian accessibility and aesthetic appeal. This can be considered a positive example which also emphasizes the importance of partnerships between public and private institutions in urban redevelopment projects, especially in busy commercial areas that depend on pedestrian traffic.

From another perspective, Thomas (2016) conducted a long-term investigation into state-led pacification projects in Brazilian cities aimed at transforming public spaces into safe pedestrian-friendly zones patrolled by the police force. Her study highlights the significant challenges decision-makers face in creating secure environments to ensure successful pedestrian experiences and dynamic public spaces. Thanks to a deep understanding of Brazil's social dynamics and urban architecture, Thomas questions the effectiveness of certain measures, such as an increase In the presence of the police, arguing that these often clash with the organic nature of urban environments. In response to these challenges, it seems that rather than imposing control mechanisms without elevating the urban environment's capacity, what is needed in such transformations is a systemic diagnosis of structural problems, the definition and evaluation of modification scenarios with higher potential for public engagement, and the adaptation of these strategies to official policies. Pedestrianisation is a cornerstone of sustainable urban design, balancing environmental imperatives with social and economic objectives. Its success relies on multi-scale planning, the integration of density, land use, and network connectivity with localised design adaptations. Emerging technologies and participatory approaches further strengthen its viability. By fostering walkable environments, cities can promote healthier, more inclusive, and more vibrant urban experiences.

3. Methodology

Space syntax measures, as discussed in the literature, offer a range of methodologies for assessing the topology of street networks, providing valuable insights into the spatial structure of cities. However, it is important to recognise that a city extends beyond its street network, which could also be analysed more accurately (Ratti, 2004). While the street layout significantly influences the organisation of other urban systems, these systems exhibit a degree of independence and flexibility. Despite correlations found in previous studies (Omer et al., 2017), urban systems are not entirely constrained by the street network, and other factors contribute to the evolutionary development of the overall urban fabric.

This study proposes an integrated approach, combining space syntax-based measures, commonly used to prioritise areas for pedestrianisation interventions, with additional urban characteristics. These supplementary factors are derived from post-implementation evaluations of pedestrianisation projects and include the presence of and proximity to green spaces, the connectivity with the existing public transportation infrastructure, the presence of ground-level commercial activities and services, and some physical attributes of the built environment. In particular, this study has applied a method that uses street links as the morphological unit to gather simple measurable attributes referring to these dimensions. The aim is to provide a more comprehensive understanding of the street properties potentially affecting the success of pedestrianisation interventions. The proposed method allows for a nuanced decision-making process, where various urban characteristics can inform and orient towards the pedestrianisation of one street instead of another, while also giving insights into the choice of pedestrianisation model, whether it be full pedestrianisation, a combination of pedestrian and public transport, part-time pedestrianisation, or traffic calming measures.

As well as being aligned with the IMM approach discussed above (Mohammad Zadeh et al., 2024), this method is grounded in empirical data, leveraging geospatial datasets from the city of Rio de Janeiro. The datasets, provided by the Instituto Municipal de Urbanismo Pereira Passos, are visualised through maps that illustrate the phenomena under study. The methodology prioritises simplicity and accessibility, using user-friendly measures that avoid overly complex indices. For this study, simple counts of elements (e.g., shops, trees, routes) and percentages of the street length with certain characteristics were used. This approach is designed to facilitate adoption by key stakeholders, such as local authorities and urban planners, who are instrumental in shaping the urban environment. The use of basic, modifiable parameters ensures that the core principles of the methodology remain intact while allowing for flexibility in application.

Thematic maps were generated to illustrate aspects related to the IMM components—void, type of uses, networks, and volumes—describing the urban structure potential, and to investigate pedestrian presence, dealing with urban performances of street use. These maps served as analytical tools for the identification of priority areas and to inform urban planning.

3.1. Voids

The void component usually includes water bodies (blue) and paved spaces such as squares (grey). The present study analyses this component with a focus on green infrastructures, which are considered to be most relevant in this context. The presence of green spaces and trees can be evaluated from two perspectives. Firstly, the existing urban vegetation can be assessed to identify areas that are already well-endowed with greenery, with the aim of prioritising these areas for pedestrianisation interventions. This approach leverages existing resources, reducing the need for extensive investments in new infrastructure. Secondly, the potential to transform areas by connecting or enhancing green spaces is considered, with the goal of maximising the impact of pedestrianisation on the surrounding urban context.

The continuity of green systems in urban areas plays a critical role in enhancing biodiversity and improving the environmental quality of public spaces. To assess green continuity in the area considered in this study, a GIS-based approach was employed to identify streets that can facilitate the direct connection of green spaces, thereby improving the continuity of the urban green infrastructure. This method does not assume that these streets already contain substantial vegetation; rather, it focuses on their potential to link distinct green areas, thus contributing to a broader network of green spaces. The analysis was informed by the IMM green continuity key category, which evaluates the potential of street segments to support the continuous flow of green infrastructure (Biraghi et al., in press). It involves drawing the shortest path on the street network to connect each green area larger than a certain size. These routes are called potential continuity corridors (PCC) and need to be counted to identify the street links with the highest value and prioritise them. Streets identified through this process may not host significant green elements at present, but their role in fostering green continuity could provide a strong rationale to prioritise them in pedestrianisation efforts. Enhancing green continuity through pedestrianisation can, in turn, contribute to increased urban biodiversity and improve the overall quality of urban life.

3.2. Type of Uses

Ground-level activities and services, often referred to as POIs, are key components in determining the suitability of a street for pedestrianisation. These activities attract people to public spaces, thereby increasing pedestrian footfall. To quantify the presence of these activities, data from the Imposto Sobre a Propriedade Predial e Territorial Urbana (IPTU) database were analysed to identify the types of services available along each street. Particular attention was given to businesses that tend to be successful in pedestrianised environments, such as bars, restaurants, schools, parks, and outdoor sports facilities. These activities not only foster social interaction but also align with the goals of pedestrianisation interventions.

Conversely, activities that rely heavily on car access, such as car repair shops, gas stations, and industrial facilities, were also considered. The objective here was to identify areas where the conversion of streets to pedestrian zones could disrupt essential services that depend on vehicle access, without penalising businesses that are integral to the urban fabric. Parking areas were also evaluated, not only for their impact on traffic but also for their potential to act as transition zones into car-free areas. By carefully balancing these factors, the proposed approach aims to optimise the street environment for both pedestrians and essential services, ensuring the long-term success of pedestrianisation initiatives.

3.3. Networks

Access to public transportation is another critical factor in determining the viability of pedestrianisation interventions. Access to public transport in densely populated urban areas is essential to ensure that pedestrianised zones remain accessible to a wide range of people, including those who rely on public transport for mobility. The degree to which the street network supports modal or line change (intermodality) was analysed using the City Transport Analyzer (Naro et al., 2024), a QGIS plugin designed to assess the potential for multimodal transport connections. This tool uses General Transit Feed Specification data to evaluate how effectively public transport stops are integrated into the street network. It assesses stops according to the number of lines passing through them, and, similarly to what was presented for green continuity, it draws potential multimodal routes (PMR) on the shortest path between any stop with no public transportation lines in common.

This analysis was particularly relevant in the context of Rio de Janeiro, where the bus network is pervasive and often exploits the same roadways as private vehicles, resulting in lower average commercial speeds. By considering the intermodality of public transportation, the study aims to ensure that the pedestrianisation of certain streets does not isolate them from the broader transit network, but rather enhances their integration within it.

3.4. Volumes

The physical characteristics of the built volumes along streets also play an important role in determining the suitability of an area for pedestrianisation. It must be said that modifications of building volumes are more complex and less feasible than interventions like greening or de-paving. For this reason, it is worth analysing the volume component as a sort of immutable framework for pedestrian activity. The street section determines the level of enclosure of spaces. This affects the presence of shadows on the streets, the perception of the space and the sky view factor (Zakšek et al., 2011), a relevant measure affecting the urban heat island effect (Dirksen et al., 2019; Zhong et al., 2024). This study adopts a simple measure developed by Biraghi and Pafka (2025) to synthetically describe these aspects. Block enclosure ratio (BER) describes the percentage of a block's perimeter with buildings aligned on it. This is complemented with the counting of sky pixels in Google Street View (GSV) images using segmentation techniques. This aspect is further analysed in Section 3.5.

A streetscape analysis was conducted through on-site visual inspections to gather essential information about the physical and functional characteristics of the street sections. Key parameters recorded included the width of the street, its configuration as one-way or two-way, traffic direction, the presence and arrangement of parking spaces, the number and dimensions of traffic lanes, and the presence and properties of sidewalks. Additionally, observations were made on the spatial dynamics of street use, such as instances of illegal parking or other factors influencing the occupation of public space. This qualitative assessment provided crucial context for understanding the functional and spatial dynamics of the streets under study.

3.5. People

Assessing pedestrian flows is important when dealing with pedestrianisation interventions. Traditional methods of people counting, such as on-site surveys, are resource-intensive and challenging to implement consistently. These methods require extensive planning, staff, and time to ensure that reliable data are collected across different locations and times. Data collected from mobile phones or internet usage are often skewed, excluding non-digital users such as elderly people and young children. Given the difficulties in obtaining very accurate data, it was decided to accept less precise data but to explore free methods capable of providing preliminary information over a potentially vast area.

In this study, alternative people-counting techniques were explored using image segmentation algorithms applied to GSV imagery. This method allows for the automated counting of pedestrians in street-level images, offering a cost-effective solution to obtain a preliminary approximation of pedestrian activity across a broad range of locations. The semantic segmentation tool, trained on the ADE20K dataset, classifies each pixel in an image into categories such as buildings, vegetation, roads, and pedestrians, providing spatial and activity data potentially useful for urban analysis. The data derived from these images were processed using algorithms to detect and quantify the presence of people, providing an estimate of pedestrian activity, and a rough estimation of the sky view factor by counting sky pixels. GSV images, captured regularly in 360-degree views, were sampled at 10 m and 100 m intervals for both detailed and broader analyses using a Google API. Pre-processing steps included resizing and normalisation to meet the requirements of the DeepLabV3+ model, a ResNet50-based segmentation framework. The model generated pixel-level class maps, enabling quantitative insights into urban features and pedestrian usage through pixel count analyses.

This method offers a cost-effective way to assess pedestrian behaviour and the distribution of urban elements, with the segmentation tool demonstrating high accuracy in identifying common features and clear boundary delineations. However, it faces some limitations, including computational intensity, API limitations and costs, and reduced accuracy for underrepresented features, which could be improved through localised fine-tuning. Additionally, the approach provides only a snapshot of pedestrian activity, capturing a single moment in time, and requires careful consideration of factors such as weather, day of the week, and holidays to ensure the validity and comparability of the data. In fact, among all the images downloaded, only those taken on a single day in May 2024 were eventually considered. Despite these challenges, the image-based approach remains a valuable tool for a rough estimate of pedestrian flows and the identification of streets suitable for pedestrianisation interventions at the neighbourhood scale.

4. Results

The proposed method has been tested on five north–south-oriented streets in the core of Vila Operária. The decision to involve a limited number of streets stems from the local yet scalable nature of the approach, aiming to address a question such as "why here and not there" in a context where streets may appear very similar and interchangeable. The streets under study are shown in Figure 1. All of the streets are one-way, characterised by typical two-storey, low-rise developments in a poor state of conservation, and by the presence of a chaotic network of electrical infrastructure above the streets. For clarity and ease of reference, the streets have been numbered sequentially, with their names provided for each. The streets included in the analysis are R. Correa Vasques (S1), R. Viscondessa de Piracinunga (S2), R. Laura de Araujo (S3), R. Carmo Neto (S4), and R. Anibal Benevolo (S5). These streets were selected for their centrality within Bairro Cidade Nova, where the REMIRIO project is implemented. The reasons for focusing specifically on these streets are numerous. They all intersect Avenida Salvador the Sá in the south, where the Municipality and the local community have proposed a greening project; they all feature a high level of enclosure and a high

Figure 1. Area of study with the five streets highlighted (base image from Bing Maps).

concentration of activities compared to the surrounding areas, two conditions considered favourable for promoting walkability; and most of the buildings in the area are owned by the Municipality.

The data were prepared and processed using QGIS 3.28.6, while the space syntax analyses were performed within DepthmapX, modelling the streets as Segments. The space syntax measures considered were choice, depth, and integration, using both angular and metric methods, for three different search radii: 400 m, 800 m, and the entire area ($r = \infty$). The area comprises 13 bairros (districts) spanning from the city centre to the east and up to Tijuca National Park to the west (Figure 2). The radii of 400 m and 800 m were chosen as representative of a 5-minute and 10-minute walk. This resulted in a total of 24 different metrics, which are reported in Table 1.

After evaluating the data, however, it was found that metric depth and metric integration exhibited minimal variance and were therefore excluded from further analysis. Angular choice and angular integration showed meaningful variation across the streets, with angular choice being prioritised for analysis due to its frequent use in the literature. Both angular depth and angular integration were significant and, as expected, negatively correlated, as they describe two inverse dimensions. Therefore, only angular integration was considered for its wider use in the literature. To simplify, from now on, these will be referred to simply as choice and integration, referring to the angular measures.

These two measures are considered to reflect key spatial characteristics: Choice indicates how likely a street segment is to be passed through on all shortest routes from all spaces to all other spaces in the entire system; integration is a normalised measure of distance from any space of origin to all others in a system. In both measures, high values are considered favourable for urban design purposes.

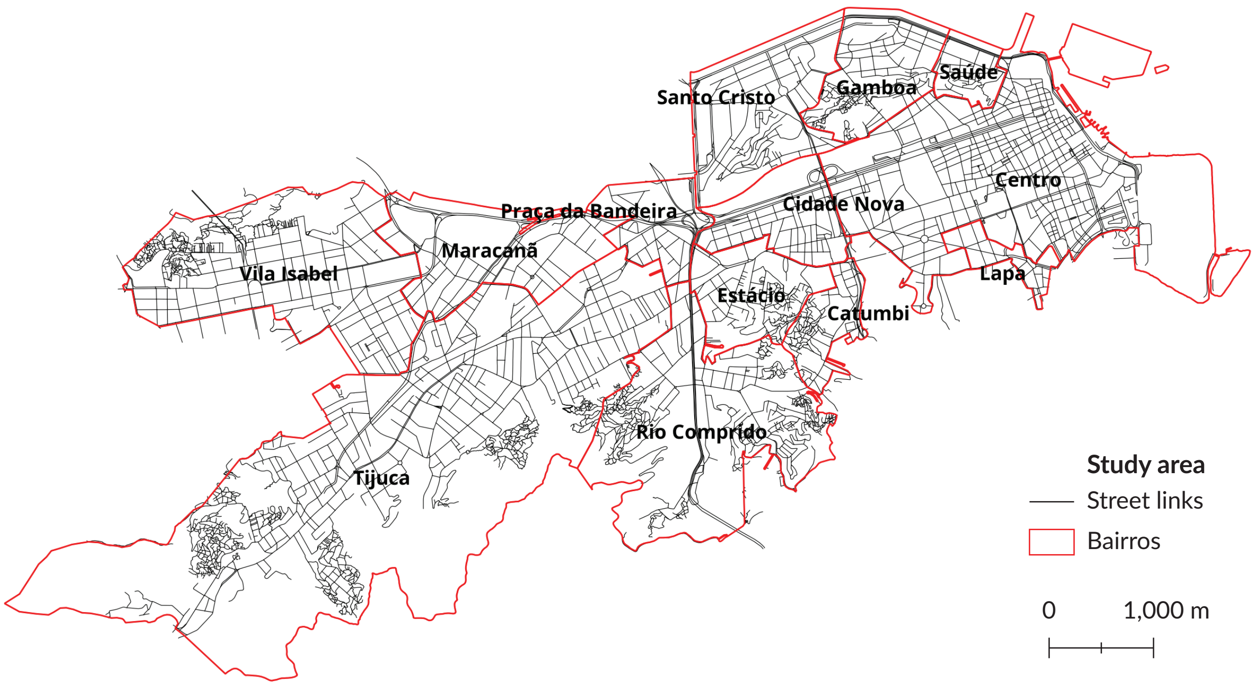


Figure 2. Study area considered for the space syntax analysis.

Table 1. Space syntax measures for the selected streets.

General	ID	S1	S2	S3	S4	S5
	Street name	R. Correa Vasques	R. Viscondessa de Piracinunga	R. Laura de Araujo	R. Carmo Neto	R. Anibal Benevolo
	cod_trecho	50469	50448	50446	50443	51440
	Length (m)	177.4	162.2	159.6	159.9	159.7
Space Syntax	Ang. Connectivity	2.8	4	3	4.2	3
	Connectivity	5	6	5	6	5
	M. Choice (∞)	814,856	2,293,925	40,326	28,189	114,005
	M. Choice 400 m	107	217	177	170	258
	M. Choice 800 m	885	1,528	935	931	1,730
	M. Mean Depth (∞)	3,379	3,398	3,467	3,471	3,486
	M. Mean Depth 400 m	278	251	271	263	257
	M. Mean Depth 800 m	539	523	517	516	500
	M. Total Integration (∞)	20,547,538	20,664,434	21,085,450	21,106,108	21,199,554
	M. Total Int. 400 m	11,695	15,050	15,158	16,831	15,950
	M. Total Int. 800 m	115,927	119,157	107,107	114,534	111,072
	Ang. Choice (∞)	33,474	3,153,576	17,234	682,017	13,508
	Ang. Choice 400 m	59	227	140	80	254
	Ang. Choice 800 m	735	2,201	790	1,281	1,217
	Ang. Integration (∞)	945	1,072	915	1,039	929
	Ang. Int. 400 m	32	53	43	49	43
	Ang. Int. 800 m	100	128	84	116	88
	Ang. Total Depth (∞)	39,161	34,496	40,447	35,586	39,832
	Ang. Total Depth 400 m	80	80	101	107	130
	Ang. Total Depth 800 m	586	411	543	525	484

The results of the space syntax analysis revealed several significant trends. S2 consistently exhibited the highest values for both choice and integration across all radii, indicating that this street plays a central role in the urban network. In contrast, S1 and S3 consistently showed low values for both measures, suggesting that these streets are more peripheral. S4 demonstrated intermediate values for choice, coupled with high values for integration, indicating that, although it is well-integrated into the network, it is not as central in terms of accessibility. S5 followed a similar pattern to S1 and S3, with the exception of the 400 m choice, where it ranked highest among all streets. Based on these values, it is only possible to establish a draft ranking of the streets, in terms of their spatial prominence, from the most to the least suitable: S2, S4, S5, S3, and S1. While these findings help establish a general hierarchy of streets in terms of spatial prominence, they do not provide sufficient information to determine the exact nature of pedestrianisation interventions. Choice ($r = \infty$) and weighted integration (considering all three radii) maps are presented in Figure 3.

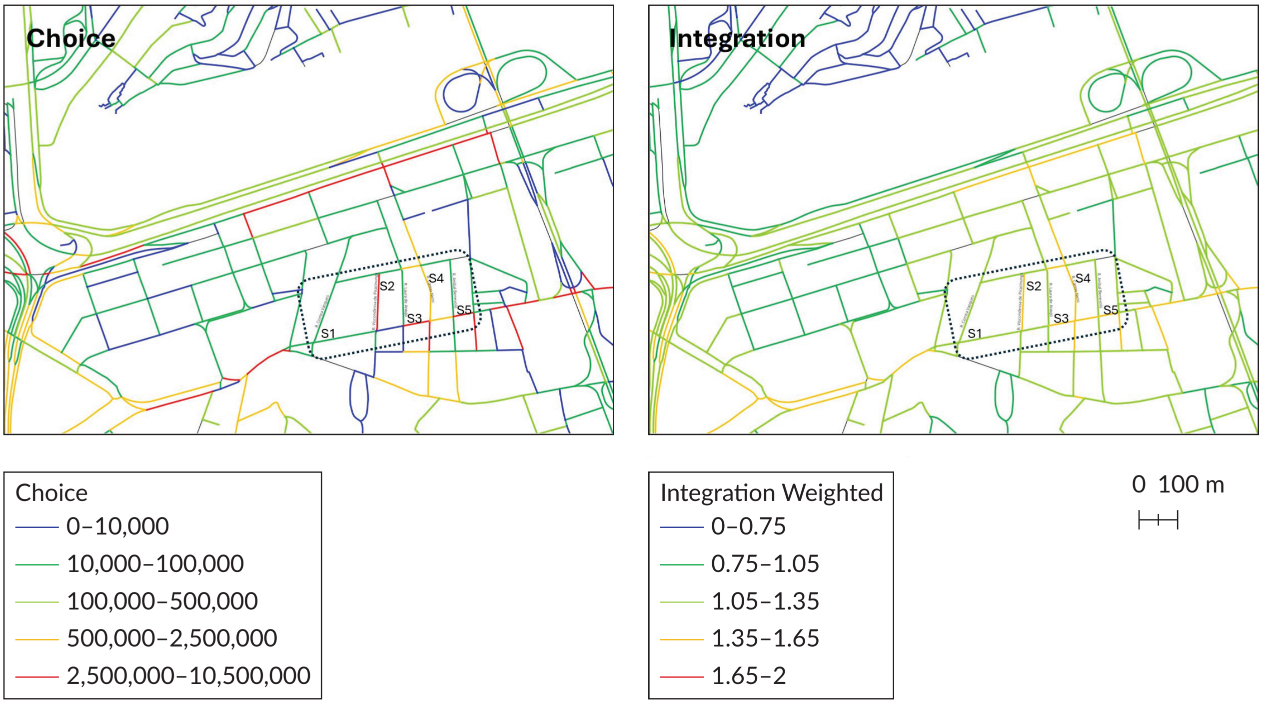


Figure 3. Angular choice (∞) and angular weighted integration maps.

Table 2 summarises all the measures proposed to size the IMM components. Voids are described by Green_% and Tree_%, which correspond to the percentage of link length within the buffer area of green areas or trees, as well as by the number of PCC (PCC_N). The type of uses divides the IPTU sub-plots data (Tot. sub-plots) into residential (Res. sub-plots) and non-residential (Non-res. sub-plots) categories. This metric differs from the number of POIs (POI_N) as it also includes vacant spaces and activities not considered relevant to proximity-related studies. The pedestrian activities such as cafes, restaurants, schools, and parks (POI_PED_N), and those reliant on cars (POI_CAR_N), have been highlighted from the POI_N dataset. The role of public transportation is quantified by counting the number of stops (PTS_N), lines (PTL_N), and PMRs (PMR_N). The volumes component is simply characterised by BER, which measures the percentage of street length with continuous building façades, and the percentage of sky pixels extracted from GSV images (Sky_%). Lastly, some aspects referring to observable features of the streetscape are reported, such as width, parking lanes, sidewalks, way, and car lanes. Figure 4 presents four maps, each representing one of the components, giving a visual understanding and evidence of the components-based measures gathered in Table 2. Figure 5 shows the results of the AI segmentation tool applied to GSV images at resolutions of 10 m and 100 m.

It is important to note that not all of these measures were ultimately relevant in informing pedestrianisation strategies. For instance, the number of POIs specifically associated with pedestrian activities (POI_PED_N) such as cafes, restaurants, and schools, ranged between 0 and 2 for the five streets considered in this study, with a total of 5 restaurants, 1 cafe, and no schools in the area. This suggests that POI_PED_N should not be considered a significant factor in determining the pedestrianisation potential of the streets. Similarly, the street width did not emerge as a meaningful distinguishing factor, with values ranging from 7.5 m (S2 and S3) to 9.1 m (S5), showing limited variation across the streets analysed. All the streets are one-way with a single car lane and parking on both sides. On S4 there are two lanes, no formal parking exists, and vehicles are parked

Table 2. Complementary measures inspired by the IMM components for the selected streets.

General	ID	S1	S2	S3	S4	S5
	Street name	R. Correa Vasques	R. Viscondessa de Piracinunga	R. Laura de Araujo	R. Carmo Neto	R. Anibal Benevolo
	cod_trecho	50469	50448	50446	50443	51440
	Length (m)	177.4	162.2	159.6	159.9	159.7
Voids	Green_%	17%	83%	4%	2%	1%
	Trees_%	30%	51%	0%	7%	19%
	PCC_N	0	0	0	2	0
Type of Uses	Tot. sub-plots (IPTU)	78	49	77	35	23
	Res. sub-plots	52	27	46	18	10
	Non-res. sub-plots	26	22	31	17	13
	POI_N	17	13	28	14	13
	POI_PED_N	2	1	1	0	1
	POI_CAR_N	4	2	4	7	1
Networks	PMR_N	7	3	0	6	0
	PTS_N	0	0	0	1	0
	PTL_N	0	0	0	5	0
Volumes	BER	1	1	1	1	1
	Sky_%	29%	16%	36%	44%	45%
Streetscape	Width (m)	8.8	7.5	7.5	7.9	9.1
	Parking lanes	2	2	2	0	2
	Sidewalks	2	2	2	2	2
	Way	1 up	1 down	1 up	1 down	1 up
	Car lanes	1	1	1	2	1
People	People pixels %	0.10%	0.04%	0.37%	0.13%	0.11%

illegally along the street. Additionally, BER was uniform across all streets with a value of 1 (indicating fully continuous building façades), further reinforcing that this measure was not useful in differentiating between the streets. However, this also indicates that all of them have a section that provides a good sense of enclosure, making them suitable as walkable environments.

4.1. Evaluations and Recommendations Based on Results

Turning to the individual streets, S1 stands out for having the highest percentage of residential sub-plots (52.67%) along with four car-related POIs. The street has a moderate amount of greenery and low pedestrian activity, as indicated by a very small percentage of people pixels (0.1%). It plays an important intermodal role, with seven PMRs passing through it. Given the combination of high residential density and the presence of car-related activities, it is recommended that car passage be maintained on S1, as other neighbouring streets may be more suitable for pedestrianisation measures. The suggested intervention for S1 includes widening

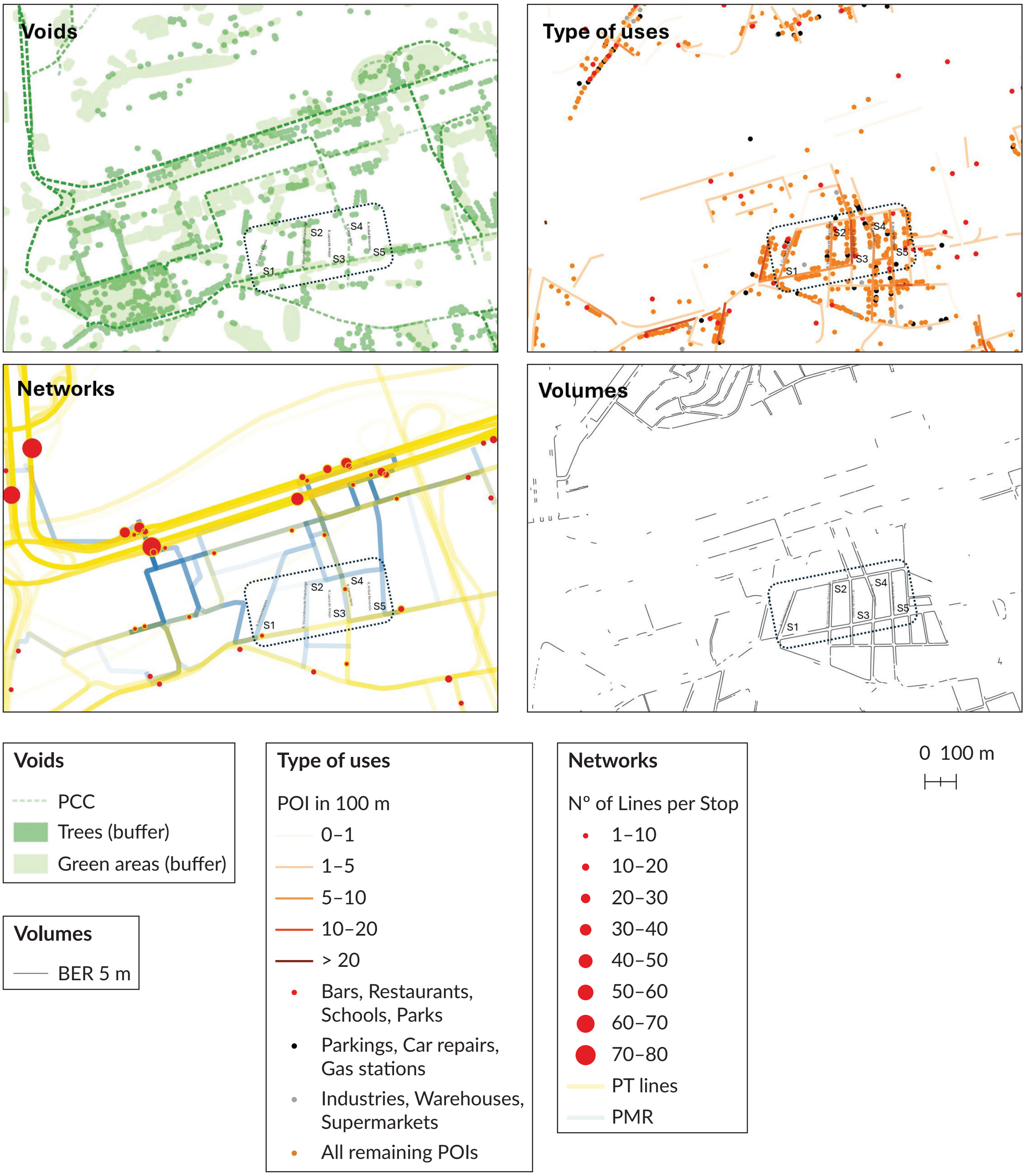


Figure 4. Voids, type of uses, networks, and volumes maps. Note: PT – Public Transportation.

the sidewalks by up to 1.2 m to accommodate additional greenery and trees, while also making the surface more permeable. Furthermore, a traffic calming intervention could be implemented by reducing the maximum speed limit to 15 or 30 km/h and potentially extending the surface to be repaved to include the car lanes. In the northern section of S1, where there is a concentration of shops, the sidewalks could be further expanded by removing one or both of the parking lanes.

Figure 5. People pixel count derived through segmentation of GSV images at 10 m and 100 m of resolution.

S2 presents a contrasting scenario. This street has a significantly higher green area and tree coverage compared to the others, resulting in a lower sky view factor. There are no public transport stops or lines, but it is crossed by three PMRs. Pedestrian activity, as shown by people's pixels, is the lowest in the study area: It equals one-third of the pedestrian activity found in S1, S4, and S5, and one-ninth of that in S3. Given the relatively low pedestrian density and the potential to improve the green infrastructure, S2 could either remain as it is with enhanced greenery or be fully pedestrianised to significantly improve its ecosystem services.

S3 exhibits the highest density of POIs (28) as well as a larger number of residential sub-plots (46%), which translates to higher pedestrian activity (with people pixels four times higher than the average). However, the street suffers from a lack of greenery and informal parking, particularly along its narrowest section. In fact, the car-related activities occupy much more public space than the shopfronts. This highlights the risk of encountering more resistance than expected in the case of a full pedestrianisation intervention, but also the risk of extending the current improper use of space if proposing a lighter approach (e.g., limiting access to residents and activities). Although no PMRs pass through S3, its high density of POIs suggests that pedestrianisation could be beneficial. The street could either remain as it is, with greenery introduced where possible, or undergo a more substantial transformation to fully pedestrianise the area. In this case, displacing some car traffic to S2 might be considered, given that S2 has a lower density of activities. A coordinated strategy involving both S2 and S3 would be necessary, as interventions on one street would significantly influence the other. However, both S2 and S3 could be pedestrianised together as mobility through the area is granted by S1 on the left and on another road, R. Presidente Barroso, on the right.

S4 differs from the other streets as it is the only one with a public transport stop, which serves five different lines, making it a key street for PMRs (6). It also has no formal parking, with sidewalks illegally occupied by cars. S4 is moderately residential, with several car-related POIs, and lacks significant greenery. It is also the only street with two PCCs, suggesting that a significant greening intervention should be considered. Assuming that at least one street out of the five considered in this study must contain public transportation lines, there are no particular reasons or advantages for relocating the public transportation stop from S4 to other streets. Instead, the street should be made more pedestrian-friendly by providing dedicated lanes for public transport and bikes while widening the sidewalks by up to 2.5 m. A portion of this widened space should be dedicated to greenery and trees to improve the street's environmental quality.

Lastly, S5 does not exhibit any particular features that set it apart from the other streets. It has the lowest number of POIs and residential sub-plots, with average levels of people pixels and limited greenery. Given its lack of strategic importance for car traffic and the opportunity to significantly improve the urban environment, S5 could be fully pedestrianised. This transformation would provide much-needed space for green infrastructure and contribute to increasing soil permeability.

In summary, the analysis reveals that while space syntax measures such as choice and integration offer useful insights into the overall spatial structure of the streets, a more detailed investigation incorporating other factors such as green infrastructure, residential density, public transport accessibility, and POIs is crucial for determining the most appropriate pedestrianisation strategies. The suggested interventions for each street aim to prioritise pedestrian comfort and environmental quality, while considering the functional needs of the urban space and its inhabitants.

5. Discussion

The results highlight the complex nature of decision-making regarding pedestrianisation strategies, where multiple factors must be considered. The proposed multi-dimensional analysis for street links aims to provide better support to decision-making about potential pedestrianisation strategies. It includes many layers, often presenting conflicting results. For instance, POI density can lead to a high presence of cars as people try to park as close as possible to their destination. Similarly, there are often more trees in streets with fewer activities, as both need street space for their survival. The main point is that the interpretation of these data and the consequent pedestrianisation strategies to be implemented strongly depend on the general approach of the decision-makers who need to choose between minimising the negative impacts on car users or maximising the positive impacts for pedestrians and the environment. The latter would be preferable. However, it is necessary to consider the overall acceptability of the interventions, which could require some compromises with the local population. In this study, this applies in particular to S2, S3, and S5, while S1 and S4 have clearer and stronger reasons to support their modification. While the ideal solution may favour pedestrian-oriented interventions, political and social factors such as public acceptance must be taken into account. Thus, more gradual, incremental approaches may be necessary to ensure that the interventions are not only effective but also broadly supported by the community.

A more transformative strategy that incorporates these findings is the proposal to convert the area between R. Correa Vasques (S1) and R. Presidente Barroso (to the left of S5) into a superblock. This superblock, approximately 150 m x 400 m in size, would limit the access to inner streets to residents, property users, and safety vehicles. Public transport would continue to operate on S4, with the benefits of a dedicated lane. Surrounding streets would maintain car passage in a clockwise loop, ensuring that vehicular accessibility is preserved while prioritising pedestrians within the core. This approach exemplifies how pedestrianisation can be scaled to address larger areas, balancing traffic management with the creation of walkable, socially vibrant spaces.

In addition, the superblocks concept can be easily adapted to the entire urban regeneration of the Vila Operária district in Rio de Janeiro as well. The neighbourhood has all the necessary geographical and geometric characteristics. It has an area of approximately 700,000 m^2, with a 1.4 km-width east–west and between 450 and 750 m north–south. This is similar to a square with an 830–840 m width. It is surrounded by main roads. It is served by two subway stops and a railway station, which implies that Mass Rapid Transit Systems (MRTS) accessibility is granted, as no individual location in Vila Operária is more than 500 m away from one of these stations. Moreover, perimetral roads are never more than 300 m away from any location in the neighbourhood. Existing blocks are sometimes several metres wide and the internal street network is quite dense, but a wide complex of public spaces is already in place along the north side of the prefecture. The world-famous Sambódromo lies on the east side. Vila Operária also has a very strong social identity and a lively cultural background. These aspects enhance the need for spaces where people can mingle and socialise. Consequently, a more ambitious mobility proposal is to perform an extensive pedestrianisation of the internal street network, making many streets exclusively accessible to pedestrian traffic and reducing the portion of road devoted to cars in many others, expanding sidewalks and introducing traffic and speed limitations (e.g., buses, residents only, and, in some cases, patrons as well). In addition to this, green spaces and urban finishes aimed at enhancing the socialization capabilities of streets have to be planned as well. The proportions of this plan must take into consideration an expected diminishing number of private cars, but perimetral parking should still be provided: Car owners will need to walk to the parking location similarly to commuters who need to walk to MRTS stations. A phased and incremental approach to pedestrianisation is suggested, starting with a single street, gradually upscaling to the five-street superblock, and finally including the entire Vila Operária. This would give citizens time to embrace the changes and to experience the positive impact of the transformations directly.

The fact that the superblock logic has already been implemented in Brazil further supports this idea. The urban regeneration of the Porto Maravilha district in Rio de Janeiro is a good example of wide strategic spaces turned from car-centric areas characteristic of the urban development in the 1960s and 1970s into more human-scaled ones focussed on liveability. Another interesting example is the Biotic Technology Park (BTP), an innovative and research-oriented masterplan in Brasilia. BTP was designed in 1955 by famous Brazilian architect and city planner Oscar Niemeyer together with urban planner Lúcio Costa with the aim of reconnecting people with nature and improving quality of life according to what nowadays are considered the basic principles of smart cities. In addition to this, BTP is based on the superblock concept, like most of Brasilia. In 2020, MIC-HUB supported Carlo Ratti Associati in conceiving a mobility and parking strategy aligning with BTP's futuristic vision. The main mobility goal has been to strongly reduce drive-alone trips to BTP. To achieve such a result, the mobility plan first focused on a GIS-based city-scale analysis to inform the client of current and future accessibility patterns, travel times, and transit options. Secondly, the plan re-managed road network geometries, parking provision, and internal mobility. Replacing less sustainable transport modes with more virtuous solutions provides high accessibility and ensures both low emissions and also a remarkable reduction in soil consumption.

6. Conclusion

This study explores a method for the evaluation of street properties that recommends interventions for their improvement. It is applied in the context of five streets within a specified urban area, integrating space syntax analysis, urban morphology, and data on pedestrian activity to assess the potential for the transformation of these streets into more walkable environments.

The results highlighted that whereas space syntax metrics such as choice and integration could be useful for the identification of areas with higher pedestrian potential at the meso scale, other factors such as accessibility to POIs, public transport, and green spaces are more relevant for the local scale, providing useful insights on the type of pedestrianisation to be implemented.

The study proposes a multi-criteria assessment of suitability for pedestrianisation to support decision-making. Balancing the needs of pedestrians and car users is essential, as these two dimensions are often in conflict. This study advocates for a phased, incremental approach to pedestrianisation, where interventions are tailored to the specific needs of each street, within the framework of a general vision for an area, like in the proposed case study of Vila Operária in Rio de Janeiro.

The metrics proposed provide useful information to orient pedestrianisation projects. In particular, PCC_N and PCR_N represent simple but not trivial aspects of the current and potential arrangement of two urban components. The simple nature of the data used and the cost-effectiveness of the people-counting technique enable the scalability of the method to wider urban scales. However, increasing the number of streets to be surveyed and the related attributes would require the adoption of more systematic data interpretation techniques. Maps, in particular those related to the type of uses, could be integrated with views that highlight sub-sections of streets of particular interest (e.g., concentrations of car-based activities) requiring specific interventions. In addition, the comparison between official datasets from the Municipality and the observation of GSV images revealed some inconsistencies (e.g., 4 vs 11 POI_CAR_N and 0 vs 6 trees in S3). The results and the subsequent assumptions in the article are based on the official data, but the introduction of a validation procedure for input data would increase the overall reliability of the process. This can be done by including additional features in the image segmentation process (e.g., cars and trees). The image segmentation process can be applied to images different from GSV as well. Moreover, taking pictures on site at different times of day and night could significantly enrich the information to be derived.

In conclusion, this multi-dimensional approach offers valuable insights for urban planners and decision-makers seeking to implement pedestrianisation strategies providing a framework for the development of sustainable, walkable, and liveable urban spaces. The findings emphasize the need for a balanced, context-sensitive methodology that considers both the physical and social dimensions of urban life, ensuring that pedestrianisation efforts contribute to more inclusive, accessible, vibrant, and healthier urban environments in line with the C40 Cities Climate Leadership Group and the SDGs.

Acknowledgments

The authors would like to express their gratitude to Jimmy Djurist Ngenzi and Dimitrije Todorovic, students in the master's program in architectural engineering at Politecnico di Milano, for their invaluable assistance in semantic segmentation for urban and pedestrian analysis.

Funding

The research described in this article is part of the project Integrated and Sustainable Urban Regeneration Milan–Rio (REMIRIO), which has been funded by the European Commission (call EuropeAid/171273/DH/ACT/Multi-3 – Local Authorities: Partnerships for Sustainable Cities 2021).

Conflict of Interests

The authors declare no conflict of interests.

References

Al-Sayed, K., Turner, A., Hillier, B., Iida, S., & Penn, A. (2014). *Space syntax methodology. A teaching textbook for the MSc Spatial Design: Architecture & Cities*. Bartlett School of Architecture.

Biraghi, C. A., Cerbella Mandarino, F., Masera, G., Gomes Souza, L., Fraga, J. P. R., Tadi, M., & Mohammad Zadeh, M. H. (in press). Integrated and sustainable urban regeneration Milan–Rio—REMIRIO: Urban diagnosis based on integrated modification methodology (IMM). In J. Littlewood, R. J. Howlett, & L. C. Jain (Eds.), *Sustainability in energy and buildings 2024*. Springer Nature.

Biraghi, C. A., & Pafka, E. (2025). Urban block enclosure and labyrinthineness: Measuring morphological attributes that matter. Journal of Urban Design, 1–19. https://doi.org/10.1080/13574809.2025.2486043

Blaga, O. E. (2013). Pedestrian zones as important urban strategies in redeveloping the community—Case study: Alba Iulia borough park. *Transylvanian Review of Administrative Sciences*, *38*, 5–22.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning*, *97*(3), 147–155.

Carmona, M. (2015). London's local high streets: The problems, potential, and complexities of mixed street corridors. *Progress in Planning*, *100*, 1–84.

de Faria Peres, L., de Lucena, A. J., & Corrêa Rotunno Filho, O. (2018). The urban heat island in Rio de Janeiro, Brazil, in the last 30 years using remote sensing data. *International Journal of Applied Earth Observation and Geoinformation*, *64*, 104–116.

Diaconu, M. (2011). City walks and tactile experiences. *Contemporary Aesthetics*, *9*, Article 14.

Dirksen, M., Ronda, R. J., Theeuwes, N. E., & Pagani, G. A. (2019). Sky view factor calculations and its application in urban heat island studies. *Urban Climate*, *30*, Article 100498. https://doi.org/10.1016/j.uclim.2019.100498

Dostal, N., & Eisenman, T. S. (2022). Pedestrianizing streets as a strategy for urban greenways. *Fábos Conference on Landscape and Greenway Planning*, *7*(1).

Duarte, J., & Celani, G. (2019). Urban street retrofitting: An application study on bottom-up design. In J. P. Sousa, G. C. Henriques, & J. P. Xavier (Eds.), *37th Conference on Education and Research in Computer Aided Architectural Design in Europe and 23rd Conference of the Iberoamerican Society Digital Graphics* (pp. 287–296). Education and Research in Computer Aided Architectural Design in Europe.

Ewing, R., & Clemente, O. (2013). *Measuring urban design. Metrics for livable places*. Island Press. https://doi.org/10.5822/978-1-61091-209-9

Ewing, R., Tian, G., & Lyons, T. (2018). Does compact development increase or reduce traffic congestion? *Cities*, *72*(Part A), 94–101. https://doi.org/10.1016/j.cities.2017.08.010

Forsyth, A., & Southworth, M. (2008). Cities afoot—Pedestrians, walkability and urban design. *Journal of Urban Design*, *13*(1), 1–3.

Fruin, J. (1971). *Pedestrian planning and design*. Metropolitan Association of Urban Designers and Environmental Planners.

Gehl, J. (2006). Life, spaces, buildings—and in said order, please. In M. Moor & J. Rowland (Eds.), *Urban design futures* (pp. 88–93). Routledge.

Gehl, J. (2011). *Life between buildings: Using public space*. Island Press.

Gössling, S., Choi, A., Dekker, K., & Metzler, D. (2019). The social cost of automobility, cycling and walking in the European Union. *Ecological Economics*, *158*, 65–74.

Hass-Klau, C. (2014). *The pedestrian and the city*. Taylor & Francis.

Hillier, B. (1996). *Space is the machine: A configurational theory of architecture*. Cambridge University Press.

Hillier, B., & Iida, S. (2005). Network and psychological effects in urban movement. In A. G. Cohn & D. M. Mark (Eds.), *International Conference on Spatial Information Theory* (pp. 475–490). Springer.

Jabbari, M., Fonseca, F., & Ramos, R. (2021). Accessibility and connectivity criteria for assessing walkability: An application in Qazvin, Iran. *Sustainability*, *13*(7), Article 3648.

Jayasinghe, A., Sano, K., Kasemsri, R., & Nishiuchi, H. (2016). Travelers' route choice: Comparing relative importance of metric, topological and geometric distance. *Procedia Engineering*, *142*, 18–25.

Kott, J., & Eells, J. (2016). Failure and success of pedestrian streets in America. *Journal of Transport & Health*, *3*(2). https://doi.org/10.1016/j.jth.2016.05.049

Kubat, A. S., Ozer, O., & Ozbil, A. (2013). Defining a strategical framework for urban pedestrianisation projects. In Y. O. Kim, H. T. Park, & K. W. Seo (Eds.), *Proceedings of the 9th International Space Syntax Symposium*. Sejong University.

Litman, T. A. (2003). Economic value of walkability. *Transportation Research Record*, *1828*(1), 3–11. https://doi.org/10.3141/1828-01

Lydon, M., & Garcia, A. (2015). *Tactical urbanism: How-to*. Island Press; Center for Resource Economics.

Mehta, V. (2014). Evaluating public space. *Journal of Urban Design*, *19*(1), 53–88.

Mohammad Zadeh, H., Lenzi, E., Dong, T., Biraghi, C. A., Pucci, E., Cerutti, F., & Tadi, M. (2024). A conceptual data model for IMM: A methodological interpretation of targets and indicators in SDG11. *Science of The Total Environment*, *956*, Article 177269. https://doi.org/10.1016/j.scitotenv.2024.177269

Monheim, R. (1980). *Fußgängerbereiche und Fußgängerverkehr in Stadtzentren in der Bundesrepublik Deutschland*. Dummler.

Nakamura, K. (2016). The spatial relationship between pedestrian flows and street characteristics around multiple destinations. *IATSS Research*, *39*(2), 156–163. https://doi.org/10.1016/j.iatssr.2015.08.001

Naro, G., Biraghi, C. A., & Lenzi, E. (2024). City Transport Analyzer: A powerful Qgis plugin for public transport accessibility and intermodality analysis. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*, 113–119. https://doi.org/10.5194/isprs-archives-XLVIII-4-W12-2024-113-2024

Nassar, U. A. A., El-Samaty, H. S., & Elzeni, M. (2018). Place syntax: An "optimal area" selection methodology proposed for pedestrianisation. *Spaces and Flows: An International Journal of Urban and Extra Urban Studies*, *9*(3), 29–53. https://doi.org/10.18848/2154-8676/CGP/v09i03/29-53

Newman, P. W. G., & Kenworthy, J. R. (1989). *Cities and automobile dependence: An international sourcebook*. Gower.

Nowak, D. J., & Dwyer, J. F. (2007). Understanding the benefits and costs of urban forest ecosystems. In J. E. Kuser (Ed.), *Urban and community forestry in the northeast* (pp. 25–46). Springer.

Nunes, K. R. A., Abelheira, M., Gomes, O. S., Martins, P., & Aguiar, I. S. (2020). Disaster risk assessment: The experience of the city of Rio De Janeiro in developing an impact scale for meteorological-related disasters. *Progress in Disaster Science*, *5*, Article 100053. https://doi.org/10.1016/j.pdisas.2019.100053

Oakes, J. M., Forsyth, A., & Schmitz, K. H. (2007). The effects of neighborhood density and street connectivity on walking behavior: The Twin Cities walking study. *Epidemiologic Perspectives & Innovations*, *4*, Article 16. https://doi.org/10.1186/1742-5573-4-16

Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban climates*. Cambridge University Press.

Omer, I., Kaplan, N., & Jiang, B. (2017). *Why angular centralities are more suitable for space syntax modeling?* [Paper presentation]. 11th International Space Syntax Symposium, Lisbon, Portugal.

Parajuli, A., & Pojani, D. (2018). Barriers to the pedestrianisation of city centres: Perspectives from the Global North and the Global South. *Journal of Urban Design*, *23*(1), 142–160.

Peponis, J., Bafna, S., & Zhang, Z. (2008). The connectivity of streets: Reach and directional distance. *Environment and Planning B: Planning and Design*, *35*, 881–901.

Ratti, C. (2004). Space syntax: Some inconsistencies. *Environment and Planning B: Planning and Design*, *31*(4), 487–499.

Rodriguez, C., Lima Sakr, F., Griffiths, S., & Hillier, B. (2012). The relationship of spatial configuration and socio-economic conditions in São Paulo, Brazil. In *Proceedings of the 8th International Space Syntax Symposium* (pp. 1–24). Pontificia Universidad Católica.

Sala Minucci, A., & Righi, R. (2016). Evaluating the quality standard of Oscar Freire Street public space, in São Paulo, Brazil. *Journal of Multidisciplinary Engineering Science and Technology*, *3*(4), 4644–4653.

Santamouris, M. (2015). Analyzing the heat island magnitude and characteristics in one hundred Asian and Australian cities and regions. *Science of The Total Environment*, *512*, 582–598.

Sheng, W., Wei, Z., & Lei, W. (2021). Understanding the configuration of bus networks in urban China from the perspective of network types and administrative division effect. *Transport Policy*, *104*(9). https://doi.org/10.1016/j.tranpol.2021.02.002

Soni, N., & Soni, N. (2016). Benefits of pedestrianisation and warrants to pedestrianize an area. *Land Use Policy*, *57*, 139–150.

Tanishita, M., & van Wee, B. (2017). Impact of regional population density on walking behavior. *Transportation Planning and Technology*, *40*(6), 661–678. https://doi.org/10.1080/03081060.2017.1325137

Thomas, R. (2016, March). *Embodying pacification processes: The case of the Brazilian urban public spaces* [Paper presentation]. Association of American Geographers, San Francisco, CA, USA.

Yassin, H. H. (2019). Livable city: An approach to pedestrianisation through tactical urbanism. *Alexandria Engineering Journal*, *58*(1), 251–259.

Zakšek, K., Oštir, K., & Kokalj, Ž. (2011). Sky-view factor as a relief visualization technique. *Remote Sensing*, *3*(2), 398–415. https://doi.org/10.3390/rs3020398

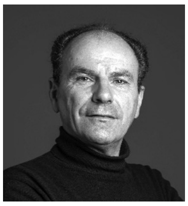
Zhong, Y., Li, S., Liang, X., & Guan, Q. (2024). Causal inference of urban heat island effect and its spatial heterogeneity: A case study of Wuhan, China. *Sustainable Cities and Society*, *115*, Article 105850. https://doi.org/10.1016/j.scs.2024.105850

About the Authors

Carlo Andrea Biraghi (PhD) is a researcher at Politecnico di Milano with a multidisciplinary attitude and a hybrid background (architecture and geomatics). He works on GIS-based urban diagnosis, spatial metrics, and algorithms. He has published over 30 scientific articles, ranging from urban morphology, citizen science, and sustainable urban planning.

Hadi Mohammad Zadeh (b. 1985) is a professor of urban design studio at Politecnico di Milano. With a PhD (2020) in built environment engineering, his research focuses on urban morphological analysis. Teaching since 2014, he has co-authored numerous scholarly publications and book chapters on urban form and its impact on cities.

Andrea Bruschi, born in Parma (1975), is an architect and transportation planner based in Milan. He works at MM, specializing in transportation systems and mobility consultancy. With expertise in city planning, he advocates for sustainable, efficient mobility solutions, contributing to conferences, publications, and international projects.



Massimo Tadi is an associate professor at Politecnico di Milano. He is the director of IMMdesignLab, leading international projects that transform urban contexts into sustainable, energy-efficient environments. He has advised municipalities on urban sustainability, authored numerous publications on sustainable architecture and energy efficiency, and lectured as a visiting professor at universities worldwide.