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Design Elements in the Spatial Integration of Public Transport Nodes with Their Environments Within the Context of Sustainable Urban Mobility

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Abstract

Investment in transportation infrastructure centred on motorized vehicles has exacerbated sustainability challenges, including traffic congestion, air pollution, and a deterioration of urban space quality. In response to these challenges, increasing attention has been directed toward advancing public transport systems and adopting pedestrian-oriented urban mobility strategies. Consequently, the spatial integration of active transport modes with public transport networks has become a critical concern. This paper identifies key design elements for integrating public transport nodes with their environments, based on data from research indexed in the Scopus database between 2010 and 2025. The findings indicate that these design elements can be classified into three main dimensions: structural (configuration, connectivity, and permeability), functional (accessibility, walkability, and land-use diversity), and perceptual (wayfinding, visual continuity, and visibility). Furthermore, the methods used to analyse the relationship between public transport nodes and their environments are divided into three distinct approaches: observation-based quantitative, perception-based qualitative, and GIS-based accessibility analyses.
Keywords: Sustainable Urban Mobility; Public Transport Nodes; Spatial Integration; Pedestrian Mobility.

1. Introduction

The integration of public transport nodes (such as metro stations and bus stops) with their environments represents a critical threshold for the spatial manifestation of sustainable urban mobility strategies and overall system efficiency. When these nodes transcend being merely technical transfer points and are articulated into the system as functional components of the urban fabric, they reduce motorized vehicle dependency and foster active transportation modes such as walking and cycling. However, in many cities, even when transport nodes are located to meet high usage demand, their positioning in isolation from their environments constitutes a structural barrier to sustainable mobility goals. In particular, physical barriers restricting pedestrian access and disruptions in spatial continuity compromise the integrity of the public transport system, creating areas of inefficiency that steer individuals toward private vehicle use.

This introductory section of the paper includes a literature review detailing the process of accessing the correct keywords, the definition of the research problem, and the corresponding primary and secondary objectives. Furthermore, it presents the research questions and hypotheses formulated in line with these objectives, followed by the research methodology and scope designed to seek answers to these questions and test the hypotheses. Below is the mind map (Figure 1) followed during the literature search and the development of the conceptual framework. In this context, this study addresses the articulation of public transport nodes into the urban built environment through the lens of sustainable urban mobility and the components of spatial integration.

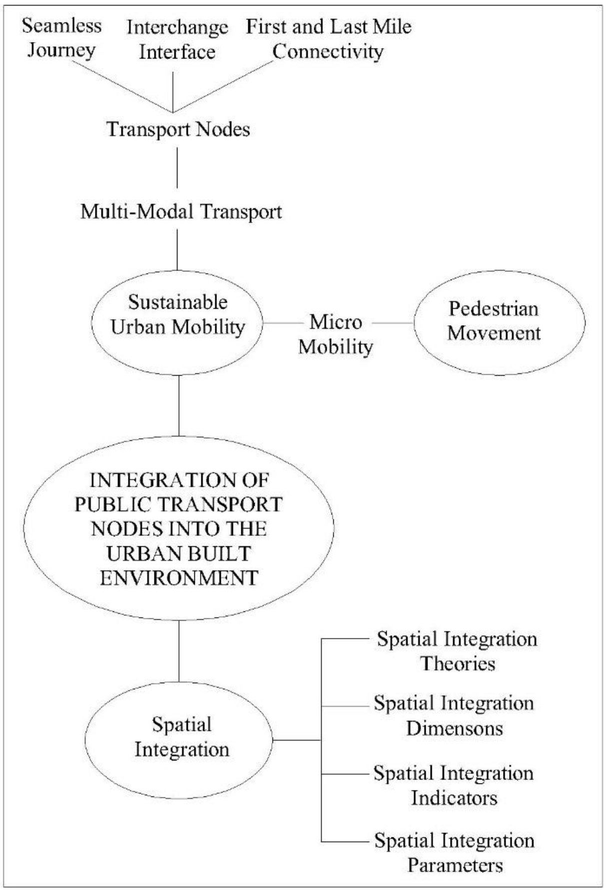

Figure 1. Research framework.

1.1 Background and Context

The weak relationship between public transport nodes and pedestrian networks, resulting from physical barriers and accessibility challenges, may push users towards other modes of transport; this can lead to inefficiencies in investments and the failure to achieve sustainability targets (European Commission, 2024). These investments, primarily developed to increase capacity with a focus on rubber-tyred and motorised vehicles, exacerbate sustainability issues such as traffic congestion, air pollution, greenhouse gas emissions, and the degradation of urban space quality. Due to these challenges, public transport systems developed in rapidly growing and sprawling cities are regarded as essential elements of urban mobility that are more sustainable, accessible, and improve the quality of life.

With the assumption that interruptions and accessibility difficulties in the relationships between different public transport and other transport systems (such as intermediate public transport, shared mobility, micro-mobility, etc.) and their environments stem from a type of "integration/non-integration" status, the literature search commenced with the concept of "spatial integration". Detailed literature analysis subsequently revealed that the solution to this problem is closely related to the concept of "sustainable urban mobility". In this context, the conceptual framework has been specialised as "spatial integration at public transport nodes within the context of sustainable urban mobility".

1.2 Problem Statement and Research Gap

Sustainable mobility targets predominantly focus on macro-level quantitative metrics, such as expanding rapid transport networks, introducing new mobility nodes, and reducing overall carbon emissions (Ewing & Cervero, 2010; Amen, 2021). While these supply-oriented strategies are essential for sustainable urban mobility, they often overshadow the micro-spatial dynamics of transport environments. Consequently, urban policies frequently lack targeted initiatives aimed at optimizing the utilization of existing or newly planned transport stations, particularly regarding underused station exits and immediate pedestrian catchment areas (Bertolini, 1999).

This oversight can result in the emergence of public transport nodes that fail to physically and socially integrate with their environments and operate below their planned capacity. Altering the built environment after a transport node is operational imposes massive socio-economic costs, disrupts community dynamics, and suffers from infrastructural path dependency (Gutiérrez et al., 2011; Loukopoulos et al., 2005). Therefore, attempting to fix spatial integration issues reactively is neither economically viable nor socially sustainable.

To prevent the emergence of poorly integrated transport nodes, station environments must be approached with a proactive, holistic design methodology. Rather than treating transport nodes merely as entry and exit points for transportation, they must be designed as integral parts of the urban fabric. This requires the development of pre-evaluative systems that can predict spatial outcomes, pedestrian behaviours, and integration success during the design phase, long before physical interventions occur (Hillier, 1996; Vale, 2015).

Despite the acknowledged importance of Transit-Oriented Development (TOD), there remains a significant research gap in the literature regarding comprehensive, predictive design frameworks that operate at the micro level. While macro scale transport planning is well documented, there is a lack of synthesized knowledge on how to systematically predict a station's success based on its immediate physical design. Specifically, there is a need for a unified framework that evaluates spatial integration prior to construction by combining structural, functional, and perceptual design elements. By addressing this gap, this study aims to provide the necessary theoretical groundwork to shift transport node design from a reactive, cost-heavy process to a predictive, preventative, and holistic practice.

1.3 Objectives and Hypotheses

The primary objective of this systematic literature review is to identify and categorize the micro-morphological design elements that facilitate the spatial integration of public transport nodes with their immediate urban environments, based on Scopus-indexed research published between 2010 and 2025. To this end, the study is structured around the following research questions and core hypothesis:

- Research Question 1: Which specific design parameters are consistently identified in the literature as key drivers for the spatial integration of transport nodes?
- Research Question 2: To what extent does the current body of research provide a holistic and integrated framework that combines structural, functional, and perceptual elements?

Hypothesis: The effective utilization and spatial integration of public transport nodes are fundamentally contingent upon the balance of structural, functional, and perceptual elements; however, this holistic synthesis is not yet sufficiently represented in the current literature.

1.4 Significance and Structure of the Paper

The significance of this study lies in its potential to bridge the critical gap between macro-scale transportation planning and micro-scale urban design. While current urban policies are heavily invested in expanding transport networks to meet carbon neutrality targets, the spatial performance of the nodes themselves, specifically their integration with the pedestrian realm, frequently remains a secondary consideration. This research provides a substantial contribution by shifting the focus toward a preventative design paradigm. By identifying specific design elements and methodologies early in the planning process, it enables the detection of potential spatial conflicts and prevents the prohibitive financial and social costs associated with post-construction structural modifications and community severance.

By synthesizing scattered literature from the Scopus database (2010-2025), this study establishes a holistic framework that categorizes transport node integration into structural, functional, and perceptual dimensions. This classification offers a more comprehensive lens than traditional accessibility models. The findings offer urban designers and policy-makers a set of evidence-based indicators to be utilized during the initial design phase. This advocates for a strategy that prevents underutilized station exits, ensuring the long-term viability of transport investments.

To fulfil these objectives, the study follows a systematic progression, first, the core concepts and keywords are examined both individually and in relation to one another to understand their interdependencies. Second, based on the synthesized literature, the study identifies the essential design components and the specific methods used to assess them. Finally, these identified components are evaluated to provide a comprehensive roadmap for future projects.

2. Literature Review

When the keyword “spatial integration” is searched over time, it is seen that the number of studies has increased exponentially in the last 10 years. Scopus has 1296 studies conducted between 2010 and 2025. It is observed that most of these studies were published in sustainability-related journals (figure 2).

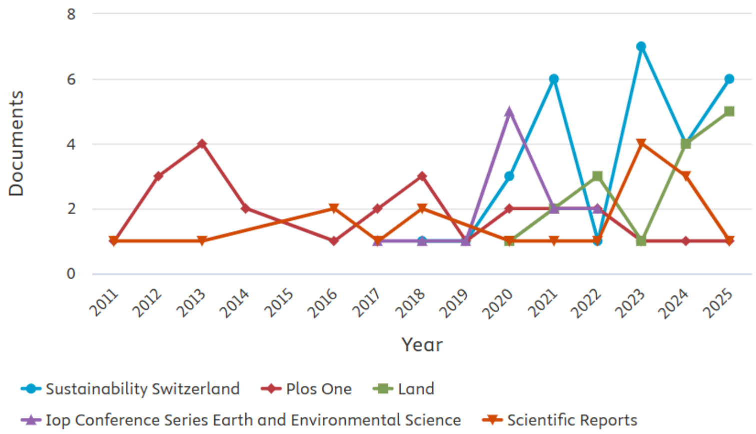

Figure 2. Documents per year by source (Generated using Scopus analyse results, 2026).

Between 2010 and 2025, there were 1635 articles published using the keyword “sustainable urban mobility”. Similarly, with the keyword “spatial integration”, a significant increase in the number of studies on this topic has been observed in recent years (figure 3).

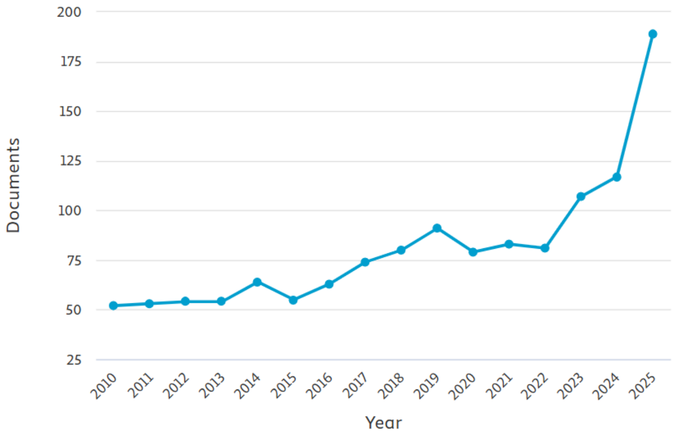

Figure 3. Documents by year (Generated using Scopus analysis results, 2026).

When the concepts in 1635 studies using the keyword “sustainable urban mobility” were analysed using the VOSviewer program, it was observed that the concepts were concentrated around the topic of “integration”; and that “assessment” and “space syntax” also occupied a significant place (figure 4).

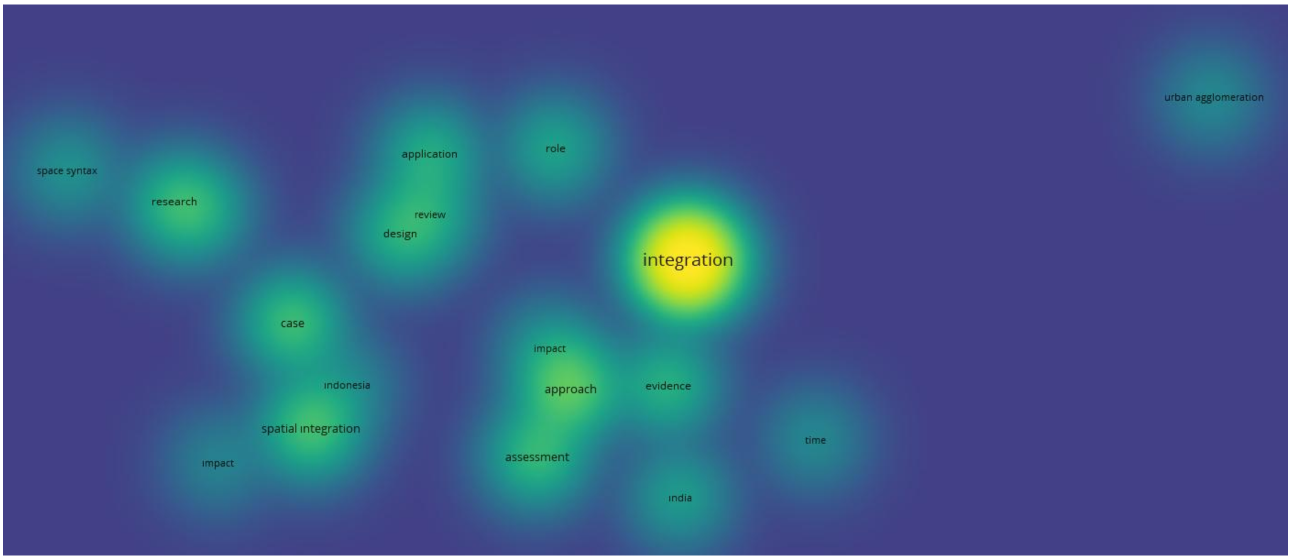

Figure 4. Density visualisation of keywords retrieved from Scopus (Generated using VOSviewer, 2026).

Only one study includes the concepts of “spatial integration” and “sustainable urban mobility” simultaneously in its title, abstract, or keywords. This study is the article “Bridging the Accessibility Gap in Green Tourism: A Framework for Sustainable Integration of Specialised Off-Road Wheelchair Services with Public Transport Networks” by Kłos & Staniek (2025), published in the journal “Sustainability Switzerland” in 2025, which addresses the issue of “sustainable mobility” in the context of “accessibility, social exclusion, and tourism economics”. Only one study includes the concepts of “transport nodes”, “integration”, and “mobility” simultaneously in its title, abstract, or keywords. That research proposes combining “smart mobility” and the “TOD approach” for “smart urban living” and incorporated eight TOD performance indicators (utilization of transportation nodes, user-friendliness of the transportation system, parking at stations, walking and cycling facilities, land-use diversity, accessibility and availability, density, and economic development) and six smart mobility indicators (location efficiency, reliable mobility, health and safety, environmental management, social equity, and a strong economy) for areas to be designed with this combination (Sharif & Rahman, 2022).
In Sections 2.1, 2.2, and 2.3, which are subsections of the second part, the main concepts of the research are examined using a descriptive literature review method. In Section 2.4, spatial integration and design elements in public transportation nodes are determined by utilizing studies published in the Scopus database between 2010 and 2025 as a result of a systematic literature review.

2.1 Sustainable Urban Mobility Paradigm

From the 1950s to the early 2000s, owning a car was not only about transportation, but also proof social status, the biggest indicator of transitioning to the middle class. Traditional transportation planning, shaped after the Industrial Revolution and cantered on car ownership, is now insufficient to address multifaceted crises such as traffic congestion, air pollution, energy consumption, and social inequality. OECD's 2004 report, “Promoting Environmentally Sustainable Transport: The Role of Behavioural Measures”, stated that despite advancements in transportation methods, the planned improvements have not been achieved, and this may be due to the neglect of the human factor. The concept of Sustainable Mobility was first defined by the European Commission in 2009 through principles such as multimodality, safety, quality of public spaces, social inclusion, and behavioural transformation. The first Sustainable Mobility Guidelines were created in 2013. In 2018, the Commission initiated a process to update these guidelines to better reflect the trends affecting the changing mobility environment. This plan is defined as a strategic plan integrated with urban transportation, aiming to restructure existing planning practices based on the principles of integration, participation, and evaluation. The main starting point of the United Nations' 2013 report, "Planning and Design for Sustainable Urban Mobility", is that despite increasing urban mobility opportunities, the observed decline in access to services indicates that the fast and efficient transportation system provided is actually only preferred for essential activities, but does not provide sufficient ease of access to ensure urban mobility. One indicator of this conclusion is that half of all travel in developing countries is done by private vehicles, and private vehicle ownership is ten times higher than in developed countries.

2.2 The Role of Public Transport Nodes in Sustainable Urban Mobility

One of the most concrete manifestations of this transformation, required by the sustainable urban mobility paradigm, is public transport nodes. Each type of public transport system, such as metrobus, sea bus, tram, funicular, metro, bus, and minibus, has distinct spatial characteristics. In sustainable urban mobility, the fundamental differences between the stops or stations of various transportation systems are shaped by accessibility, capacity, cost, and their relationship with the urban environment. To achieve sustainable mobility goals, a system where different modes of transportation complement each other needs to be established. In this system, a journey is a chain that begins with leaving home and ends with arriving at the destination. Multimodality is the use of multiple modes of transportation in combination from the beginning to the end of a journey. The extent to which this structure offers a seamless experience during access and transfer phases is as crucial as the spatial and operational aspects of multimodality.

Public transport nodes function as critical mode transition points where the journey chain is broken or continues. In this context, the different modes of urban transportation, rather than being competing substitutes, form a holistic ecosystem that can only compete with private vehicles when they work together and the necessary conditions for micro-mobility are met.

2.3 Spatial Integration in Urban Space in the context of Micro-Meso-Macro Scale Relationships

Spatial integration is a fundamental concept in understanding the relationship between sustainable urban mobility and public transport nodes. It is a conceptual definition that expresses the level of relationship established by different units within a spatial system, and what is essential here is not the parts themselves, but the spatial characteristics of the new form that the parts bring together. As the scale increases, spatial integration is associated with more complex spatial networks and user groups. At the city scale, spatial integration is a fundamental requirement in terms of accessibility, social interaction, and the continuity of public life, and it is a concept that needs to be understood through relational and structural mechanisms that ensure continuity in the urban built environment. In the literature, the importance of spatial integration has been evaluated with different themes such as "generating mobility, safe and vibrant public spaces, economic and functional efficiency". One example where spatial integration is considered to have been successfully achieved in urban space is the London Millennium Bridge, designed by Foster+Partners and completed in 2000. The map in the lower left shows the changing integration graph of the environment as a result of the pedestrian bridge, whose location and angle were determined through spatial arrangement analyses. This project is not just a bridge connecting two sides; it is a design that spreads vitality throughout the entire city through the analysis of elevation differences, ramp slopes, and pedestrian paths. Public transport nodes, where urban mobility is concentrated and interactions at different scales occur simultaneously, are critical thresholds where spatial integration must be concretely realized.

2.4 Spatial Integration and Design Elements in Public Transport Nodes

Achieving the sustainable urban mobility objectives requires making public transportation the primary mode of transport in cities; this necessitates not compromising on physical, functional, and perceptual accessibility dimensions. The subsections detail the structural, functional, and perceptual components of integration in public transportation nodes, and the design elements related to these components.

2.4.1 Structural Components

Structural components focus on the physical form, geometry, and topological structure of the street network within the urban fabric in which the station is located; they constitute the physical infrastructure where human movement takes place. In studies in the literature that address the successful integration of public transport nodes with their environments in the context of structural components, different design elements are highlighted. Uyar et al. (2017) focuses on "spatial configuration"; Gümüş et al. (2022) on "connectivity"; and Mindell (2017) on "permeability".

Spatial configuration, specifically in station design, refers to considering how the streets forming the pedestrian network and the public transport nodes where the transportation network interacts with pedestrians come together. In the context of public transport node structures and their environments, spatial configuration functions as an invisible infrastructure that determines the natural flow of pedestrian movement, ease of orientation, and accessibility. Uyar et al. (2017) developed an applied study at the micro-scale, generating alternatives for the "spatial configuration" of a station using the "agent-based modelling" method. In this study, where space syntax was used in the micro-scale design of metro exits, the problem area consisted of newly constructed metro stations with very low occupancy rates. Micro-scale analyses were conducted in these areas, and alternative station designs were developed using the space syntax method, with predictions made for possible outcomes. The analyses compared the integration value changes when connecting from the same entry and exit points at different elevations, directions, or distances. This study also included factors such as movement from the perimeter to the station, movement from the station to the perimeter, and background movements, including pedestrian crossings, overpasses, ramps, stairs, traffic lights, and access to other modes of transport. The analyses shown on the left, include pedestrian request lines, a spatial integration map of the current situation (figure 5), and three proposed design studies. The proposal in the right in figure 5 includes a pedestrian bridge, while the analysis in the left shows a design without a pedestrian bridge, using pedestrian crossings and traffic lights in figure 6. In figure 6, the option on the right shows the integration map for both the option without a pedestrian bridge and the option where the exit point is moved to the other side of the road.

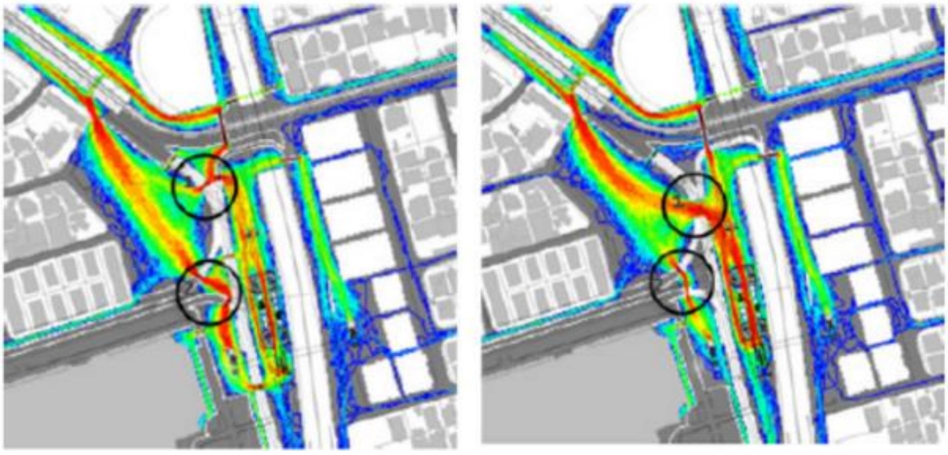

Figure 5. Spatial integration map of the current situation (left) and the first proposal created in line with pedestrian request lines (right) (Uyar et al., 2017).

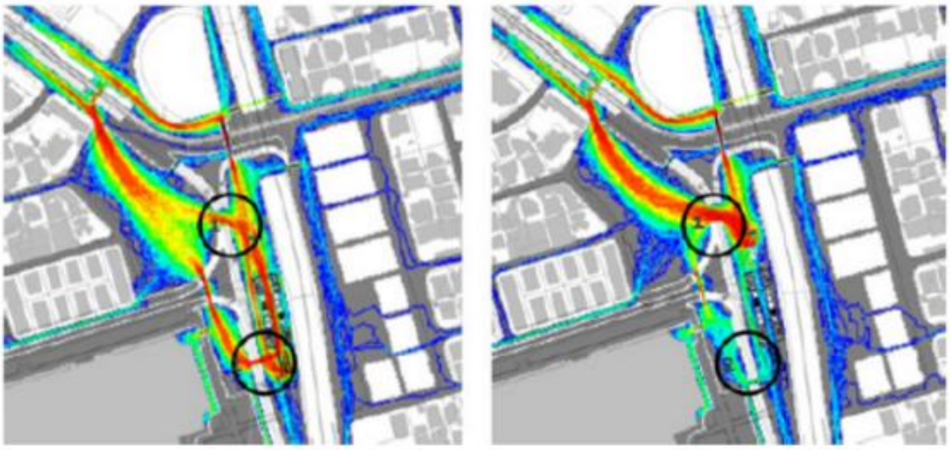

Figure 6. The second proposal without a pedestrian bridge (left) and the third proposal without a pedestrian bridge and with the entrance reversed (right) (Uyar et al., 2017).

Connectivity is related to the frequency of nodal points, or intersections, and the number of direct connections in the street network around the station. A low number of dead-end streets and a high number of intersections around the station are characteristics that increase connectivity. According to the analysis findings in Gümüş et al.'s (2022) study, which comparatively analyses the “space syntax” and “Project for Public Spaces (PPS)” methods, connectivity alone does not guarantee spatial integration, but it determines the social potential of the area. In the example area, low connectivity in the streets connecting the metro and tram axes can lead to low integration values despite circulation. Gümüş et al. (2022) also found that high connectivity values strengthen individuals' perception of the environment and sense of place.

The intersections in figures 7 and figure 8 are an indicator of the dense and multi-directional pedestrian flow on the metro. The circular area in the centre of the intersection and the diagonal pedestrian crossing completely stop vehicular traffic, allowing pedestrians to walk in all directions. This design aims to increase pedestrian mobility and reduce transfer times for public transport users.

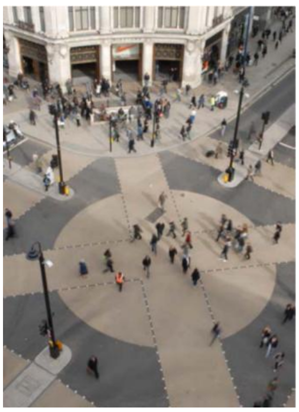

Figure 7. Intersection between the exits of London Oxford Circus underground station (Transport for London, 2015).

Figure 8. Satellite image of London Oxford Circus metro station (Source: google.com/maps, 2025).

To achieve the sustainable urban mobility objectives, the street network surrounding public transport nodes must be permeable and accessible. The walking route a pedestrian takes from the node to their home, workplace, or destination should be unobstructed, safe, and as short as possible. Permeability is the degree to which the physical boundaries of the urban fabric, in other words, building blocks, allow passage.

Mindell (2017), evaluating public transport nodes in the context of sustainable urban mobility through the element of "permeability", tested this element using the pedestrian environment study system-PERS (participatory mapping, spatial analysis, video observations, and surveys). She used the participatory mapping method to understand the impact of roads on the daily practices of the local population, destinations visited, places avoided, and pedestrian routes. Using spatial analysis and space syntax, she analysed the geometry of the street network to identify important routes for pedestrian and vehicular movement. She determined crossing rates at specific points using video observations. She also measured physical barriers and pedestrian infrastructure using the PERS method. In this method, the following elements were considered for crossings: crossing possibilities, delay time, deviation from the main route, accessibility for people with disabilities, traffic islands, and signalling quality; for pedestrian paths: effective width, surface quality, lighting, safety, obstacles, and signage; and for environmental quality: landscape, cleanliness, drainage, and maintenance. It is argued that large station structures, such as train stations, create a barrier effect that prevents individuals from accessing goods, services, and social networks when they lack sufficient permeability. Analyses have observed that low permeability creates significant imbalances in pedestrian usage on both sides of the transportation corridor. Therefore, even if accessibility, comfort, and safety are ensured along the route of a public transportation node located between large building blocks, its usage rate may decrease due to long distances or a lack of alternative routes.

2.4.2 Functional Components

Functional integration is the interaction of the transportation services offered by a public transport node3 with other functions of urban life. This section focuses on how the physically existing space is used, its performance, and the variety of activities it offers in terms of the functional components that influence the integration of public transport nodes with their environments. Curtis & Scheurer (2010) and Cascetta et al. (2013) focuses on the impact of "accessibility"; Ewing & Cervero (2010), Forsyth (2015), Stockton et al. (2016), Bivina et al. (2020) and Gupta et al. (2020) focused on "walkability"; and Sung & Oh (2011), Xu & Chen (2021) and Dong et al. (2025) focused on the impact of "land-use diversity" on the spatial integration of public transport nodes.

In the context of public transportation nodes, accessibility refers to the ability of the population within the service area to reach the station on foot, by bicycle, or by car without encountering physical or temporal barriers. For individuals with physical disabilities, it is important that sidewalks leading to stops are of standard width, smooth, and level; that stations have elevators and wheelchair ramps; that there are tactile surfaces for the visually impaired; and that the gap between the stop platform and the vehicle floor is minimized. Stop and route information should be easily understandable by everyone. For individuals with visual impairments, route and timetable information should be presented on large-print, contrasting-coloured panels; and an audio announcement system should be used for the hearing impaired (United Nations, 2025). Curtis & Scheurer (2010) developed a GIS-based tool called "Spatial Network Analysis for Multimodal Urban Transportation Systems (SNAMUTS)" for "sustainable accessibility" planning. This tool analyses the performance of the transportation system by reflecting users' decision-making processes (travel time, frequency, and mode preference). The model is based on the perceived difficulty by the user rather than the physical distance of the network. Cascetta et al. (2013), who define accessibility as "perceived opportunities", argue that for a public transport node to integrate with its environments, the user must perceive a benefit in being able to access nearby services when exiting that stop. In their analysis, Cascetta et al. (2013) divide accessibility into two groups, "active accessibility and passive accessibility" based on the number of perceived opportunities. Active accessibility is pedestrian-oriented and is an indicator of the capacity to meet the needs of individuals. Passive accessibility, on the other hand, is location-oriented and is measured by how easily it can be reached by potential users.

Walkability is a functional parameter that refers to the quality and comfort of pedestrian access to services. The continuity of sidewalks around the station, the quality of the pavement, and the safety of pedestrian crossings increases the level of functional integration of the station with its environments. In their meta-analysis study, Ewing & Cervero (2010), using their 5D model developed in 2001, examined the impact of design on travel demand. Their findings indicate that walking is most strongly associated with "distance to stops" and "street network design". According to the analysis, intersection density is a more significant factor influencing people's decision to walk than street connectivity. The variables in the 5D model, created to analyse the effects of the urban built environment on travel behaviour, are "density", "diversity", "design", "destination accessibility", and "distance to public transport". Forsyth (2015) divides walkability into recreational and functional walking. He considers public transport nodes as one of the target points in the functional walking category, which is undertaken to achieve a specific goal. He classifies places like homes and workplaces as first-level destinations, public transport nodes as second-level destinations, and distant urban opportunities as third-level destinations. According to the author, these focal points are not random targets, but strategic nodal points that ensure the functioning of the urban system. They point out that a clear definition of walkability should be made in projects; otherwise, while trying to create a social vibrancy area, the goal of exercise might be missed, or aesthetic appeal might be sacrificed while trying to increase safety. Liu et al. (2020) highlight a similar contradiction, stating that the presence of residential, office, and commercial units within walking distance of the station encourages walking, but the presence of too many retail units can lead to crowded sidewalks or illegal occupation, reducing ease of walking. They suggest that routes with 25%-50% commercial frontage are ideal for pedestrians.

Stockton et al. (2016) argue that the existing W-Index walkability index in the literature has some shortcomings in terms of micro-scale data analysis. In this study, walkability is a measure; "residential density, street connectivity, and land use diversity" are also considered as measurement criteria. Stockton et al. Bivina et al. (2016) demonstrate in this study that walkability is not a homogeneous characteristic spread across the city, but can vary significantly from one neighbourhood to another, and even from one public transport node to another. The study shows that high walkability scores in analyses conducted in London coincide with the areas around stations with the densest public transport networks. Bivina et al. (2020), in their study examining factors affecting pedestrian access to metro stations in Delhi, India, argue that both micro-scale and meso-scale factors are important in the context of the built environment. Analysis using structural equation modelling shows that micro-scale factors have a more dominant effect on pedestrian satisfaction; elements such as street lighting, traffic signs, and signalling make pedestrians feel safe; the presence of pedestrian crossings and the unobstructed nature, continuity, and width of sidewalks directly affect walking comfort; and low vehicle traffic speed and volume increase the desire to walk. According to the study results, the coexistence of residential, commercial, and recreational areas is the meso-factor that most increases the likelihood of walking. Another finding is that more vibrant streets in high-density areas help pedestrians feel safer. Instead of making large-scale urban changes, micro-scale improvements such as improving pavements and enhancing safety are considered a more cost-effective way to increase pedestrian accessibility. In developing cities like Delhi, it was concluded that focusing on physical distance to facilitate access to the metro, as well as pedestrians' perception of safety and comfort on the street, is necessary. The research emphasized that a pedestrian-friendly environment supports the use of public transportation. Gupta et al. (2022) continued this study using structural equation modelling, but with a hybrid discrete mode selection method. In the hybrid discrete choice model, psychological variables that cannot be directly observed but can be measured in surveys were integrated into the analyses.

A dense, mixed-use, and pedestrian-prioritized spatial organization around public transport nodes is a fundamental design strategy that strengthens the spatial integration of these nodes. The coexistence of functions such as housing, offices, commerce, and recreation around the station is referred to as "land-use diversity". Sung & Oh (2011), in their research focusing on design elements affecting public transportation use, used multiple linear regression analysis to determine the relationship between TOD factors and public transportation passenger numbers, based on a 500-meter radius of 214 metro station areas in Seoul. The analyses revealed that in compact cities like Seoul, simply increasing density is insufficient; instead, pedestrian-friendly designs and mixed land-use should be prioritized. According to the findings regarding "diversity", the coexistence of commercial and residential areas spreads travel demand throughout the day and increases vibrancy around public transportation nodes. Xu & Chen (2021), using space syntax, traditional field research, and point-of-interest data (POI) in their spatial analysis, showed that underground vibrancy depends not only on interior architectural structures but also on external factors such as the location of station entrances, accessibility to metro lines, and above-ground commercial diversity. The study emphasizes that "functional mixed-use" and "pedestrian flow predictions" play a strategic role in the planning phase to prevent underground channels from becoming idle.

Dong et al. (2025) examine metro stations in three different dimensions (passenger mobility, land use, street view) within the framework of "multidimensional semantic analysis". All semantic data obtained from smart card, POI data and street views are grouped using algorithms such as K-means, fuzzy C-means and spectral clustering. Thanks to these groupings, both the individually determined dimensions of the stations and the similarities and differences between dimensions are analysed. Passenger mobility is analysed using records obtained from smart card data to create a "passenger flow interaction-time matrix". A topic modelling method called "LDA" is used to extract low-dimensional mobility semantics from this data. "POI" data are used to understand the land use around the station. The researchers designed an indicator called "POI contribution factor" to determine the importance of each POI category. The research findings regarding land use suggest "promoting mixed land use in residential-oriented areas".

2.4.3 Perceptual Components

Perceptual components focus on how the user experiences a space, how they map it in their mind, and how they establish visual relationships. These components ensure the readability of the space. In public transportation contexts, this differs, especially for a user unfamiliar with the destination, from the perceptual level of a pedestrian who uses urban space simply by walking. This is because there is a difference between the space where the user boards public transportation and the space after they disembark. Liu et al. (2020) and Charalambous et al. (2021) examine the perceptual components affecting

the integration of public transport nodes with their environments, focusing on the elements of “intelligibility and wayfinding”; while Natapov et al. (2024) and Dong et al. (2025) address the elements of “visual continuity and visibility”. Intelligibility refers to the ease with which an urban environment can be understood and mentally organized by its users. A station environment where the user can navigate without hesitation, without fear of getting lost, and where they can constantly update their mental map indicates high spatial quality and strong perceptual integration.
Intelligibility is a property of space; wayfinding is the action of humans within that space. In public transportation nodes that are spatially integrated with their environments, users can intuitively find their way using architectural cues and hierarchies of the space, with minimal need for signage. Liu et al. (2020) examine the “wayfinding” element through route selection behaviours during the process of going to and from a metro station. The data used in the research was obtained from face-to-face interviews with 803 participants within an 800-meter radius of a typical metro station in a second-tier city. The “Multinomial logit model” method was used to model preferences. The analysis findings indicate that factors such as traffic lights and pedestrian crossings, sidewalk width, and bicycle lane separation, which influence passengers' route selection behaviour around stations, make the wayfinding process safer and more accessible, and that street lengths between 100-200 meters are ideal. The findings also state that pedestrians prefer routes with 4-6 story buildings to routes with taller buildings because they offer a more spacious field of vision, and that street lighting density and crowding are factors determining how safe or comfortable users perceive a route to be. The basis of the studies by Charalambous et al. (2021), which focus on repositioning (aha! moment) and exploratory behaviours during wayfinding in complex urban environments, is the “visibility graphs” developed by Turner et al. (2001), which are based on “isovist (field of vision)” analyses. Isovist, representing the area directly visible from a point, allows for the analysis of space as perceived and experienced by the individual. The study states that passive movement (moving the body without physical effort) in an individual traveling on public transport disrupts spatial updating in the mind, and creates a need for repositioning upon exiting a stop or station where public transport use ends. It argues that designing station exits to offer multi-directional fields of vision will help passengers match their mental maps with the physical environment and find their way.
Visual continuity refers to the observer's ability to perceive spatial depth and target while in motion. In physically disconnected areas like stations, having visually interconnected design elements is a crucial factor in ensuring users move around safely. Natapov et al. (2024) criticize the focus on street networks for pedestrian navigation in most designs, arguing that pedestrian navigation is generally guided by “points of interest” and “visibility”. Based on this hypothesis, Natapov et al. (2024) integrate “points of interest” and “visibility” into a network-based framework using open-source data with their tool called “POI VizNet”. In the study by Dong et al. (2025), which analyses metro stations in three different dimensions (passenger mobility, land use, street view), visual semantic features in the sample areas are analysed using pixel-level semantic segmentation with the DeepLab v3+ deep learning model. With this analysis, indicators such as visual closure, green space ratio, activity level, and openness are calculated, and it is determined that some stations may have different land use and street-level visual data despite having similar mobility patterns. As a result of the research, it is recommended to “increase green areas in central stations with high closure ratios”.

3. Findings

The systematic literature review conducted between 2010 and 2025 using the keywords “sustainable urban mobility, public transport nodes, spatial integration” in the Scopus database revealed that spatial integration in public transport nodes is based on three fundamental pillars: structural, functional, and perceptual. Structural components determine the physical framework and accessibility of the space, while functional components shape the intensity of use and vitality of the space, and perceptual components shape the user's capacity to embrace and mentally map the space. The data obtained from the literature review are presented in table 1, table 2 and table 3.

Table 1: Structural design elements for spatial integration in public transport nodes.

Spatial integration	Design element	Indicators	Variables	Methodology	Researcher
Structural components	Spatial configuration	Intelligibility	Simple entry and exit points to the station, clear signage	Space syntax, agent-based modelling	Uyar et al., 2017
	Connectivity	The values of integration and intelligibility, synergy	Topological depth, number of turns, distance to the system	Space syntax, PPP approach	Gümüş et al., 2022
	Permeability	Human welfare	Presence of physical barriers, deviations from supply lines, continuity of pedestrian flow	PERS, space syntax	Mindell, 2017

Table 2: Functional design elements for spatial integration in public transport nodes.

Spatial integration	Design element	Indicators	Variables	Methodology	Researcher
Functional components	Accessibility	Sustainable accessibility	Number of transfers, interference (time/frequency), isochronous coverage	SNAMUTS model, composite accessibility index	Curtis & Scheurer, 2010
		Active and passive accessibility	The number of perceived available opportunities, time-space prisms	Perceived opportunities model	Cascetta et al., 2012
	Walkability	Travel demand (micro-mobility, public transport, car)	Population density, functional diversity, urban design, accessibility to public transport nodes	Meta-analysis	Ewing & Cervero, 2010
		Walkability as a holistic solution	Individuals' perception of the environment, the definition of walkability in projects	Literature review	Forsyth, 2015
		Walking time in adults	Housing density, street connectivity, land-use diversity	Neighbourhood walkability index	Stockton et al., 2016
		Perception of walking accessibility	Mesoscale built environment, microscale-built environment, socioeconomic factors	Structural equation modelling, GIS datasets, surveys	Bivina et al., 2020
		Walking time, vehicle traffic speed, pavement width and continuity, difficulty of crossing the street, visibility of the destination, aesthetic appeal, building density, population and employment density.	Walking behaviour, built environment characteristics, urban fabric type, socio-demographic characteristics, land use type	Space syntax, GIS	Sun et al., 2016
		Transportation options within walking distance of metro stations	Neighbourhood design, micro-scale built environment	Hybrid Structural equation modelling, binominal logit model	Gupta et al., 2022
	Land use diversity	Public transport usage rate	Density, diversity, street network, and building forms	Multiple linear regression analysis, land use mix index, variance inflation factor	Sung & Oh, 2011
		Spatial vitality	Analysis radius (r=250/500/1200), potential motion flows	Space syntax, POI data analysis	Xu & Chen, 2021
		POI category	Density and distribution of urban functions within the station's impact area.	POI contribution factor	Dong et al., 2025

Table 3: Perceptual design elements for spatial integration in public transport nodes.

Spatial integration	Design element	Indicators	Variables	Methodology	Researcher
Perceptual components	Intelligibility and way finding	Pedestrian route selection behaviour	The built environment at the street scale (street length, building heights, retail frontage, passageways, road width, greenery, lighting, crowding)	Multinomial logit model	Liu et al., 2020
		Wayfinding performance	Perceived geometric information, brain dynamics	Electroencephalography spatial sequence visibility graph analyses	Charalambous et al., 2021
	Visu al conti nuity	Accessibility and urban vitality	POI locations, metric distance, average path length.	POI VizNet and network analysis	Natapov et al., 2024

	Visual semantic indicators	Coverage (building ratio), open space (sky ratio), green space ratio	SVI semantic segmentation (street view)	Dong et al., 2025

4. Discussion

4.1 Interpretation of Key Findings

The literature shows that structural components create the potential of a space, functional components transform this potential into usability, and perceptual components link this usability to experience and passenger loyalty (Table 4). Therefore, there is an interactive, rather than hierarchical, relationship between design elements.

Table 4: Component s of spatial integration in public transport nodes.

Components	Design element	Rationale in the literature	Comparative assessment
Structural	Pedestrian network continuity	Removal of physical barriers	It forms the core infrastructure; they are a prerequisite for the operation of all other systems
Functional	Active frontages	Social surveillance and economic vitality	It turns structural form into a vibrant space
Perceptual	Lighting and comfort	Sense of belonging and security	Ensures the user's intention to reuse the system

4.2 Strengths and Limitations

The systematic literature review presented in Section 2.4 includes studies from 2010 to 2025 within the scope of the defined keywords. Initial filtering of the studies to be considered among all listed results was done by title, keywords, and abstract. Studies excluded in this initial filtering phase may have addressed the design elements examined in this study as a sub-topic. This research may be addressed under different conceptual names in different databases. The design elements that are the subject of this research have been the subject of many different studies. However, there are few studies that comprehensively address how these design elements are specific in public transportation contexts. Increasing the number of such studies is essential to enable comparisons in light of changing mobility needs.

4.3 Implications and Future Directions

The literature reviewed shows that the problem of spatial integration is generally addressed through isolated dimensions. The vast majority of research focuses on functional criteria such as accessibility, walkability, and land-use diversity. When existing approaches in the literature are synthesized, it is seen that the success of sustainable urban mobility depends on the simultaneous provision of structural, functional, and perceptual components. If an area with high functional diversity lacks visual continuity or street permeability, spatial integration remains incomplete. Most current studies examine cross-sections at specific time periods. It is understood that future research should model time-space dynamics more precisely by combining deep learning (semantic segmentation) and real-time passenger mobility (smart card/cell phone signals) data. Visibility analyses have mostly focused on above-ground street networks. There is a need for micro-scale studies that will examine “repositioning” and wayfinding behaviours, especially when exiting underground rail systems to the surface, through cognitive mapping. Much of the literature is based on best practice examples from compact/developed cities in Western Europe, North America, and East Asia. Comparative case studies examining how these integration components perform in the context of chaotic urban fabrics or varying climatic conditions in developing countries will make a significant contribution to the literature.

5. Conclusion

The findings indicate a conceptual disconnect between macro-scale urban planning decisions and micro-scale design elements. As understood from the studies of Mindell (2017) and Liu et al. (2020), a correctly positioned station at the macro scale may not provide the expected pedestrian flow and vibrancy due to poor orientation, blind facades, or barrier effects at the micro scale. Studies using space syntax and isovist analyses demonstrate how structural geometry and perceptual wayfinding processes mutually reinforce each other. However, interdisciplinary studies that examine physical permeability in conjunction with individual perceptions of safety and comfort occupy a more limited space in the literature. The research reveals that the methods used are evolving from static analyses to dynamic and user-oriented analyses. While early studies relied mainly on surveys, pedestrian counts, and static GIS analyses; current literature shows that data and machine learning-supported visual semantic analyses such as “DeepLab v3+” are coming to the forefront. While objective measurements of the physical environment can be modelled with high accuracy, Bivina et al. (2020). As highlighted by Gupta et al. (2016), hybrid methodologies that integrate pedestrians' psychological safety and aesthetic perceptions into these numerical models are still an area open to development in the literature. This systematic literature review confirms that spatial integration in public transport nodes is not merely an engineering and transportation planning problem; it is a “multi-layered design problem” that needs to be solved at the intersection of architecture, urban design, and environmental psychology.

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