

Key Quality Criteria in an Integrated Multiple Transport Systems Scenario: A Systematic Literature Review

Laura Ferretto, Martina Carra(✉), and Benedetto Barabino

Department of Civil, Environment, Land and Architecture Engineering and Mathematics (DICATAM), University of Brescia, Brescia, Italy
martina.carra@unibs.it

Abstract. Sustainable mobility represents a paradigm widely shared within the international panorama. It aims to encourage mobility alternatives to private cars, which can reduce externalities associated with transportation, meeting the principles of innovation and efficiency close to the *Smart city* concept. These forms include public transport, non-motorized mobility (pedestrian and cycling) and electric micro-mobility. The quality of these transport systems is one of the main factors influencing the user's transport modal choice. It depends on several factors related to services, infrastructure and the surrounding urban environment. The quality evaluation of public transport has been widely investigated, while that of non-motorized mobility and electric micro-mobility still needs to be explored, especially considering their interaction. This paper presents a systematic literature review fitting into this research area, providing a general overview and a first list of key quality criteria, underlying research gaps to support possible research developments. The proposed approach focuses on the integration of multiple transport systems, trying to understand how to encourage multimodality through the assessment and improvement of the entire travel experience. At the same time, it aims to provide practical tools for triggering regenerative processes in the urban context, which can respond to the new needs of contemporary society referring back to the *Smart city* concept, increasingly oriented toward creating public spaces for people rather than cars.

Keywords: Transport quality · Key quality criteria · Transport planning

1 Introduction

The urban environment relates daily to multiple and unprecedented challenges due to high urbanization and growing population density [1]. These economic, social and environmental challenges highlight how the traditional urban growth model is inadequate to meet the needs of contemporary cities, increasing the pressure that urban centers face. Within the complex urban system, mobility plays a central role in managing these externalities and, in recent decades, has become increasingly associated with the concept of "sustainability". Given the heavy weight that the transport sector takes on in

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024
O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14823, pp. 114–132, 2024.
https://doi.org/10.1007/978-3-031-65329-2_8

terms of externalities, the issue of sustainable mobility is one of the most debated topics in urban policies, aside from being an ace of the *Smart city* concept. Making cities "smart" requires providing a better quality of life [2] and finding environmentally sustainable urban mobility solutions. The development of sustainable urban transport systems depends on multiple factors and involves several transport modes, which include public transport, non-motorized mobility and newer forms of micro-electric mobility.

Public transport is considered an alternative to private cars, but it must provide quality services to be competitive. Knowing evaluation methods supported by quality criteria and indicators is essential for improving the quality of a transport system. Scientific research has been focusing on this issue for quite some time, making several contributions [3–6]. Some scientific interest has also developed toward pedestrian mobility quality assessment. Indeed, the development of a sustainable urban transport system also depends to a large extent on the propensity of users to consider "walking" an efficient transport mode for short-distance travel [7–10], which is closely dependent on their perception of the urban environment. Therefore, evaluating the quality of service (QoS) of infrastructures dedicated to pedestrian mobility, considering objective factors and the user's perception of the urban environment, is essential [11]. In addition, pedestrian mobility, as a conjunction between different modes of transport, strongly influences multimodality. Poor-quality pedestrian routes can discourage users from using public transport [12]. Consequently, more is needed to provide a good level of public transport quality to ensure its use by users. The quality of urban mobility must be considered, integrating different transport modes and land use [13, 14]. Cycling mobility can also contribute to developing a more sustainable transport system among these modes. Developing a set of assessment quality criteria and indicators to analyze the condition of existing bicycle lanes can be an effective tool for identifying infrastructure vulnerabilities and directing urban policies towards public space regeneration interventions [15, 16]. The same can be said of bike-sharing services [17–19] and electric micro-mobility [20, 21], which still need to be explored in the literature. Even these emerging forms of mobility offer the opportunity to rethink the urban space in which they operate, to build urban centers that are not only accessible and safe but also qualitatively attractive and "smart".

While there are numerous studies on the evaluation of urban transport quality, most of them focus on specific sectors. There is a significant gap in research that takes a holistic approach, evaluating the integration of various mobility systems and the urban environment. Therefore, this paper aims to fill this gap by investigating the key quality criteria and indicators that can assess the multimodality of an urban mobility system, going beyond the current segmentation between different modes of transport. The outcome of this research is crucial for deploying integrated solutions that enhance the quality of sustainable transportation services and infrastructures, from tangible implementations across networks to immaterial digital solutions like multimodal platforms and the development of quality indicators aiding in strategic planning [22].

Through a systematic literature review, this article provides an overview of how the concept of quality has been associated with transport systems. It identifies the most investigated forms of sustainable mobility and potential research gaps for future studies. The article also offers a preliminary set of criteria to assess the quality of urban mobility forms considered most sustainable and their integration. This identification of criteria

is crucial for improving the transport quality and its offer in terms of services, infrastructures and integration between several systems. It also enables the testing of effective urban policies in terms of public space regeneration and the management of conflicts linked to land use transformations.

The paper is organized as follows. Section 2 presents the methodology, including the search strategy and the type of analysis. Section 3 reports results with relevant descriptive statistics. Section 4 briefly reviews 49 publications, providing the current knowledge base and research gaps. Sections 5 and 6 present discussion and conclusions.

2 Methodology

The methodology applied to this systematic literature review is based on the technique PRISMA [23]. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement is a method for conducting systematic reviews and meta-analyses. It aims to collect all scientific evidence that meets predefined inclusion criteria and answers a given research question. This methodology consists of four stages: identification, screening, eligibility, and inclusion of collected articles (Fig. 1).

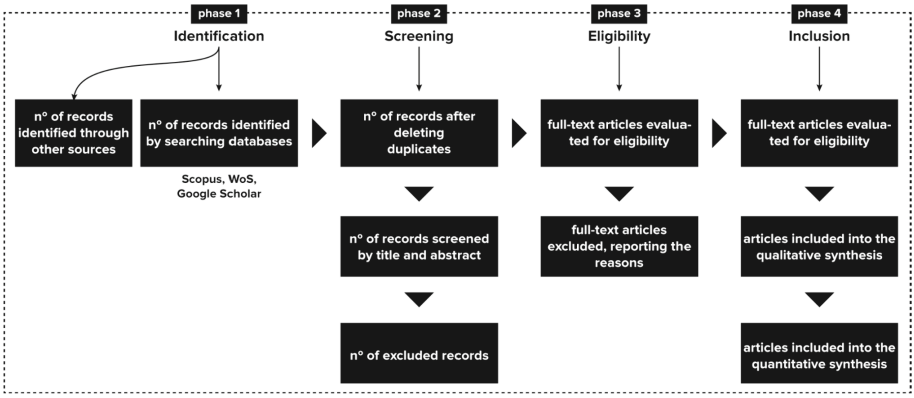

Fig. 1. Methodology flow chart. Source: personal elaboration based on [23].

The research question of this study focuses on the quality assessment of sustainable urban transport systems with a view to multimodality. An entire travel experience may include several transport modes, such as public transport, non-motorized mobility and electric micro-mobility, which may differ in terms of quality perceived by users. Given the research focus, private transport and studies relating to non-urban areas are excluded. The research aim is to identify key criteria for assessing the quality of a sustainable and integrated urban transport system.

3 Summary Results

3.1 Identification

The first phase of identification focused on identifying articles related to the quality of urban transport systems and infrastructure, starting with a keyword search conducted in three databases (DBs): Web of Science (WoS), Scopus, and Google Scholar. On Scopus and WoS the search was carried out on title, abstract and keywords, while on Google Scholar on title only, since the search system does not include the abstract and keywords. In all DBs, the same keywords were used to relate the quality assessment to the forms of urban transport mentioned above. After obtaining the search results, a single DB containing all scientific articles and their characterization was structured.

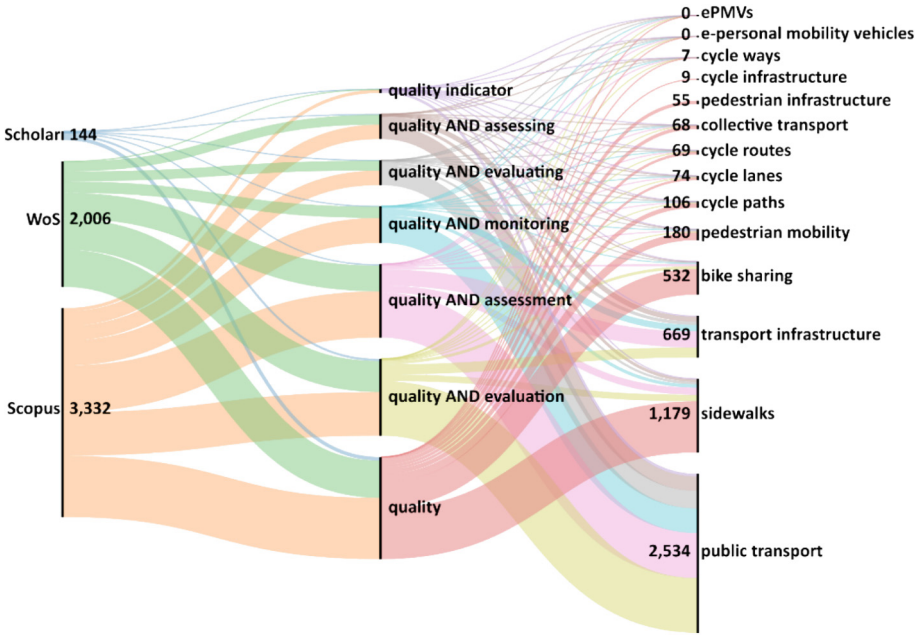

Fig. 2. Summary diagram of the results obtained from the first phase of the PRISMA statement. Source: personal elaboration adapted from Ferretto et al. (in press) [24].

Within the three chosen DBs, the keywords "quality" and "quality indicator" were cross-referenced with "assessing", "evaluating", "monitoring", and with "public transport", "collective transport", "sidewalks", "pedestrian mobility", "cycle lanes", "cycle paths", "cycle ways", "cycle routes", "bike sharing", "ePMVs", "electric personal mobility vehicles", "transport infrastructure", "pedestrian infrastructure", and "cycle infrastructure" for a total of 84 different combinations. Searching for scientific articles through these keyword combinations resulted in 5,482 records: 144 on Google Scholar, 2,006 on WoS, and 3,332 on Scopus. The records from Google Scholar are inferior because the search was only carried out by title, not by abstract and keywords.

Numbers in the first block of Fig. 2 represent the number of articles that emerged from the search in the three DBs, where the same keywords, given by the combination of the words in the second and third blocks, were searched. The width of the streams connecting the different blocks represents the number of articles that emerged from each keyword combination in each DB.

Therefore, the words in the second block were searched in association with those in the third block, corresponding to the mobility systems that were investigated. A first clear result, already at this preliminary level of analysis, concerns the prevalence of scientific studies focusing on public transport, rather than electric micro-mobility and non-motorized mobility systems (see Fig. 2). Indeed, 47.5% of the articles obtained come from the association with the keywords "public transport" and "collective transport"; 25.8% from the association with "sidewalks," "pedestrian mobility," and "pedestrian infrastructure"; 12.2% from the association with "transport infrastructure"; 9.7% from the association with "bike sharing"; finally, 4.8% from the association with "cycle lanes," "cycle paths," "cycle ways," "cycle routes," and "cycle infrastructure." There is no record of the association with "electric personal mobility vehicles" and its acronym "ePMVs," indicating that the most emerging forms of electric micro-mobility are still poorly explored in the literature from the point of view of their quality.

3.2 Screening

The second phase of screening is divided into three parts.

The first part involved the elimination of duplicates within each single DB and led to the removal of 1,516 articles; subsequently, the three DBs were merged, and another 1,099 articles present in more than one of them were eliminated, thus going from 5,482 to 2,867. This step led to a single DB containing the articles whose title and/or abstract contain one or more combinations of the chosen keywords. The DB is structured according to a matrix of rows corresponding to the articles and columns containing different information levels useful for characterizing scientific contributions.

The second part is based on the analysis of the relevance of the titles of the articles present in the overall DB with respect to the research topic. By analyzing the title of each article obtained from the previous step, 2,475 records were eliminated, going from 2,867 to 392.

Finally, the third part focuses on the relevance of the abstracts of the remaining 392 articles to the initial research question. From this further screening, 153 articles were removed, and 239 remained.

The screening phase guaranteed a restricted selection of articles and allowed the identification of more specific categories than those used in the identification phase. The 239 articles were then classified according to the different modes of transport (see Fig. 3) to facilitate the subsequent phases of analysis and to identify the focus of the scientific contributions more precisely. The clustering reveals a distribution aligned with the one identified in the preceding "Identification" phase. As depicted in Fig. 3, the distribution of scientific articles, categorized by transport categories and modes and represented as semicircles or concentric arcs across four distinct groups, predominantly features studies on the quality of public transport (specifically bus services), followed by research on

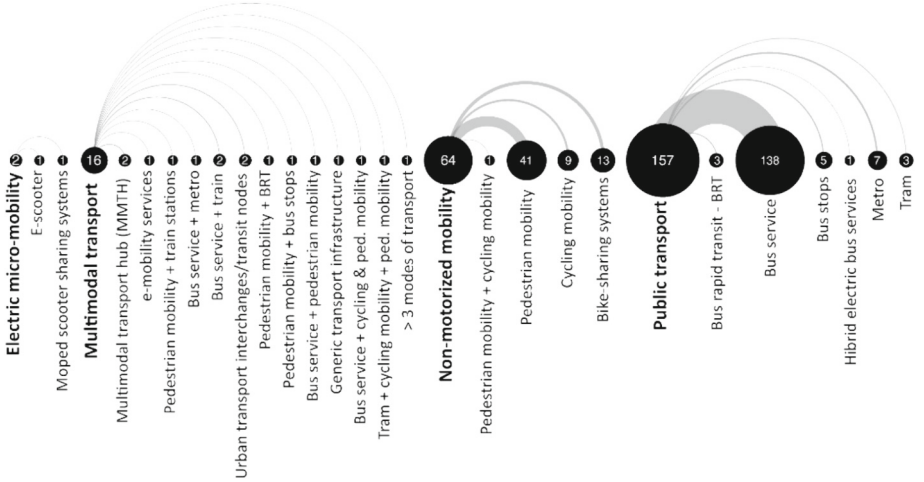

Fig. 3. Number of articles divided by transport categories and transport modes. Source: personal elaboration.

non-motorized (pedestrian) mobility. Research on the quality of multimodal transport systems is notably limited, as is the case with studies concerning electric micro-mobility.

3.3 Eligibility

The third phase of eligibility is based on the integral reading of the articles derived from the previous phase.

Before proceeding to the full reading of the articles, those concerning bus services have been excluded, except those focusing on bus stops. This choice is justified by the fact that there are already paper reviews that provide a viable methodology for defining a set of quality criteria and indicators for evaluating public transport services [25]. Infrastructural rather than service aspects of public transport have been less investigated and are strictly integrated with the infrastructures dedicated to non-motorized mobility, especially pedestrian mobility. For this reason, studies on bus/train/metro stops have moved on to the eligibility phase. The same goes for studies focusing on forms of mass transit such as trams, which have been far less investigative than bus service. Articles on the metro were also excluded, as it is a transport system that is not common in all urban centers but is typical of large cities/metropolitan cities. In light of this, 90 papers have passed the eligibility stage.

The integral reading of the articles led to further screening, identifying the scientific contributions that fully meet the criteria defined upstream of the development of the four phases of the PRISMA statement. At this stage, 23 articles were excluded because they did not fully meet the search criteria: (i) one was not strictly related to the urban area; (ii) one was specific to an exceptional situation (such as a sporting event), which implies a change in temporary transport demand, and its results could be difficult to apply to any urban context; (iii) one article considered the point of view of the service provider rather than the user; (iv) two were not in English; (v) two were of the same author and

reported the same indicators, and only one was considered; (vi) two provided general guidelines but did not include methods of evaluation of the quality of transport; (vii) 14 considered the transport quality only partially, and their evaluation was not coherent with the focus of this research. Another 18 articles were not available and/or downloadable. Consequently, 49 articles passed to the final inclusion phase.

3.4 Inclusion

The results of the 49 papers passed to the inclusion phase allow us to reconstruct a set of criteria and indicators for evaluating the quality of an integrated urban transport system, which includes multiple transport modes: pedestrian and cycle mobility, also considering bike-sharing, electric micro-mobility and public transport. Furthermore, this analysis enabled us to identify the geographical contexts, scientific journals and applied case studies that address the topic of the assessment of transport quality. A statistical summary of the main paper information levels that emerged from the systematic review is provided in the next section.

General Statistics About the Review

The selected publications reviewed comprised 35 articles, 9 conference papers, 4 conference proceedings, and 1 report. Therefore, 69% of the papers appeared in journals, whereas the remaining 31% were elsewhere. As for journals, 23% covered generically engineering, 17% business and economics, 17% transportation, 14% science and technology, 9% social science, 6% computer science, 6% green and sustainable science and technology, 3% urban studies, 3% earth and planetary science and 3% psychology. Recurrent journals were *Sustainability, Transportation, Transportation Research Record and Journal of Cleaner Production.* About 34% of the selected articles appeared in these 4 journals, the remaining 66% in the other 21. These different outlets showed the fragmentation of the journals addressing the transport quality assessment.

Concerning the geographical publications' distribution, the total number of authors is 144. Out of the total, 41% are affiliated with European institutions, 37% with Asian institutions, 22% with American institutions and 1% with Oceanian institutions. Europe has the largest coverage among the continents. In Europe, Italy constitutes 44% of the selected publications, followed by Poland (12%), Portugal (10%), United Kingdom (8%), Spain and Netherlands (7%), Croatia (3%), Austria, Belgium, Romania, France, Switzerland (2%). In Asia, China constitutes 42% of the selected publications, followed by India (17%), Malaysia and Bangladesh (9%), Taiwan (8%), Iran (6%), Turkey and South Korea (4%) and Iraq (2%). In America, Brazil constitutes 52% of the selected publications, followed by Colombia (32%), USA (10%) and Chile (6%). In Oceania, an author is affiliated with a New Zealand institution.

Figure 4 shows the geographic distribution by continents and countries of the case studies treated within the papers and the focus on the different categories and modes of transport analyzed. As with Fig. 2, the width of the flows connecting the different blocks represents the number of articles that have emerged in each continent/country, in association with different transport categories focused on service or infrastructure aspects. The analysis reports that 67 case studies were distributed as follows: 49% in Europe, 27% in Asia, 19% in America, and 4% in Oceania. 55% of the case studies

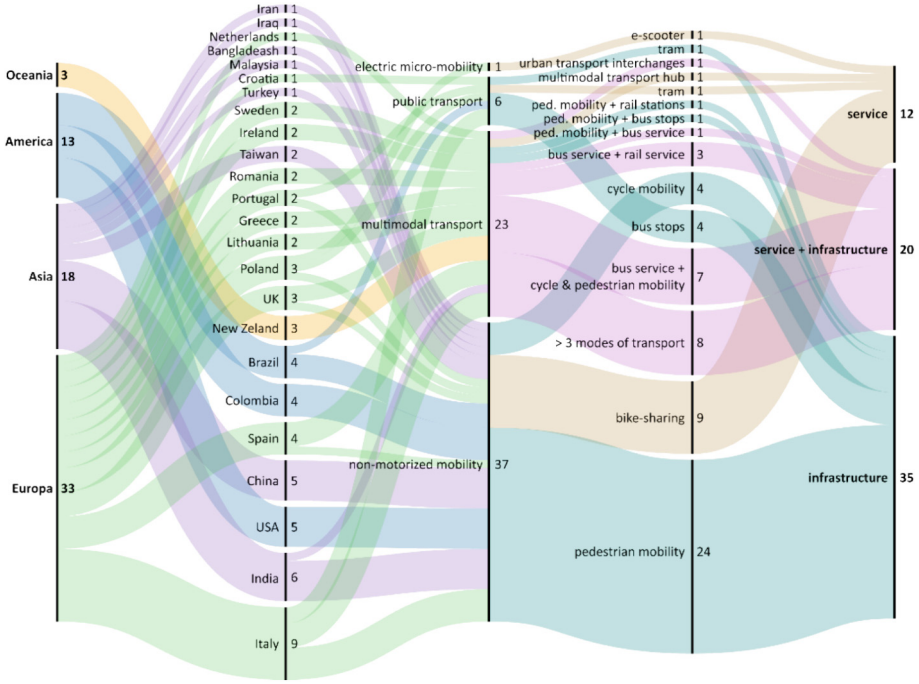

Fig. 4. Geographical distribution of the case studies divided by continent, country, transport category and mode. Source: personal elaboration.

concern non-motorized mobility, 34% multimodality, 9% public transport and 1% electric micro-mobility. The last flow of Fig. 4 shows how a reasonable part of case studies investigated the infrastructural aspects, especially concerning pedestrian mobility. It is interesting to note that in America and Asia there is a prevailing interest in non-motorized mobility. In Europe, interest is also largely in public transport, as well as pedestrian and cycling mobility. In terms of multimodality, most of the studies included non-motorized mobility and public transport services, which were investigated in Europe and Oceania.

4 Current Knowledge

This chapter presents the key quality criteria and indicators for evaluating urban transport systems, which have emerged from the literature review. In this phase, the quality criteria are divided into transport categories, as analyzed previously: electric micro-mobility, public transport, multimodal transport, and non-motorized mobility (see Fig. 5).

First, unique terminologies were identified to simplify the criteria that emerged from the systematic literature review. The chosen terminologies can represent parameters written differently but with the same (or similar) meaning.

The first list of parameters was picked up by [25], which provides eight service aspects articulated in 30 criteria and 103 indicators, based on the classification introduced by CEN/TC 320 (2002)[1]. The criteria derived from the last phase of the PRISMA methodology were partially associated with the classification terminologies provided by the European Norm. Therefore, the European normative recognition of the quality criteria presented in this paper, the involvement of international experts in their evaluation, and the review of relatively recent literature are the main reasons for choosing this paper. Many of the quality criteria associated with non-motorized or micro-electric mobility were consistent with those for public transport presented in [25]. In some cases, they found perfect coherence: for example, cleanliness is applicable for both buses and sidewalks. In other cases, they have been modified slightly while retaining the main meaning. For instance, in public transport, 'drive comfort' is associated with driving, for pedestrian mobility, it is associated with walking and for cyclists with cycling.

The quality criteria that emerged from the latest phase of PRISMA are 995 (which include duplicates): 17 for electric micro-mobility, 126 for public transport, 282 for multimodal transport, and 570 for non-motorized mobility.

"Comfort" was represented by indicators related to the pleasantness and amenities of the trip and environment. It included indicators related to the design of transport infrastructures and their practicability in moving and using urban space while waiting. Furthermore, it included the state of the environment, such as maintenance and cleanliness [26] and the presence of facilities, points of interest, and landscape [27]. Comfort was the most common criterion for all transport categories except for electric micro-mobility.

"Accessibility" included indicators related to access to a specific transport system and interface with others. It was second for both public, multimodal transport and non-motorized mobility. Differently, it did not appear to be relevant in micro-electric mobility.

A third relevant criterion for all transport categories was "Safety and security" [28–30], the second most frequent for non-motorized mobility, the third for public transport and electric micro-mobility, and the fourth for multimodal transport. It included criteria that provide personal protection (objective and subjective) from accidents (safety) and crime (security) experienced by users.

"Customer service" included indicators introduced to influence the closest practicable match between the standard service and the requirements of any individual customer/user. It represented the most important aspects of the bike-sharing and micro-mobility categories.

"Availability" included indicators in terms of service localization, area covered, operating timing, frequency, and characterizes all categories. Similarly, "Customer service" appeared in minor characterization compared to three previous ones.

"Information" included indicators related to the systematic provision of knowledge about the transport system to help the user before (trip planning phase) and during trips.

In contrast, "Time" includes indicators relevant to the planning and execution of trips in terms of length of the trip time and adherence to schedule. Both "Information" and "Time" were not associated with micro-electric mobility.

[1] CEN/TC 320 (2002) issued the European Norm EN 13816:2002 for the definition, targeting and measurement of transit service quality.

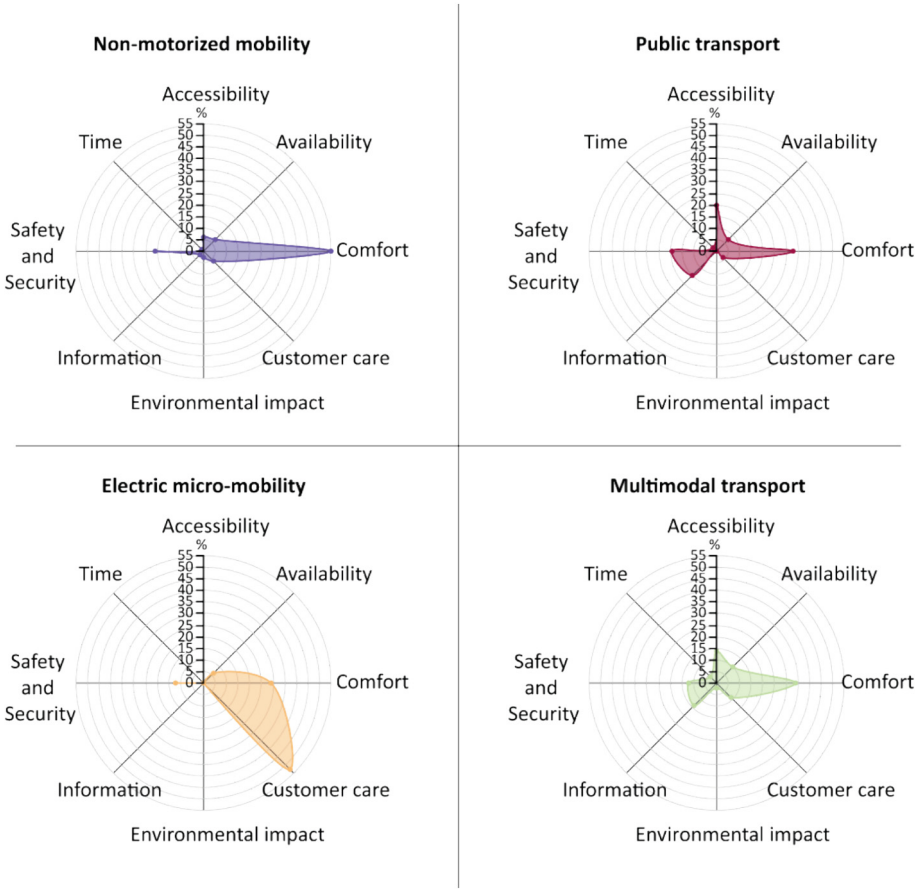

Fig. 5. The most common criteria in the categories of public, multimodal, non-motorized, and micro-electric transport (expressed in percentage) emerged from the systematic literature review.

Finally, "Environmental impact" included indicators related to the environment affected by the transport system analyzed and associated with multimodal and non-motorized transport.

Each of these criteria was represented by indicators that characterize specific aspects (see Table 1).

Some significant findings for research purposes emerged.

First, the result in "comfort" indicators demonstrated the high relevance of a transport system-land use relationship as a qualitative element of integrated travel experiences.

Second, although most indicators referred to a specific transport mode, several included the multimodality aspect as a key quality factor. It implicitly underscored the relevance of integrated quality, thereby reinforcing the research. For instance, [31] considered the type and distance of interchange opportunities with public transport. [32] considered the convenience of bike-sharing to connect to other modes of transportation.

Table 1. Criteria, indicators, and number of times they appear in papers (frequency) for assessing urban transport quality.

Criteria	Indicators	Indicator frequency
Accessibility	External interface	47
	External/internal interface	5
	Internal interface	25
	Ticketing availability	16
	Undefined	6
Availability	Dependability	4
	Network	37
	Operation	13
	Suitability	23
	Undefined	2
Comfort	Ambient conditions	109
	Complementary facilities	97
	Ergonomy	51
	Ride comfort	150
	Seating and personal space	23
	Usability for user facilities	17
	Undefined	7
Customer care	Assistance	5
	Commitment	5
	Customer interface	13
	Staff	18
	Ticketing options	32
	Undefined	2
Environmental impact	Infrastructure	2
	Pollution	20
	Undefined	4
Information	General information	60
	Travel information normal conditions	8
Safety and security	Emergency management	1
	Freedom from accident	108
	Freedom from crime	56

(*continued*)

Table 1. (*continued*)

Criteria	Indicators	Indicator frequency
	Undefined	12
Time	Adherence to schedule	13
	Length of the trip time	5

Accessibility was one of the criteria that most considered the interaction between different transport modes, represented by the indicator "external interface". The external interface was mainly concerned with accessibility to other forms of mobility than the one analyzed. Availability in some cases has also been related to multimodality, with indicators such as network-level distance between different transport nodes [33]. Safety and security, on the other hand, have taken on a negative valence when associated with multiple modes of transport. For example, the coexistence of pedestrians and cyclists in the same urban space was seen as critical from the perspective of user perception and accident risk [28]. The need to separate transport modes is expressed more clearly concerning active and vehicular mobility, with preventative design indicators such as barriers for pedestrian protection from vehicles or buffer zones between sidewalks and carriageways [12]. Information was mainly associated with individual modes of transport. Only in relation to mobility-restricted individuals does information about disabled-friendly interchanges (main terminals) assume the multimodal dimension [34]. Customer care and time have always treated a single transport mode.

5 Discussion

The literature review underlined different points of discussion on knowledge gaps that future research should focus on, especially concerning the specific modes of transport. Table 2 presents the knowledge gaps that emerged across the four macro-categories of transport. This overview provides a quick understanding of the areas that require further research and can guide future studies in filling these gaps.

In the domain of multimodality, a comprehensive array of quality indicators is imperative, especially focusing on the pre-travel, waiting, and walking phases. This is a complex area that requires in-depth exploration. An intriguing avenue for future research involves constructing a measurement model using structural equation modeling to assess how these indicators amalgamate to shape the overall traveler experience [54]. This approach will provide a more nuanced understanding of multimodality and its impact on transportation quality.

Moreover, recent research has tended to overlook the objective aspects of urban public mobility infrastructure. Studies should prioritize comparing objective mobility features, such as bus line quantity relative to population size, bus frequency, and incidents involving elderly pedestrians, with neighborhood quality indicators like shop density, green spaces, and attacks on the elderly. This research approach facilitates cross-validation between objective and subjective analyses, yielding comprehensive insights into mobility conditions [55].

Table 2. Knowledge gaps emerged for the four macro-categories of transport.

Transport categories	Source	Knowledge gaps
Electric micro-mobility	[21]	To replicate and improve the limited approaches to building theoretical frameworks for assessing quality
Public transport	[35]	To expand the analytical scope to encompass a broader array of services and parameters
	[36]	To conduct analyses during summer periods as well, considering that users' perceptions may be influenced by elevated temperatures and the influx of tourists during this time
	[37]	To differentiate between user demographics, as distinct groups, such as the elderly, may harbor varying perceptions
	[38]	To integrate environmental indicators into the analysis is essential for providing a comprehensive understanding of the subject
Non-motorized mobility//cycling mobility	[39, 40]	To provide additional details about the evaluation indexes and how to generate more suitable reconstruction projects to improve bicycle suitability of the road network by involving more resources
	[41]	To integrate the cycling network with other public transport and bike-sharing systems, considering its ability to serve urban places where mobility demand is concentrated
Non-motorized mobility//bike-sharing	[42]	To develop analytic methods, integrating information from social media with traditional data. Furthermore, for the regions where both dockless and dock-based bike-sharing systems, as well as reviews on both systems exist, it would be worth comparing these two different systems in terms of users' evaluations

(*continued*)

Table 2. (*continued*)

Transport categories	Source	Knowledge gaps
	[32]	To include both current users and non-users to foster loyalty among new users. Furthermore, comparative research should be carried out under different conditions and in relation to topography, weather, temporal, and cultural variables. Demographic characteristics of users should be accounted for: making bike sharing suitable for the elderly will be a valuable research direction
	[43]	Service operators should focus on retaining subscribers and addressing common priorities with users, like bike availability and totem operation
	[44]	To analyze local authorities' actions in co-designing public bike systems with residents
Non-motorized mobility//pedestrian mobility	[45]	To consider temporal variables and socio-demographic characteristics of users in future studies on pedestrian mobility is emphasized
	[46]	To evaluate sidewalks from the perspective of specific social groups such as the elderly
	[47]	To evaluate sidewalks from the perspective of specific social groups such as children
	[48–51]	To incorporate additional variables related to protection from climatic conditions and available services into evaluation models. Extending experiments to diverse case studies is necessary to understand how various factors influence user behavior
	[52]	To widen the sample and explore different statistical approaches
	[53]	To elements that impact user behavior and the role of Quality of Service (QoS) in route and mode choice

Finally, scholarly literature emphasizes the necessity to scrutinize the quality of transportation services and infrastructure across diverse locations, employing analyses through multiple case studies [56]. Prospective studies could investigate the effects on land use, accessibility, and congestion after the establishment of multimodal hubs. Furthermore, there is a demand to examine the correlations between socio-demographic

data and users' perceptions of the quality attributes of emerging services [57]. Finally, an interesting aspect of the research concerned the identification of indicators focused on vulnerable users. [58] provided several indicators for user groups, such as information about disabled-friendly interchanges for mobility-restricted travelers, provision of tactile information and clearly marked routes for communication-impaired, infrastructure design and information aspects for those older than 65 years, low-cost services for those younger than 24 years, design and quality on board for travelers with children. [59] considered the indicator "tactile paving" for sight-impaired, [12] included in transport quality the sidewalk slope to elderly people and wheelchair users, while [60] considered as a key quality indicator the sidewalk pavement for disabled people and handicapped.

6 Conclusions

Given the increasing complexity and density of urban centers under constant pressure from transportation demands, focusing on sustainable and smart mobility alternatives to cars is more crucial than ever. An important factor in incentivizing the modal shift toward less impactful forms of mobility and favoring integration of multiple transport systems concerns the quality of transport supply and its users' perception [51]. Its assessment is crucial both for understanding how to make existing services and infrastructure more attractive and for addressing urban policies toward urban space regeneration and smart mobility. Indeed, the perception of transport quality is strongly linked to the quality of infrastructure and services, surrounding public space, and land use. Route pleasantness is decisive when it comes to users' modal choice. Indeed, indicators such as the presence of urban design, elements of shelter from the sun or rain, green spaces, stores, services [12], and the type of pavement [59] are mentioned in the literature as factors that influence the quality perceived by users in non-motorized mobility [11]. Public transport can be perceived as more or less attractive, accessible, and safe depending on the aspects that characterize the context in which its stops are placed, such as the quality of sidewalks [60], the presence/absence of barriers [61], non-slip surfaces, lighting, ramps, and seating.

A recurring challenge for urban and transport planners is to comprehend how these interrelated parameters can be managed to create an urban environment that is responsive to users' needs and expectations [62]. The ultimate goal is to enhance the quality of existing infrastructure and services, thereby motivating users to adopt more sustainable modes of transport as a viable alternative to the car [63, 64]. The identification and assessment of these characteristics and their quality can provide valuable insights for planners, practitioners and policymakers, guiding them in designing public space, mobility infrastructure, and services. This approach fosters a full synergy between urban planning and transport planning [65, 66].

This paper has shed light on a significant gap in current understanding of quality assessment, which has been predominantly investigated in a sectorial manner. By identifying knowledge gaps and first- and second-level indicators, this study has laid the groundwork for evaluating an integrated urban mobility system in a multimodal transport scenario. This novel approach to quality assessment in the context of urban mobility represents a significant contribution to the field.

This research represents a first step towards addressing current knowledge gaps. Future development will delve into the indicators, providing a comprehensive understanding of their relationship with infrastructural and service aspects in each transport category. Furthermore, the research will focus on identifying key quality indicators that contribute to evaluating and improving integrated transport supply. The identification of these indicators will play a crucial role in strategic planning and mobility management, enabling the prioritization of smart sustainable mobility interventions.

Acknowledgments. This study was partially funded by the University of Brescia within the Grant "CUP: D75F21002920001" PON R&I 2014–2020 (FSE REACT-EU).

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. United Nations, Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2018 Revision. United Nations, New York (2019)
2. Dall'Ò, G.: Smart City. Il Mulino, Bologna (2015)
3. Das, S.: Importance of user perception in evaluating level of service for bus transit for a developing country like India: a review. Transp. Rev. **33**(4), 402–420 (2013)
4. De Oña, J., De Oña, R.: Quality of service in public transport based on customer satisfaction surveys: a review and assessment of methodological approaches. Transp. Sci. **49**(3), 605–622 (2015)
5. Sidorchuk, R., Skorobogatykh, I.I.: Marketing evaluation of public transport quality attributes: review of two waves of research. Mediterr. J. Soc. Sci. **6**(3), 275–282 (2015)
6. Bakar, M.F.A., Norhisam, S., Katman, H.Y., Fai, C.M., Azlan, N.N.I.M., Samsudin, N.S.S.: Service quality of bus performance in Asia: a systematic literature review and conceptual framework. Sustainability **14**(13), 7998 (2022)
7. Jahan, M.I., Mazumdar, A.A.B., Hadiuzzaman, M, Mashrur, S.M.: Analyzing service quality of pedestrian sidewalks under mixed traffic condition considering latent variables. J. Urban Plan. Dev. **146**(2), 04020011 (2020)
8. Zazzi, M., Ventura, P., Caselli, B., Carra, M.: GIS-based monitoring and evaluation system as an urban planning tool to enhance the quality of pedestrian mobility in Parma. In: Pezzagno, M., Tira, M. (eds.) Town and Infrastructure Planning for Safety and Urban Quality, pp. 87–93. CRC Press, Leiden. (2018). ISBN 9780815387312
9. Caselli, B., Carra, M., Rossetti, S., Zazzi, M.: From urban planning techniques to 15-minute neighbourhoods. A theoretical framework and GIS-based analysis of pedestrian accessibility to public services. Eur. Transp. Trasporti Europei **85**, 1–15 (2021)
10. Caselli, B., Rossetti, S., Ignaccolo, M., Zazzi, M., Torrisi, V.: Towards the definition of a comprehensive walkability index for historical centres. In: Gervasi, O., et al. (eds.) ICCSA 2021. LNCS, vol. 12958, pp. 493–508. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-87016-4_36
11. Vallejo-Borda, J.A., Cantillo, V., Rodriguez-Valencia, A.: A perception-based cognitive map of the pedestrian perceived quality of service on urban sidewalks. Transp. Res. F Traffic Psychol. Behav. **73**, 107–118 (2020)
12. D'Orso, G., Migliore, M.: A GIS-based method for evaluating the walkability of a pedestrian environment and prioritised investments. J. Transp. Geogr. **82**, 102555 (2020)

13. Guida, C., Carpentieri, G., Zacharias, J.: A smart approach for integrated land-use and transport planning—an application to the Naples metro station areas. In: Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Garau, C. (eds.) ICCSA 2022. LNCS, vol 13382, pp. 395–409. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-10592-0_29
14. Carra, M., Ventura, P.: HSR stations' urban redevelopments as an impulse for pedestrian mobility. An evaluation model for a comparative perspective. In: Tira, M., Pezzagno, M., Richiedei, A. (eds.) Pedestrians, Urban Spaces and Health, pp. 120–124. CRC Press, London (2020)
15. Calvey, J.C., Shackleton, J.P., Taylor, M.D., Llewellyn, R.: Engineering condition assessment of cycling infrastructure: cyclists' perceptions of satisfaction and comfort. Transp. Res. Part A Policy Pract. **78**, 134–143 (2015)
16. de Aquino Traldi, W., de França Marques, S., Pitombo, C.S., de Sousa, P.B., de Melo, R.A.: Evaluating the cycling infrastructure and spatial interpolation of quality indicators: an approach based on the analytic hierarchy process and geostatistics. Rev. Bras. Cartogr. **74**(4), 986–1002 (2022)
17. Tian, Z., Wang, J., Wang, J., Zhang, H.: A multi-phase QFD-based hybrid fuzzy MCDM approach for performance evaluation: a case of smart bike-sharing programs in Changsha. J. Clean. Prod. **171**, 1068–1083 (2018)
18. Ma, F., Shi, W., Yuen, K.F., Sun, Q., Guo, Y.: Multi-stakeholders' assessment of bike sharing service quality based on DEMATEL–VIKOR method. Int. J. Logist. Res. Appl. **22**(5), 449–472 (2019)
19. Liang, X., Chen, T., Ye, M., Lin, H., Li, Z.: A hybrid fuzzy BWM-VIKOR MCDM to evaluate the service level of bike-sharing companies: a case study from Chengdu, China. J. Clean. Prod. **289**, 126759 (2021)
20. Carrara, E., Ciavarella, R., Boglietti, S., Carra, M., Maternini, G., Barabino, B.: Identifying and selecting key sustainable parameters for the monitoring of e-powered micro personal mobility vehicles. Evidence from Italy. Sustainability **13**(16), 9226 (2021)
21. Hamerska, M., Ziółko, M., Stawiarski, P.: A sustainable transport system – the MMQUAL model of shared micromobility service quality assessment. Sustainability **14**(7), 4168 (2022)
22. Garau, C., Desogus, G., Barabino, B., Coni, M.: Accessibility and public transport mobility for a smart(er) island: evidence from Sardinia (Italy). Sustain. Cities Soc. **87**, 104145 (2022)
23. Moher, D., Liberati, A., Tetziaff, J., Altman, D.G.: Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J. Clin. Epidemiol. **62**, 1006–1012 (2009)
24. Ferretto, L., Carra, M., Barabino, B.: Mobilità non motorizzata: una revisione sistematica della letteratura sui principali parametri di qualità. In: Atti XXV Conferenza SIU – Transitions, Spatial Justice and Territorial Planning, Cagliari 15–16 June 2023. Planum Publisher e Società Italiana degli Urbanisti, Roma-Milano (2023, in press)
25. Barabino, B., Cabras, N.A., Conversano, C., Olivo, A.: An integrated approach to select key quality indicators in transit services. Soc. Indic. Res. **149**, 1045–1080 (2020)
26. Douglas, N.J.: Valuing public transport service quality using a combined rating & stated preference survey. In: 37th Australasian Transport Research Forum, ATRF 2015, Sydney, Australia, 30 September–2 October 2015 (2015)
27. Talavera-Garcia, R., Soria-Lara, J.A.: Q-PLOS, developing an alternative walking index. A method based on urban design quality. Cities **45**, 7–17 (2015)
28. Bellizzi, M.G., Eboli, L., Forciniti, C.: Segregation vs interaction in the walkways: an analysis of pedestrians' perceptions. Res. Transp. Bus. Manag. **33**, 100410 (2019)
29. Ismail, N.I.N., Abd Rahman, N.A., Muhamad, N.S., Yaccob, A.A., Mohtar, N.H.: Pedestrian's perception toward quality of sidewalk facilities case study: UiTM Pulau Pinang. IOP Conf. Ser. Mater. Sci. Eng. **849**, 012057 (2020)

30. Ujjwal, J., Bandyopadhyaya, R.: Development of pedestrian level of service assessment guidelines for mixed land use areas considering quality of service parameters. Transp. Dev. Econ. **7**(7), (2021)
31. Rossetti, S., Tiboni, M.: In field assessment of safety, security, comfort and accessibility of bus stops: a planning perspective. Eur. Transp. Trasporti Europei **80**(8), (2020)
32. Xue, X.J., Wang, Z.X., Liu, X.J., Zhou, Z., Song, R.: A choice behavior model of bike-sharing based on user perception, psychological expectations, and loyalty. J. Adv. Transp. **2022**, 6695977 (2022)
33. Chauhan, V., Gupta, A., Parida, M.: Demystifying service quality of Multimodal Transportation Hub (MMTH) through measuring users' satisfaction of public transport. Transp. Policy **102**, 47–60 (2021)
34. Diana, M., et al.: Development of an integrated set of indicators to measure the quality of the whole traveller experience. Transp. Res. Procedia **14**, 1164–1173 (2016)
35. Barabino, B.: Automatic recognition of "low-quality" vehicles and bus stops in bus services. Public Transp. **10**, 257–289 (2018)
36. Ely, V.H.M.B., De Oliveira, J.M., Logsdon, L.: A bus stop shelter evaluated from the user's perspective. Work **41**(1), 1226–1233 (2012)
37. Rosa, M.P., Lopes, J.D.C.: Senior tourists' perceptions of bus stop environments used in collaborative design. WIT Trans. Built Environ. **186**, 121–132 (2019)
38. Vujičić, M., Jasna, P.: Assessing service quality of public tram transport in Zagreb city using P-TRANSQUAL model. Zbornik Ekonomskog fakulteta u Zagrebu **17**(1), 19–31 (2019)
39. Hsu, T.P., Lin, Y.T.: A model for planning a bicycle network with multi-criteria suitability evaluation using GIS. WIT Trans. Ecol. Environ. **148**, 243–252 (2011)
40. Hsu, C.C., Liou, J.J.H., Lo, H.W., Wang, Y.C.: Using a hybrid method for evaluating and improving the service quality of public bike-sharing systems. J. Clean. Prod. **202**, 1131–1144 (2018)
41. Fistola, R., Gallo, M., La Rocca, R.A., Russo, F.: The effectiveness of urban cycle lanes: from dyscrasias to potential solutions. Sustainability **12**(6), 2321 (2020)
42. Shin, E.J.: A comparative study of bike-sharing systems from a user's perspective: an analysis of online reviews in three U.S. regions between 2010 and 2018. Int. J. Sustain. Transp. **15**(12), 908–923 (2021)
43. Julio, R., Monzon, A., Susilo, Y.O.: Identifying key elements for user satisfaction of bike-sharing systems: a combination of direct and indirect evaluations. Transportation (2022)
44. Podgorniak-Krzykacz, A., Przywojska, J., Trippner-Hrabi, J.: A public value-based, multi-level evaluation framework to examine public bike-sharing systems. Implications for cities' sustainable transport policies. Transp. Telecommun. J. **23**(2), 180–194 (2022)
45. Vallejo-Borda, J.A., Ortiz-Ramirez, H.A., Rodriguez-Valencia, A., Hurtubia, R., de D. Ortúzar, J.: Forecasting the quality of service of Bogota's sidewalks from pedestrian perceptions: an ordered probit MIMIC approach. Transp. Res. Rec. **2674**(1), 205–216 (2020)
46. Du, Y., Huang, W.: Evaluation of street space quality using streetscape data: perspective from recreational physical activity of the elderly. ISPRS Int. J. Geo Inf. **11**(4), 241 (2022)
47. Argin, G., Ozbil, A.: Walking to school: the effects of street network configuration and urban design qualities on route selection behaviour of elementary school students. In: SSS 2015 - 10th International Space Syntax Symposium (2015)
48. Rocha, V.T., Brandli, L.L., Kalil, R.M.L., Salvia, A.L., Prietto, P.D.M.: Quality of sidewalks in a Brazilian city: a broad vision. Theor. Empir. Res. Urban Manag. **14**(2), 41–58 (2019)
49. Arellana, J., Saltarín, M., Larrañaga, A.M., Alvarez, V., Henao, C.A.: Urban walkability considering pedestrians' perceptions of the built environment: a 10-year review and a case study in a medium-sized city in Latin America. Transp. Rev. **40**(2), 183–203 (2019)
50. Raswol, M.L.: Qualitative assessment for walkability: Duhok university campus as a case study. IOP Conf. Ser. Mater. Sci. Eng. **978**(1), 012001 (2020)

51. Ujjwal, J., Bandyopadhyaya, R.: Development of Pedestrian Level of Service (PLOS) model and satisfaction perception rating models for pedestrian infrastructure for mixed land-use urban areas. Transportation **50**, 355–381 (2021)
52. Blečić, I., Canu, D., Cecchini, A., Congiu, T., Fancello, G.: Factors of perceived walkability: a pilot empirical study. In: 16th International Conference on Computational Science and Its Applications, ICCSA 2016, Beijing, China, 4 July 2016–7 July 2016, vol. 9789, pp. 125–137 (2016)
53. Rodriguez-Valencia, A., Barrero, G.A., Ortiz-Ramirez, H.A., Vallejo-Borda, J.A.: Power of user perception on pedestrian quality of service. Transp. Res. Rec. **2674**(5), 250–258 (2020)
54. Diana, M., Duarte, A., Pirra, M.: Transport quality profiles of european cities based on a multidimensional set of satisfaction ratings indicators. Transp. Res. Rec. **2643**(1), 84–92 (2017)
55. Groenendijk, L., Rezaei, J., Correia, G.: Incorporating the travellers' experience value in assessing the quality of transit nodes: a Rotterdam case study. Case Stud. Transp. Policy **6**(4), 564–576 (2018)
56. Bellizzi, M.G., Forciniti, C., Mazzulla, G.: A stated preference survey for evaluating young pedestrians' preferences on walkways. Sustainability **13** (2021)
57. Podciborski, T.: A method for evaluating tram stops based on passenger expectations and the needs of disabled persons. In: 10th International Conference on Environmental Engineering (ICEE), Vilnius Gediminas Technical University Lithuania, 27–28 April 2017 (2017)
58. Soltani, A., Fazeli, S., Eskandari, S.: Comparing sidewalk design status from the pedestrians' perspective versus urban street design standards. World Rev. Intermodal Transp. Res. **6**(3), 193–208 (2017)
59. Burlando, C., Ivaldi, E., Ciacci, A.: Seniors' mobility and perceptions in different urban neighbourhoods: a non-aggregative approach. Sustainability **13**(12), 6647 (2021)
60. Rowangould, G., Corning-Padilla, A.: Evaluating how the quality of pedestrian infrastructure affects the choice to walk. Transportation Consortium of South-Central States (Tran-SET) (2019)
61. Sousa, A., Santos, B., Gonçalves, J.: Pedestrian environment quality assessment in Portuguese medium-sized cities (pedestrian environment quality assessment for promotion of urban mobility in Portuguese medium-sized cities). IOP Conf. Ser. Mater. Sci. Eng. **471**(6), 062033 (2019)
62. Tan, D., Wang, W., Lu, J., Bian, Y.: Research on methods of assessing pedestrian level of service for sidewalk. J. Transp. Syst. Eng. Inf. Technol. **7**(5), 74–79 (2007)
63. Larranaga, A.M., Arellana, J., Rizzi, L.I., Strambi, O., Betella Cybis, H.B.: Using best–worst scaling to identify barriers to walkability: a study of Porto Alegre, Brazil. Transportation **46**(6), 2347–2379 (2019)
64. Beura, S.K., Chellapilla, H., Jena, S., Bhuyan, P.K.: Service quality assessment of shared use road segments: a pedestrian perspective. Adv. Intell. Syst. Comput. **467**, 653–669 (2017)
65. Sarkar, S.: Qualitative evaluation of comfort needs in urban walkways in major activity centers. Transp. Q. **57**(4), 39–59 (2003)
66. Amoroso, S., Castelluccio, F., Maritano, L.: Indicators for sustainable pedestrian mobility. WIT Trans. Built Environ. **128**, 173–185 (2012)