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Micromobility and public transport integration: The current state of knowledge

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ABSTRACT

Cities globally are grappling with the negative externalities of car travel and are therefore striving to move towards a more sustainable urban transportation system. The introduction and popularity of new personal transport modes, such as e-scooters and electric bicycles, could potentially accelerate this transition as they become more commonplace and are accepted into regulatory frameworks. The integration of these new modes and vehicles into public transport systems, for example, could enhance accessibility and lead to potential modal shifts away from private car use. In order to assess the potential for change that micromobility holds, it is key to study these new modes in the context of access and egress trips to and from public transport.

This paper presents an extensive systematic literature review of studies that focus specifically on the integration of micromobility and public transport systems and is, to the knowledge of the authors, the first review focusing on this specific aspect of micromobility. This paper offers an understanding of how this topic has been studied to date, which factors and aspects have been considered and analysed, which causalities have been identified in the research, in addition to identifying gaps in the literature and providing guidance for future research on this topic. Furthermore, this paper provides a comprehensive collection and critical discussion of suggestions and recommendations included in the literature which are analysed in this study, aimed at improving and further promoting the effective integration of micromobility and public transport services.

1. Introduction

Micromobility is an exponentially growing new trend in urban mobility. Common, human-powered micro-vehicles such as bicycles, as well as new micro-vehicles such as e-scooters, e-bikes and various other electrically powered micro-vehicles can now be found in countless cities around the world. Many different types of micro-vehicles, both for shared and private use, have launched in recent years and have been met with great approval. Bicycle sharing systems worldwide, for example, have increased rapidly, from 17 bike-sharing programs worldwide in 2005 to over 2,900 in 2019 (Galatoulas et al., 2020) with more and more electric bicycles and pedelecs becoming available. Dockless bike-sharing has similarly grown in popularity from 2010 onwards, initially in China before soon appearing all over the world (Chen et al., 2020). Similarly, e-scooter providers such as Lime and Bird launched their services in California in 2017 and two years later they expanded to over 100 cities worldwide and have since logged millions of trips (POLIS,

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2019). In Europe, the e-scooter provider VOI has experienced similar growth, expanding to 10 countries within one year of the launch of its services in Sweden in 2018, having logged over 16 million rides (Holm Møller et al., 2019).

Micromobility has the potential to help solve many of the transport related problems that cities worldwide are facing at the moment and can potentially promote significant modal shifts away from private motorised vehicles. But what exactly is micromobility? In this paper, the definition proposed by the International Transport Forum (ITF), based on the vehicles' kinetic energy is adopted. In the ITF report "Safe Micromobility" (ITF, 2020), micromobility is defined as: "[…] *the use of micro-vehicles: vehicles with a mass of no more than 350 kg (771 lb) and a design speed no higher than 45 km/h. This definition limits the vehicle's kinetic energy to 27 kJ, which is one hundred times less than the kinetic energy reached by a compact car at top speed.*" This definition includes both human-powered and electrically assisted vehicles such as bicycles, e-bikes and pedelecs, kick scooters and e-scooters but also skateboards, one-wheeled balancing boards and four-wheeled electric micro-vehicles. This list is not exhaustive and the authors are aware of the fact that the concept of micromobility is constantly evolving. For this reason, the definition of micromobility is rather broad, as it is designed to be future proofed and therefore cannot be limited to a certain type of vehicle or power source. In this way it can be utilised to facilitate regulation of new vehicles that come on the market and to create a category that encompasses all micro-vehicles irrespective of vehicle characteristics such as number of wheels or riding position. However, regulating and implementing measures to facilitate and control the use of many of these new vehicles is proving to be a challenging task for planners and policymakers everywhere. Therefore, in order to facilitate regulations of micro-vehicles with different characteristics, the ITF suggests 4 categories of micro-vehicle types, based on their top speed and mass. More details on this definition and on all the types of micro-vehicles and their classification can be found in the "Safe micromobility" report (ITF, 2020).

The main potential of micromobility in the urban context lies in solving the first- and last-mile problem by improving access to public transport, and thus increasing access to services and opportunities, and similarly contributing to changes in mobility patterns and behaviours, aimed at less car-centred urban mobility systems (Holm Møller et al., 2019). The aim of this paper is therefore to provide an extensive overview of the literature published in relation to micromobility and public transport integration, while also presenting the state of knowledge in this field, identifying gaps in the literature and synthesising the findings, fundamentally to investigate what type of studies have been conducted on the issue and how it has been examined to date. The review is accompanied by recommendations and guidance for planners and practitioners in order to improve and promote micromobility and public transport integration. The articles included in this systematic literature review are predominantly centred on bicycles and bicycle sharing systems. This is due to the novelty of other types of micro-vehicles and the lack of data on the integration of other micro-vehicles and public transport. However, the findings from this systematic literature review will provide insights into relevant aspects and valuable guidance for the analysis of all kinds of micro-vehicles when studied in combination with public transport, in an integrated transport system. To the knowledge of the authors, no review of this kind has been published as of August 2020. The systematic literature review presented in this paper therefore constitutes an invaluable contribution to the current debate about micromobility and provides insights and guidance on micromobility in the context of first- and last-mile access to public transport.

This paper is structured as follows: in Section 2, the integration of micromobility and public transport will be defined and introduced, to provide an overview of the topic studied; in Section 3 the methodology employed will be outlined, the results of which will be presented and discussed in Section 4; while Section 5 will conclude the article and provide an outlook for further research.

2. Micromobility and public transport integration – Definition and overview

The integration of micromobility and public transport, if treated as a '*hybrid, distinct transport mode*' (Kager et al., 2016) and regarded as a single trip chain, can be considered a sustainable transport mode in which the advantages of both modes can complement each other. Micromobility can offer flexibility and efficient door-to-door accessibility, while public transport is characterised by higher speeds and greater spatial reach. The resulting synergy of high speed (and thus spatial reach) of public transport with the door-to-door accessibility provided by micromobility creates a degree of access, speed and comfort that can compete with that of private motorised vehicles (Kager et al., 2016). Therefore, this combination makes modal shifts more likely and has a significant potential to contribute to more liveable cities, less congestion, and reduced levels of air and noise pollution.

In order to unlock the full potential that micromobility potentially holds for the transition to more sustainable urban mobility systems, it is crucial to analyse and study micromobility in the context of first- and last-mile access to and from public transport (Holm Møller et al., 2019; POLIS, 2019). Planners, practitioners, micromobility and public transport providers, and all other involved stakeholders should treat micromobility and public transport as two interconnected aspects of the same system, in order to fully harness the potential and the synergies of the two modes.

Micromobility and public transport integration is a mobility practice that can be achieved in many different ways, depending on the infrastructure and services available. The main difference in micromobility use to date, consist of the use of either shared or private micro-vehicles. Private micro-vehicles, and in particular bicycles, have been used as transport modes for a long time. Shared micro-vehicle systems, however, have increasingly gained popularity over the last few years and are available in cities all over the world. Thanks to technological advancements and overall system improvements, these services have become increasingly efficient and user-friendly, resulting in a competitive and attractive alternative for access and egress trips for public transport. The two main types of shared systems are station-based and dockless sharing systems. While in a station-based system users can start or end their trips only at predefined locations, the dockless system allows users to start or end their trips (almonst) anywhere in the city. Due to issues pertaining to parking in public spaces and on sidewalks, however, many cities have started to address this problem by defining specific zones where dockless micro-vehicles can be parked.

As shown in Table 1, the infrastructure and services needed for different types of integration differ. For the examples (1) to (4), the main difference consists in the use of either shared or private micro-vehicles. If the micro-vehicle is private, storage is usually required at both ends of the trip i.e. first or last mile trip, whereas with shared micro-vehicles, the availability of such vehicles and the availability of free docks or designated areas to park free-floating micro-vehicles is the most pertinent requirement.

The examples in Table 1, (1) to (4) show different options for first and last mile journeys. These can however be used in any combination, if services and infrastructure are available. So, for example, a first mile trip as described in (1) can be combined with a last mile trip as outlined in (2), (3) or (4). One variation that is not directly included in the table is the practice of longer-term rental of bicycles, such as for example the OV-fiets service available in the Netherlands (BiTiBi.EU, 2017; NS - Nederlandse Spoorwegen, 2020), which allows users to rent bicycles at train stations for 24 h or longer periods. The bicycle in that case will be used the same way as a private micro-vehicle (stored at origin and destination locations) until it is returned. The last example in Table 1, (5), however, shows a particular way of integrating private micro-vehicles and public transport: the user takes the micro-vehicle on board of the public transport service and is therefore able to use the same vehicle both for the first and the last mile of the intermodal trip chain. This type of integration, as is described in Table 1, requires easily accessible public transport platforms and vehicles as well as sufficient capacity for micro-vehicles on board. While regular bicycles require more space and can be bulky and difficult to carry on board, lighter and more compact micro-vehicles such as foldable bicycles or e-scooters and kick scooters are more suitable for this type of integration. The same applies to storage at origin and destination as well: smaller, compact and foldable micro-vehicles can be easily carried and stored and do not require a lot of space.

In order to aid understanding of this mobility practice and its multiple facets, how it has been studied thus far, what the main findings are and what gaps exist in the literature, a systematic literature review is presented in this paper, that focuses on the specific issue of integrating micromobility and public transport.

3. Methodology

The aim of this study is to determine the state of knowledge on the topic of micromobility and public transport integration, not only

Table 1
Different options of micromobility and public transport integration and the required infrastructure and services.

	First mile – from origin to PT station			PT journey	Last mile – from PT station to destination		
	Mode	Infrastructure/ Service at origin	Infrastructure/Service at PT station	PT	Mode	Infrastructure/ Service at PT station	Infrastructure/Service at destination
(1)	Private micro-vehicle	Safe and convenient storage for micro-vehicle	Safe, convenient and affordable storage for micro-vehicle, safe and segregated pedestrian infrastructure to reach the PT station/stop	Train, Metro, Tram, Bus,…	Walking	Safe and segregated pedestrian infrastructure to reach destination	
(2)	Shared micro-vehicle from docking station	Availability of micro-vehicle sharing station in proximity of trip origin, availability of micro-vehicles at time of departure	Availability of micro-vehicle sharing station in proximity of PT station, availability of free spaces/docks, safe and segregated pedestrian infrastructure to reach the PT station/stop	Train, Metro, Tram, Bus,…	Free-floating, docklessshared micro-vehicle	Availability of micro-vehicle in proximity of PT station at time of departure	Availability of space/ designated zone to end trip in proximity of destination, safe and segregated pedestrian infrastructure to reach destination
(3)	Free-floating, dockless shared micro-vehicle	Availability of micro-vehicle in proximity of trip origin at time of departure	Availability of space/ designated zone to end trip in proximity of PT station, safe and segregated pedestrian infrastructure to reach the PT station/stop	Train, Metro, Tram, Bus,…	Shared micro-vehicle from docking station	Availability of micro-vehicle sharing station in proximity of PT station, availability of micro-vehicles at time of departure	Availability of micro-vehicle sharing station in proximity of destination, availability of free spaces/docks, safe and segregated pedestrian infrastructure to reach destination
(4)	Walking	Safe and segregated pedestrian infrastructure to reach the PT station/stop		Train, Metro, Tram, Bus,…	Private micro-vehicle	Safe and convenient storage for micro-vehicle	Safe, convenient and affordable storage for micro-vehicle, safe and segregated pedestrian infrastructure to reach destination
(5)	Private micro-vehicle	Safe and convenient storage for micro-vehicle	Comfortable and convenient access to platform/PT vehicle	Train, Metro, Tram, Bus,… Sufficient capacity for micro-vehicles on board	Private micro-vehicle	Comfortable and convenient egress from platform/PT vehicle	Safe and convenient storage for micro-vehicle, safe and segregated pedestrian infrastructure to reach destination

to identify evidence of certain effects, but also to identify any gaps in the literature that need to be addressed.

A systematic literature review in four steps

The method used to conduct this systematic literature review was developed and adapted based on guidelines presented by Thomas & Harden (2008) and the Transportation Research Board of the National Academies (2015), which consist of the following four steps:

i. Designing the research process
ii. Conducting the research
iii. Analysing and extracting information
iv. Reviewing the findings

In the first step, the research goal and strategy were defined, including a clear and methodically documented definition of search terms as shown in Table 2 and combinations of those terms in search strings, identification of databases to be used, filters and inclusion and exclusion criteria on which to base the search and selection processes.

The research question that is at the core of this study is: How has the integration of micromobility and public transport been studied and analysed to date? This question encompasses several other questions such as: which aspects of the integration have been studied, which effects have been discovered, what recommendations have been made in order to further promote the integration of the two modes? The aim of this literature review is fundamentally to investigate what type of studies have been conducted on the issue and how it has been examined, while also providing an overview of the results and recommendations presented in the literature as of August 2020.

It is important to note at this point that, in order to identify the most relevant articles, only those articles that had the integration of micromobility and public transport at the core of their research question were selected. This meant that articles that, for instance, analysed the multimodal behaviour of commuters including private motorised vehicles or articles that focused on micromobility without considering its integration with public transport were excluded. This decision was made as it was seen as more appropriate to select articles that directly address the integration of micromobility and public transport to understand how the research is framed in such studies and to determine the aspects of this particular topic that are studied. It is also worth noting that, as micromobility is a relatively new concept, most studies identified through the literature search focused on bicycle and public transport integration. As stated in the introduction, bicycles are considered micro-vehicles based on the definition of micromobility adopted for this study, and it is safe to say that the way in which cycling and public transport integration has been studied in recent years can provide relevant insights, methods and starting points for research that will be conducted on the integration of other micro-vehicles with public transport. In order to ensure the quality and relevance of the articles and studies presented, only research articles from peer-reviewed journals were chosen. The authors acknowledge that some literature on this topic might be excluded by searching only articles written in English. Due to the novelty of the topic and the technological advancements made in the field of micromobility in recent years, most articles on the topic have been published in the last decade. However, some earlier studies (Martens, 2007, Martens, 2004; Rietveld, 2000), particularly from the Netherlands – where bicycle and train integration has been a common practice for a long time – have been included.

In the second step, the literature search was conducted. The following search portals were consulted for this purpose: ScienceDirect/Scopus, Taylor & Francis online, OneSearch – the online research portal of the University College Dublin Library. These three databases were selected for their user friendliness, the possibility to use filters and operators and the quality of the results obtained. Various other sources such as Google Scholar, TRID, Web of Science, JSTOR and SAGE were used to find additional literature. Compared to the selected databases, however, very few articles pertaining to the research topic were identified, and in particular on Google Scholar the vast amount of unrelated results presented challenges to identify relevant articles. In addition to that, Google searches to identify grey literature on this specific topic were conducted, using the keywords listed in Table 2, but no results were found that specifically consider micromobility and public transport integration. The search process for each database was meticulously documented in a research log, where information on search strings, number of results obtained, papers selected or discarded with reasons and papers already previously selected were recorded. Each search process was assigned a unique tag. Articles were selected based on their pertinence to the research question, by reading the title and abstract. Articles that only marginally discussed the topic were not included. The selected articles were then downloaded and imported to Mendeley, where a full text review was conducted. Each article was assigned a unique tag and a short summary of the main points was drafted. A further sifting selection process was carried out at this stage, since not all papers that had originally appeared suitable were actually considered relevant after a closer look.

Table 2
List of the search terms used to find relevant articles.

SEARCH TERMS	
Key concepts	Synonyms/Related concepts/Variations
Integration	Multimodality; Intermodality; Integrated transport; Multimodal;Bike-and-ride; Combination
Micromobility	E-rideables; E-bikes; E-scooters; Bicycles; Scooters; Mopeds; Active travel modes; PPV; Bike-sharing; Shared mobility; (P)BSS; Micromobility providers
Public transport	Mass transit; Quality of PT provision; Bus; Light rail; Train; BRT; LRT; Networks; Systems; Transportation; Urban mobility services; PT providers
Access/Egress	Provision; Feeder mode; Access trips; Egress trips; Access/Egress mode choice; Supply; Coverage; First and last mile trips; Accessibility to transit; Availability; Frequency; Underserved neighbourhoods

The reasons for exclusion at this stage were documented for each paper. After this thorough and systematic selection process, a total of 48 articles were chosen to be analysed in this systematic literature review.

In the third step, relevant information was extracted and documented for each article, such as the type of integration studied i.e. types of micro-vehicles, type of public transport service; the city or country the study focuses on (if any), the methodology used, etc. The articles were divided into two groups, (i) articles that focused on shared micro-vehicles, and (ii) articles that focused on private micro-vehicles. This distinction was made as it allows adding an ulterior layer to the analysis and discussion, given that most new micromobility services are based on a sharing system, in order to understand similarities and differences between these two types of concepts. In a first step of the analysis (Section 3.1), all the relevant aspects of the integration of micromobility and public transport that were considered in the literature were listed for each article, while in a second step (Section 3.2), the suggestions and recommendations made in each of the 48 articles were collected and discussed.

3.1. Aspects of micromobility and public transport integration studied

The 48 articles selected for this systematic literature review were first divided into two groups: studies pertaining to shared micro-vehicles and studies that focused on private micro-vehicles in combination with public transport. In a first step, the types of integration studies and the case study areas (city/region) were documented for each study. After that, to further specify the types of integration studied, the way in which the integration process has been identified in each study has been documented, as well as the methodologies used in each article.

To facilitate the analysis of the 48 articles selected, a grid was then created that includes all the aspects of the ‘micromobility and public transport integration’ system that are considered most relevant for this overview. These aspects are grouped into the following 4 categories:

3.1.1. Data sources

In this category a distinction was made between five different data sources in order to classify the articles based on the data sources used. The data sources are:

(i) big data from public transport or micromobility providers; (ii) stated preference surveys; (iii) mobility surveys/travel journals; (iv) local authorities, transport modelling tools, statistics, census; (v) interviews or workshops with stakeholders and experts in the field of micromobility and sustainable mobility.

Depending on the data source, and therefore on the data used, the analysis and the results will be either more qualitative or more quantitative in nature. Both insights are relevant in order to obtain a clear picture of the system and can highlight the different dimensions of urban mobility and, in particular, the different aspects of the integration of micromobility and public transport. In this analysis it was considered relevant to understand what type of data sources were used when studying different aspects of micromobility and public transport integration, which is why this category was included in the grid.

3.1.2. System characteristics

This category encompasses all the aspects of the ‘micromobility and public transport integration’ system that determine its functioning:

(i) network and public transport station catchment area; (ii) infrastructure for micromobility within the catchment area; (iii) infrastructure, facilities and services available at public transport stops or stations; (iv) allocation of micromobility sharing stations; (v) built environment characteristics such as land use, density, greenery, etc.; (vi) access to public transport stations or stops; (vii) access to micromobility services; (viii) access to services and opportunities; (ix) vehicle requirements; (x) costs of implementation; (xi) costs for users; (xii) policies put in place to promote micromobility.

All the aspects in this category significantly influence the functioning of the ‘micromobility and public transport integration’ system, which is why it is relevant to determine which of these have been included in the research so far, what impacts have been determined and what recommendations have been made in order to improve and consolidate the system.

3.1.3. Users

This category lists the main user characteristics that have an influence on the ‘micromobility and public transport integration’ system and that, if studied, can provide deeper insights into its functioning and on measures or changes needed in order to promote it. Therefore, it is relevant to gain an overview of how these characteristics have been studied and included in previous research and in combination with which aspects they have revealed certain findings or produced recommendations. The selected characteristics are:

(i) socio-demographic and socio-economic attributes; (ii) preferences; (iii) reasons for modal choice/perceived inconvenience/propensity to choose micromobility; (iv) mobility patterns/micromobility usage patterns/degree of multimodality; (v) perception and acceptance of micromobility services, including the perception of safety of micro-vehicles or micromobility in general and other associations that are made, for example about status or wealth of those that use certain vehicles.

3.1.4. Impacts

In the final category all the most relevant impacts of the integration of micromobility and public transport are listed: (i) increased access to services and opportunities, for instance, improved job accessibility; (ii) modal shifts; (iii) impacts on social inclusion and equity; (iv) increase in public transport ridership; (v) increase in micromobility demand; (vi) economic benefit for the local community; (vii) health effects; (viii) safety and liveability; (ix) energy/fuel consumption; (x) environmental impacts such as carbon footprint, emissions, air and noise pollution reduction.

It was considered relevant, within this study, to investigate which and how the impacts of the integration of micromobility and public transport are studied and quantified. This is especially relevant to understand the discourse used, the aspects that are considered relevant or the arguments that are proposed on this topic. Focusing on relevant impacts and centring the discourse on those aspects that highlight the true potential and beneficial effects of micromobility and public transport integration, allows presenting stronger arguments in decision-making processes to improve the system. Only "what gets measured gets managed" and it is therefore key to understand and measure all relevant impacts in order to further improve the system and generate true change within the urban transportation sector.

Once these categories were defined and the grid was created, the selected articles were screened for each one of those aspects. The according cell in the grid was marked if the paper included a certain aspect in the analysis – it must be noted at this point that if one of the aspects was only briefly mentioned at some point in the article, without it having any influence on the outcome or findings, it was not marked in the grid. The rationale for the grid was to provide an overview of: (i) the different aspects of the micromobility and public transport integration system that have been examined in recent years; (ii) the gaps present in the literature that need to be addressed; (iii) which aspects have been studied in combination, and (iv) to comprehend how this system could be analysed in the future, including all classes of micro-vehicles in combination with public transport.

3.2. Recommendations and suggestions

In a second step of the analysis, in order to generate an overview of the main recommendations and suggestions to improve the integration of micromobility and public transport made by the authors of the 48 articles selected, all the recommendations were collected and grouped into 6 categories. Two tables were then created – one for shared and one for private micro-vehicles – to provide an overview of the types of suggestions contained in the articles. The six categories created are: (i) infrastructure; (ii) built environment; (iii) vehicles, technology & data; (iv) planning; (v) policies, regulations, incentives; (vi) educational campaigns & training

All the specific suggestions made in each category are then presented and discussed more in detail. The purpose of this step was mainly to present an overview for planners, practitioners and all other stakeholders involved, of the insights already gained by research on this subject and to reflect and build on the recommendations, in order to provide guidance on how to improve the planning process and implementation of infrastructure, facilities and services that encourage modal shifts and changes in travel behaviour.

In the fourth step, the findings obtained from the analysis conducted in the previous step are discussed and put into perspective, reflecting on the contribution this review makes while also considering its limitations and ways to go forward.

4. Results and discussion

In this chapter, the results of the systematic literature review are presented and discussed. In the first section, the 48 selected articles are reviewed based on the integration types, data sources, methodologies used and aspects of the integration of micromobility and public transport studied. In the second section then, a review and discussion of the suggesstions and recommendations made in the 48 articles are presented. In the last section of this chapter, the main findings obtained from this systematic literature review are

Table 3
Articles that focus on the integration of shared micro-vehicles with public transport.

	Type of integration studied		City/Region and Country
Adnan et al., 2019	BSS/single docking station	Train	Small/medium cities in Belgium
Bachand-Marleau et al., 2011	Bicycles/BSS/multiple docking stations	Public transit	Montreal, Canada
Böcker et al., 2020	BSS/multiple docking stations	Metro/Rail	Oslo, Norway
Cheng and Lin, 2018	BSS/multiple docking stations	Metro	Kaohsiung, Taiwan
Fan et al., 2019	Bicycle-sharing system (BSS)	Metro	Beijing, China
Griffin and Sener, 2016	BSS/multiple docking stations	Rail	Austin (TX) & Chicago (IL), USA
Grosshuesch, 2020	Dockless e-scooters and bicycles	Public Transit	USA
Guo and He, 2020	Dockless bicycle-sharing system	Metro	Shenzhen, China
Hamidi et al., 2019	BSS/multiple docking stations	Bus, Train, Metro	Malmö, Sweden
Ji et al., 2017	BSS/multiple docking stations	Metro	Nanjing, China
Ji et al., 2018	BSS/multiple docking stations	Metro	Nanjing, China
Li et al., 2020	BSS/multiple docking stations	Public Transit	Xi'an, China
Lin et al., 2018	BSS/multiple docking stations	Metro	Beijing, Taipei, Tokyo
Lin et al., 2019	Dockless bicycle-sharing system	Metro	Shanghai, China
Liu et al., 2020	BSS/multiple docking stations	Metro	Nanjing, China
Ma et al., 2018a	BSS/multiple docking stations	Metro	Nanjing, China
Ma et al., 2018b	BSS/multiple docking stations	Metro	Nanjing, China
Miramontes et al., 2017	Intermodal mobility hub	Tram, Bus, Metro	Munich, Germany
Qin et al., 2018	BSS/multiple docking stations	Metro	Beijing, China
Schröder et al., 2014	Electric micro-vehicles and EVs	Rail-based PT	Southern Germany
Tavassoli and Tamannaei, 2020	BSS/multiple docking stations	BRT	Isfahan, Iran
Wu et al., 2019	Dockless bicycle-sharing system	Metro	Shenzhen, China
Yang et al., 2019	Dockless bicycle-sharing system	Metro	Nanchang, China
Zhao and Li, 2017	BSS/multiple docking stations	Metro	Beijing, China

presented, as well as the limitations and suggestions for further research.

4.1. Review of integration types, data sources, methodologies and aspects studied

The 48 articles that have been selected for this systematic literature review have been divided into two groups: in the first group, the 24 articles listed in Table 3 focus on shared micro-vehicle services, mainly bicycle sharing systems with multiple docking stations; in the second group, the 24 articles that focus on private micro-vehicles, mainly private bicycles, listed in Table 4. In a first step, the type of integration studied and the city or country the study is based in where identified. After, how the integration is measured and identified has been documented, as well as the methodologies used in the 48 selected articles. These two preliminary steps provide an overview of the variety of studies analysed and of the type of integration studied, while also addressing the different types of methodologies used to identify and study intermodal trip chains.

4.1.1. Types of integration studied and case study areas

Several of the articles in the first group compare the use of private and shared bicycles in their analysis, either when studying the reasons for choosing one over the other (Bachand-Marleau et al., 2011; Krizek & Stonebraker, 2011) or when investigating the accessibility and equity of access to the two different types of micro-vehicles (Hamidi et al., 2019).

Some of the articles in the second group suggest that the implementation of a micro-vehicle sharing system could be beneficial to improve the integration of micromobility and public transport and also to promote and raise awareness on micromobility in general (de Souza et al., 2017; Krizek & Stonebraker, 2011; Pritchard et al., 2019; Sagaris et al., 2017; Zuo et al., 2020).

When reviewing the types of integration studied and the sample areas and comparing the two tables, one main difference becomes evident: in the first group (Table 3), several studies focus on Chinese cities, where sharing systems are quite advanced and well integrated into the urban transportation network. Another reason may be due to data availability in those cities, where the technology and the ticketing system have been integrated and combined. Many of the articles utilised smartcard data, with which it is possible to identify integrated trip chains, for instance combinations of bicycle sharing and metro use in the same trip. The other articles, for which this kind of data was not available or was not used, focus on the location and accessibility of bicycle sharing stations and their impact on travel mode choice.

Grosshuesch (2020) discusses the use of shared e-scooters and dockless shared bicycles for first and last mile trips for public transport, and in particular the regulation and policies for these new micro-vehicles in cities in the USA. The other studies focusing on dockless bicycle sharing systems (Guo & He, 2020; Lin et al., 2019; Wu et al., 2019; Yang et al., 2019) are all studies based in Chinese cities that have been published between 2019 and 2020.

The articles from Adnan et al. (2019) and Miramontes et al. (2017), in contrast, are studies conducted on a microscopic/localised scale. Adnan et al. (2019) focuses on a bicycle sharing system with a single docking station at the local train station in small and medium cities in Belgium, to which the shared bicycles have to be returned, while Miramontes et al. (2017) offers a case study of the acceptance and usage of Munich's first intermodality hub, a designated zone at an intermodal transit stop (tram, bus, metro) that provides different vehicle sharing alternatives.

Table 4
Articles that focus on the integration of private micro-vehicles with public transport.

	Type of integration studied		City/Region and Country
Cervero et al., 2013	Bicycles	Bay Area Rapid Transit	San Francisco (CA), USA
Chan and Farber, 2019	Bicycles (+walking)	Commuter rail	Greater Toronto and Hamilton Area, Canada
Cheng and Liu, 2012	Bicycles	Metro/Transit	Kaohsiung, Taiwan
de Souza et al., 2017	Bicycles	Bus, Train, Metro	Rio de Janeiro, Brazil
Geurs et al., 2016	Bicycles	Train	Randstad South, the Netherlands
Heinen and Bohte, 2014	Bicycles	Public Transport	Delft , Zwolle, …, the Netherlands
Hochmair, 2015	Bicycles	Bus or Rail	Los Angeles, Atlanta, Twin Cities, USA
Kager et al., 2016	Bicycles	High-speed + -capacity transit	Amsterdam region, the Netherlands
Krizek and Stonebraker, 2010	Bicycles	Commuter rail/Regional Bus	Boulder, Longmont (CO), USA
Krizek and Stonebraker, 2011	Bicycles	Public Transit	Various cities, USA
Lee et al., 2016	Bicycles	Public Transit	Seoul and Daejeong, South Korea
Marqués et al., 2015	Bicycles	Commuter trains + LRT	Seville, Spain
Marqués and Lovelace, 2017	Bicycles	Public Transit	Seville, Spain
Martens, 2004	Bicycles	Public Transit	The Netherlands, UK, Germany
Martens, 2007	Bicycles	Public Transit	The Netherlands
Midenet et al., 2018	Bicycles + Pedelecs	Train (exurban areas)	Val d'Amboise, France
Pritchard et al., 2019	Bicycles	Metro and Train	São Paulo, Brazil
Pucher and Buehler, 2009	Bicycles	Public Transit	USA and Canada
Rietveld, 2000	Bicycles	Train	The Netherlands
Sagaris et al., 2017	Bicycles (+walking)	Bus, Metro, Transit	Metropolitan Santiago, Chile
Saplıoğlu and Aydın, 2018	Bicycles	Bus	Isparta, Turkey
Tobias et al., 2012	Bicycles	Bus and Metro	Belem, Recife, Salvador, Brazil
Weliwitiya et al., 2019	Bicycles	Train	Melbourne, Australia
Zuo et al., 2020	Bicycles (+walking)	Bus	Hamilton County, Ohio, USA

Schröder et al. (2014) focus on the particular vehicle requirements of electric vehicles intended for a sharing system integrated with public transport and therefore does not study an existing case but rather defines the requirements for electric micro-vehicles, specifically designed for the integration with public transport. When compared with Table 4, Table 3 appears much more homogeneous. Table 4 presents a variety of different integration types from all over the world. Most articles focus on cycling and public transport while only one article considers the use and introduction of pedelecs/electric bicycles in the analysis (Midenet et al., 2018).

In the European context, in particular in the Netherlands, the integration of private bicycles and trains has been studied in detail (Heinen & Bohte, 2014; Geurs et al., 2016; Kager et al., 2016; Martens, 2004, 2007; Rietveld, 2000), due to the popularity of bicycles and the availability of state of the art cycling infrastructure.

In most articles in both groups, the focus lies on rail-based public transport – metro, train, tram/light rail transit (LRT) – and while in some cases the studies include buses, especially in North and South America, where rail-based public transport is not as developed and buses or bus rapid transit (BRT) systems are much more common, high-speed and high-capacity public transport services are predominantly at the centre of attention in these studies. In particular in the studies about cycling and bus integration in North America (Hochmair, 2015; Krizek & Stonebraker, 2010, 2011; Zuo et al., 2020), the option of bringing the bicycle on the bus is often studied, as one of the preferred types of integration by users (Krizek & Stonebraker, 2010).

4.1.2. How the integration has been studied

Another relevant aspect that has been analysed in this systematic literature review is how the integration between micromobility and public transport has been studied and identified. Studying integrated trip chains is not trivial and identifying and selecting data on intermodal travel behaviour requires specific methodologies. As can be seen in Tables 5 and 6, there are several ways in which the integration can be studied. The most common and arguably the easiest method is to use a survey and get the information about the integration practice or preferences from the respondents. For shared micro-vehicles, as can be seen in Table 5, big data from bicycle sharing companies can be used – namely GPS data of start and end locations, trip duration and information about the users. To identify those trips that serve as access or egress for public transport, however, further steps are necessary. Usually the trips are selected creating a buffer around public transport stations, and those micromobility sharing trips that start or end within that buffer are considered access or egress trips. This method is most commonly used in studies pertaining to dockless bicycle sharing services (Guo & He, 2020; Lin et al., 2019; Wu et al., 2019; Yang et al., 2019).

The extent of the buffer varies from study to study, in a range from 50 m (Lin et al., 2019) to 250 m (Yang et al., 2019). Further steps are usually taken to eliminate trips that are not part of an integrated trip chain. The most accurate selection method is given by the use of smart card data, where bicycle sharing trips and metro use for each user can be identified with a specific user ID (Ji et al., 2018; Liu et al., 2020; Ma et al., 2018a, 2018b). In these studies, bicycle sharing trips that start or end within 300 m of a metro station are selected and subsequently matched with metro trips by the same users that have started or ended within 10 min. This means that the transfer process at the metro station has to take 10 min or less for the trip to be considered in the analysis. Spatial data analysis is sometimes also used to model and determine the potential for micromobility and public transport integration, based on factors such as the public transport network characteristics, available infrastructure, built environment. This kind of analysis can be used to compare different scenarios and predict the potential for micromobility and public transport integration in a given area, under specific circumstances. In some of the studies, as can be seen in Table 6, a combination of different methods was used to determine the levels of

Table 5
How the integration has been studied in articles about shared micro-vehicles and public transport.

How is the integration of micromobility and public transport determined? Shared micro-vehicles		
Adnan et al., 2019	Survey	Respondents are asked about their integration practice or preferences
Bachand-Marleau et al., 2011	Survey	Respondents are asked about their integration practice or preferences
Böcker et al., 2020	Big data	Bicycle sharing trips that start or end within 200 m of a PT station
Cheng and Lin, 2018	Survey	Respondents are asked about their integration practice or preferences
Fan et al., 2019	Survey	Respondents are asked about their integration practice or preferences
Griffin and Sener, 2016	Survey + BSS data	Bicycle sharing trips that start or end within 400 m of a PT station
Grosshuesch, 2020	Conceptual analysis	–
Guo and He, 2020	Big data – Dockless BSS	Bicycle sharing trips that start or end within 100 m of a PT station entrance
Hamidi et al., 2019	Spatial data analysis	Number of parking spots and BSS stations within 250 m of PT station
Ji et al., 2017	Survey	Respondents are asked about their integration practice or preferences
Ji et al., 2018	Smart card data BSS & Metro	10 min and 300 m transfer limits
Li et al., 2020	Spatial data analysis	Availability of BSS stations at origin, PT station & destination
Lin et al., 2018	Survey	Respondents are asked about their integration practice or preferences
Lin et al., 2019	Big data – Dockless BSS	50 m buffer around PT station entrance for origin/destination of BSS trips
Liu et al., 2020	Smart card data BSS & Metro	10 min and 300 m transfer limits
Ma et al., 2018a	Smart card data BSS & Metro	10 min and 300 m transfer limits
Ma et al., 2018b	Smart card data BSS & Metro	10 min and 300 m transfer limits
Miramontes et al., 2017	Survey	Respondents are asked about their integration practice or preferences
Qin et al., 2018	Survey	Respondents are asked about their integration practice or preferences
Schröder et al., 2014	Conceptual analysis	Vehicle requirements for electric micro-vehicles
Tavassoli and Tamannaei, 2020	Spatial data analysis	PT network and catchment areas are analysed to determine potential
Wu et al., 2019	Big data – Dockless BSS	Bicycle sharing trips that start or end within 100 m of a PT station entrance
Yang et al., 2019	Big data – Dockless BSS	Origin and destination of each trip within 250 m and 2000 m around PT stations
Zhao and Li, 2017	Survey	Respondents are asked about their integration practice or preferences

Table 6
How the integration has been studied in articles about private micro-vehicles and public transport.

How is the integration of micromobility and public transport determined? Private micro-vehicles		
Cervero et al., 2013	Survey	Respondents are asked about their integration practice or preferences
Chan and Farber, 2019	Survey	Respondents are asked about their integration practice or preferences
Cheng and Liu, 2012	Survey	Respondents are asked about their integration practice or preferences
de Souza et al., 2017	Survey	Respondents are asked about their integration practice or preferences
Geurs et al., 2016	Dutch National Transport Model	Modal share of bicycles for access/egress trips is determined
Heinen and Bohte, 2014	Survey	Respondents are asked about their integration practice or preferences
Hochmair, 2015	Survey	Respondents are asked about their integration practice or preferences
Kager et al., 2016	Spatial data analysis	Train + bicycle infrastructure is analysed to determine travel times
Krizek and Stonebraker, 2010	Survey + Spatial data analysis	Data from respondents and catchment area characteristics
Krizek and Stonebraker, 2011	Conceptual analysis	Comparison of different infrastructure improvements
Lee et al., 2016	Spatial data/conceptual analysis	PT catchment area characteristics/Bicycle-Transit Oriented Design
Marqués et al., 2015	Spatial data analysis	PT catchment area characteristics to determine potential for integration
Marqués and Lovelace, 2017	Survey + Spatial data analysis	Data from respondents and catchment area characteristics
Martens, 2004	Survey	Respondents are asked about their integration practice or preferences
Martens, 2007	Survey	Respondents are asked about their integration practice or preferences
Midenet et al., 2018	Spatial data analysis	Spatial distribution of access modes is determined via a model
Pritchard et al., 2019	Spatial data analysis	Bike-and-ride model based on infrastructure and built environment
Pucher and Buehler, 2009	Survey	Respondents are asked about their integration practice or preferences
Rietveld, 2000	Survey	Respondents are asked about their integration practice or preferences
Sagaris et al., 2017	Conceptual analysis	Hypothetical considerations on combined use of cycling and PT
Saplıoğlu and Aydın, 2018	Survey	Respondents are asked about their integration practice or preferences
Tobias et al., 2012	Survey	Respondents are asked about their integration practice or preferences
Weliwitiya et al., 2019	Survey + Spatial data analysis	Data from respondents and catchment area characteristics
Zuo et al., 2020	Spatial data analysis	Accessibility analysis by bicycle in PT catchment area

integration between micromobility and public transport: information obtained from surveys was combined with spatial data analyses of the public transport catchment areas around public transport stations (Krizek & Stonebraker, 2010; Marqués and Lovelace, 2017; Weliwitiya et al., 2019). A limited number of studies, Grosshuesch (2020) and Schröder et al. (2014) in Table 5 and Krizek & Stonebraker (2011) and Sagaris et al. (2017) in Table 6 conducted a conceptual analysis, meaning that they did not specifically identify integrated trips. In these studies, the concept of the integration of micromobility and public transport was studied as such, taking the integration of the two modes as a given. .

As well as the data collection types and methodologies used to determine the integration of micromobility and public transport, the methodologies used to answer the research question in each of the 48 selected articles were reviewed and are presented in Table 7. A variety of different methodologies were used in the 48 articles reviewed in this study. A significant number of articles, as shown in Table 7, are based on findings from regression analyses and several studies use GIS-based spatial analyses to determine different aspects and spatial characteristics of the integration of micromoiblity and public transport. Many studies presented in Table 7 centre the enquiry on accessibility analyses, to determine how the integration of micromobility and public transport influences access to public transport and to services and opportunities. In particular, as shown in Table 7, a number of studies use inequality indices and equity analyses to determine the social impacts of micromobility and public transport integration (Hamidi et al., 2019; Pritchard et al., 2019; Zuo et al., 2020). A number of qualitative studies have also been reviewed, where the main methodologies used include the direct involvement of stakeholders through workshops and focus groups (Griffin & Sener, 2016; Krizek & Stonebraker, 2011; Miramontes et al., 2017; Schröder et al., 2014). Some studies present a conceptual analysis and a review of policies and incentives put in place to promote the integration of micromobility and public transport (Grosshuesch, 2020; Kager et al., 2016; Sagaris et al., 2017) while others focus on a discussion based on national trends and case studies (Cervero, Caldwell, & Cuellar, 2013; Pucher & Buehler, 2009; Rietveld, 2000). Overall, the variety of methodologies used shows the extent and complexity of the topic and equally suggests that, in order to gain an overview of the countless aspects and facets that characterise the integration of micromobility and public transport, it is necessary to study and approach the topic from a range of angles and viewpoints.

4.1.3. *Aspects of micromobility and public transport integration studied*

The grid presented in Table 8, which includes all 48 articles selected for this study divided into the two groups of either shared or private micro-vehicles, provides an overview of the different aspects and characteristics of the micromobility and public transport integration system studied.

4.1.4. *Data sources*

In the data sources category, it can be seen that most studies rely on stated preference and mobility surveys and data from transport modelling tools or from local authorities for the analysis. Big data volumes from micromobility or public transport providers, as previously mentioned, are mainly used in articles examining bicycle sharing systems in Chinese cities. These kinds of data allow for obtaining results on a large scale and can help identify mobility patterns and determine the size of the catchment area and activity spaces around public transport stations. While some socio-economic and demographic characteristics of the users are also known, this type of data source only provides limited explanations for preferences, choices or the acceptance of different types of services. To investigate these aspects, a stated preference survey or mobility survey are generally utilised. This is also well reflected in the grid,

Table 7
Methodologies used to study the integration of micromobility and public transport.

Adnan et al., 2019	Hybrid Choice Model (HCM)
Bachand-Marleau et al., 2011	Market Segmentation Analysis
Böcker et al., 2020	Three types of multivariate modelling techniques
Cheng and Lin, 2018	Mixed-logit model (ML), GIS analysis, Cost-benefit analysis
Fan et al., 2019	Multinomial logit model
Griffin and Sener, 2016	Descriptive statistics, Plan evaluation techniques, Semi-structured interviews
Grosshuesch, 2020	Discussion based on data from cities/surveys, reports, news articles
Guo and He, 2020	Negative binomial regression model
Hamidi et al., 2019	Accessibility analysis, Inequality analysis (Theils Inequality index)
Ji et al., 2017	Multinomial and nested logit models
Ji et al., 2018	Global Poisson regression model, GWPR model
Li et al., 2020	Continuum model to jointly optimize the bimodal transit system and shared bikes in a grid network
Lin et al., 2018	Binary logit and latent class models
Lin et al., 2019	Spatial analysis and regression models
Liu et al., 2020	Negative binomial regression model
Ma et al., 2018a	Standard deviation ellipse (SDE), Ordinary least squares (OLS), Spatial error model (SEM)
Ma et al., 2018b	Bikeshare data analysis
Miramontes et al., 2017	Mixed methods approach: Stakeholder inteviews, User surveys, Focus groups
Qin et al., 2018	Stated preference survey design, Logit models, Comparative analysis, Sensitivity analysis
Schröder et al., 2014	A multi-method approach for developing and evaluating intermodal sharing services
Tavassoli and Tamannaei, 2020	Mathematical model to solve BSS station allocation problem
Wu et al., 2019	Bicycle accessibility model, Regression model
Yang et al., 2019	A combination of geo-statistical and graph theory approaches
Zhao and Li, 2017	Multilevel logistic model
Cervero et al., 2013	Case study
Chan and Farber, 2019	Binomial logit model
Cheng and Liu, 2012	Rasch model
de Souza et al., 2017	Binary logit model
Geurs et al., 2016	Multi-modal transport network modelling and accessibility modelling
Heinen and Bohte, 2014	Analysis of users' attitudes towards transport modes through survey (theory of planned behaviour)
Hochmair, 2015	Prediction model, ordinary least-squares (OLS) regression
Kager et al., 2016	Combination of system perspective and conceptual analysis
Krizek and Stonebraker, 2010	Review/Summary
Krizek and Stonebraker, 2011	Comparative study, Cost-effectiveness assessment, Survey, Focus groups, Analytic Hierarchy Process
Lee et al., 2016	Regression and cumulative distribution models
Marqués et al., 2015	GIS based methodology, Survey
Marqués and Lovelace, 2017	GIS based methodology, Stated preference surveys
Martens, 2004	Gathering and analysis of data on bike-and-ride trips
Martens, 2007	Discussion of experiences and impacts of bike-and-ride policy initiatives
Midenet et al., 2018	Access mode share model
Pritchard et al., 2019	Accessibility analysis, Equity analysis (Gini coefficient)
Pucher and Buehler, 2009	Analysis of national trends, Case studies
Rietveld, 2000	Discussion/Review
Sagaris et al., 2017	Conceptual, social and spatial analysis
Saplıoğlu and Aydın, 2018	Analytic Hierarchy Process (AHP) method, GIS analysis
Tobias et al., 2012	Survey data analysis
Weliwitiya et al., 2019	'Overdispersed' Poisson and negative binomial regression, goodness of fit
Zuo et al., 2020	GIS analysis, Accessibility analysis, Equity analysis

where these pairings can be seen, both for the shared and private micro-vehicles. Only five of the 48 articles (de Souza et al., 2017; Griffin & Sener, 2016; Krizek & Stonebraker, 2011; Miramontes et al., 2017; Schröder et al., 2014) included data and information obtained from interviews with stakeholders or experts or during workshops and work groups. The collection of this type of qualitative data requires a significant amount of time and resources and these data are very case specific, since it is usually limited to a particular vehicle or small area. Nevertheless, in order to gain a full perspective of the system, it is important to acquire knowledge and information at all scales and levels, including the very personal and detailed information that can be gathered during workshops or in workgroups of experts. As discussed further in Section 3.2, it is crucial to include all stakeholders early on in the planning process, in order to take into account all the different aspects that are relevant to different actors in the system, namely the local authorities, public transport and micromobility providers, and especially the users.

4.1.5. System characteristics

When it comes to the system's characteristics, the built environment, micromobility infrastructure and the facilities for micromobility at public transport stations play a major role in most studies. Since these are all factors that significantly influence people's propensity of using micromobility as an access mode to public transport. Many studies focus on the catchment area surrounding public transport stations and on how the size of these catchment areas can be influenced by the introduction or presence of micromobility services and infrastructure. In particular, the availability of safe, convenient and protected infrastructure for micromobility in the catchment areas of public transport stations is one of the most relevant factors in determining the potential and propensity of

Table 8
Overview of the main aspects considered in each of the 48 articles selected for this systematic literature review.

		Data sources					System characteristics												Users					Impacts										
		Big data from PT or micromobility providers	Stated preference survey	Mobility survey / Travel diary	Local authorities / Traffic models / Statistics	Stakeholder or experts interviews / Workshops	Catchment Area / Network	Infrastructure for micromobility	Facilities at PT stations	Sharing station locations	Built environment	Access to PT stations	Access to micromobility	Access to S&Os	Vehicle requirements	Cost of implementation	Cost for users	Policies in favour of micromobil.	Socio-demographic attributes	Preferences	Reasons for modal choice	Mobility patterns	Perception and accept.	Increase access to S&Os	Modal shifts	Promote social inclusion/equity	Increase PT ridership	Increase micromobility demand	Economic benefit	Health effects	Safety and liveability	Energy/fuel consumption	Environmental impacts	
Shared micro-vehicles	Adnan et al., 2019		X					X	X		X	X					X		X	X	X	X												10
	Bachand-Marleau et al., 2011		X	X					X										X	X		X			X									7
	Böcker et al., 2020	X					X				X	X							X															5
	Cheng & Lin, 2018		X	X	X		X		X	X		X	X			X			X	X		X		X					X				X	15
	Fan et al., 2019			X				X		X		X							X		X	X	X		X									9
	Griffin & Sener, 2016	X			X	X				X	X	X						X																7
	Grosshuesch, 2020											X						X						X										2
	Guo & He, 2020	X						X			X	X							X															5
	Hamidi et al., 2019			X				X	X			X	X	X					X							X								8
	Ji et al., 2017			X							X						X		X		X	X				X								7
	Ji et al., 2018	X						X	X		X			X			X		X			X												8
	Li et al., 2020				X		X	X		X						X	X												X					7
	Lin et al., 2018			X			X				X	X					X		X			X												7
	Lin et al., 2019	X			X		X	X			X	X							X					X										8
	Liu et al., 2020	X							X	X	X								X															5
	Ma et al., 2018a	X					X			X	X	X							X			X												7
	Ma et al., 2018b	X																	X			X												3
	Miramontes et al., 2017			X		X							X							X	X	X	X		X			X						9
	Qin et al., 2018		X					X	X		X		X						X	X	X	X	X		X			X						12
	Schröder et al., 2014		X	X	X	X									X		X			X			X											8
	Tavassoli & Tamannaei, 2020				X		X			X		X	X			X	X								X		X							9
	Wu et al., 2019	X					X	X	X		X	X		X			X	X						X										10
	Yang et al., 2019	X									X	X										X												4
	Zhao & Li, 2017			X	X				X		X							X	X	X		X	X											9
Private micro-vehicles	Cervero et al., 2013				X		X	X	X		X	X																						6
	Chan & Farber, 2019				X			X	X		X	X							X		X	X												8
	Cheng & Liu, 2012			X				X	X									X	X		X													6
	de Souza et al., 2017			X		X			X		X	X							X		X	X												8
	Geurs et al., 2016		X		X			X	X		X	X		X			X	X	X					X			X							12
	Heinen & Bohte, 2014			X														X	X	X	X	X	X											7
	Hochmair, 2015			X	X		X	X	X		X	X																						7
	Kager et al., 2016				X		X	X			X																							4
	Krizek & Stonebraker, 2010				X		X	X			X							X							X									6
	Krizek & Stonebraker, 2011		X			X		X	X							X	X			X									X					8
	Lee et al., 2016		X	X			X					X								X	X	X			X		X	X						10
	Marqués et al., 2015			X	X		X	X	X									X							X			X						8
	Marqués & Lovelace,, 2017		X	X			X		X		X									X		X												7
	Martens, 2004				X		X				X							X			X	X												6
	Martens, 2007				X			X	X			X									X	X												6
	Midenet et al., 2018				X		X		X			X						X							X									6
	Pritchard et al., 2019		X	X				X			X			X					X	X				X		X								9
	Pucher & Buehler, 2009				X			X	X		X							X		X														6
	Rietveld, 2000				X							X																						2
	Sagaris et al., 2017				X						X			X			X		X		X	X		X		X								9
	Saplıoğlu & Aydın, 2018		X		X			X			X	X							X															6
	Tobias et al., 2012		X		X				X			X					X			X	X													7
	Weliwitiya et al., 2019				X			X	X		X	X							X															6
	Zuo et al., 2020	X			X			X						X					X							X								6
		10	12	17	24	5	17	23	23	7	27	25	5	7	1	4	12	12	25	14	14	21	6	7	9	5	3	4	3	0	0	0	1	

commuters to use micromobility as an access and egress mode. Likewise, the availability of services at public transport stations that promote and facilitate the integration of micromobility and public transport is equally important. Safe, convenient and affordable parking facilities for private micro-vehicles, the availability of micro-mobility sharing stations or designated areas to park dockless shared micro-vehicles in proximity of the public transport station, as well as a safe and pedestrian-friendly environment to access the public transport station/stop are crucial. These elements contribute to a smooth, quick and effortless transfer from one mode to the other, improving the overall user experience and satisfaction.

The built environment characteristics in the surroundings of public transport stations have been considered in 27 of the 48 selected articles (Table 8), often times in terms of population density and land use in the catchment area of public transport stations. These characteristics significantly influence the propensity of choosing micromobility as an access or egress mode for public transport, both for private and shared micro-vehicles. For instance, when analysing and planning the amount of parking spaces required at a given public transport station or the optimal allocation of docking stations for shared micro-vehicles in the catchment area. The presence of greenery within the catchment area and along or around the infrastructure that connects trip origins/destinations to public transport stations is also considered in several studies, since it has a positive effect on the propensity to use micromobility in access or egress trips to and from public transport (Chan & Farber, 2019; Guo & He, 2020; Zhao & Li, 2017).

Another important factor is accessibility. When analysing the integration of micromobility and public transport it is crucial to understand how accessible public transport stations are, how well sharing services, micromobility infrastructure and facilities can be accessed and how well these provide access to services and opportunities within a given time. This is particularly relevant when analysing mobility patterns and user behaviour, to understand the inequalities in level of access. By addressing these elements, a more equal service that fosters social inclusion can be provided, which can help marginalised groups to become more integrated (Hamidi et al., 2019; Ji et al., 2017; Pritchard et al., 2019; Sagaris et al., 2017; Zuo et al., 2020).

Four of the articles in Table 8 have included implementation costs of different integration measures in their analysis and determined the cost-effectiveness of micromobility and public transport integration compared to other measures and strategies (Cheng & Lin, 2018; Krizek & Stonebraker, 2011; Li et al., 2020; Tavassoli & Tamannaei, 2020). As can be seen in Table 8, the costs for users that integrate micromobility and public transport have been included in 12 of the 48 studies, given that costs, particularly of sharing services and parking facilities, can be a determining factor of modal choice and as such can often act as a barrier. As will be discussed in Section 3.2, incentives and discounts are often suggested as a strategy to attract new users and to include marginalised population groups.

The presence or introduction of policies in favour of micromobility and public transport integration has been considered more often in studies concerning private micro-vehicles, and is often related to policies and regulations that allow micromobility users to carry their micro-vehicles on board of the public transport service or bike-and-ride policies that facilitate the integration of the two modes. In the studies concerning shared micro-vehicles - the policies and regulations considered pertain to the improvement of cycling infrastructure and the implementation of safe and protected cycling lanes (see Table 8).

In this category, the grid (Table 8) also displays that some aspects of the system that are relevant for the use of shared micro-vehicles are not relevant for the use of private micro-vehicles. For instance, the location or distance to sharing stations and therefore the access to micro-vehicles, vehicle requirements and the costs of implementation of the service or the rental cost for users are of course not relevant when the user owns a micro-vehicle. Articles considering the use of private micro-vehicles are more focused on the influence that policies in favour of micromobility have on the ridership and modal share of micromobility in access and egress trips. The vehicle requirements of micro-vehicles, in the specific context of their integration with public transport, are only studied in one of the 48 articles (Schröder et al., 2014), which concentrates on the design of electric micro-vehicles for a sharing system for access and egress trips to and from public transport.

4.1.6. Users

Regarding user characteristics, demographic and socio-economic attributes are included in most studies since this information can be obtained from surveys and from census data or statistics provided by local authorities. This type of data is often also included in big data from public transport or micromobility providers, as is the case in the studies carried out using smart card data in Chinese cities (Ji et al., 2018; Lin et al., 2019; Liu et al., 2020; Ma et al., 2018a, 2018b; Wu et al., 2019; Yang et al., 2019). Many studies, as can be seen in Table 8, also consider the mobility patterns of users, to try to uncover the interdependencies of modal choice and the spatial extent and reach of each mode within the intermodal trip chain. When trying to understand the behaviour of users that integrate micromobility and public transport it is relevant to understand how and when they choose to integrate these two modes and for what types of trips. Approximately 25% of all the studies considered also include preferences and reasons for modal choice in their analyses, while only six studies that focus on shared micro-vehicles (none in the second group) include the perception and acceptance of micromobility as a factor in their research (Fan et al., 2019; Heinen and Bohte, 2014; Miramontes et al., 2017; Qin et al., 2018; Schröder et al., 2014; Zhao and Li, 2017). Heinen and Bohte (2014), in particular, studied the impact of personal beliefs and attitudes towards transport modes on actual mode choice and preferences.

The reasons and factors that influence modal choice are key as they can often pose a barrier for new users to try a vehicle or mode that they perceive to be unsafe or that they associate with a certain type of user behaviour. In Zhao and Li (2017), for example, it is mentioned that cycling is associated with low-income groups in Beijing, and many users avoid cycling because of its negative image and links to societal status.

4.1.7. Impacts

In the final category, the impacts of the integration of micromobility and public transport are listed. By examining Table 8 it is evident that the impacts do not feature in the analysis in most articles. Most articles mentioned some of the benefits or effects of micromobility and public transport integration in the introduction, literature review or conclusion, but the impacts do not form part of the analysis, and the impacts were not calculated or quantified in any way. As can be seen in the columns on the right of the grid in Table 8, the impact that has been quantified the most (in 9 out of 48 articles), is the modal shift that can be expected from the improvement of the micromobility and public transport integration system.

Seven of the selected studies in Table 8 conducted an analysis with the goal of quantifying the improvement in the access to services and opportunities (S&O), while in five of the articles, the analysis included a quantification of the impact of micromobility and public transport integration on social inclusion and equity among different population groups. Four of the studies quantified the impact of micromobility and public transport integration on the demand for micromobility services, while three of them quantified the increase in public transport ridership due to an improved integration with micromobility. Li et al. (2020) have analysed the economic impact of different types of measures and improvements to promote the integration of micromobility and a bi-modal transit network, while Krizek and Stonebraker (2011) have assessed the cost-effectiveness of measures of different types of integration such as bike on transit, shared bicycles or bicycle parking facilities at public transport stations. Cheng and Lin (2018) conducted a cost-benefit analysis of the integration of a bicycle sharing system with the metro network, and considered cost and economic impacts of the integration, while also calculating CO_2-emission reduction following modal shifts from private cars as an environmental impact/benefit.

The grid in Table 8 clearly shows that there are gaps in the literature that need to be investigated and combined with previous findings in order to fully understand the system and implement changes that can lead to more sustainable mobility systems.

Table 9
Overview of suggestions included in the articles reviewed in this analysis.

		Infrastructure	Built Environment	Vehicles, Technology & Data	Planning	Policies & Regulations	Pricing & Incentives	Educational campaigns & Training
Shared micro-vehicles	Adnan et al., 2019	x				x	x	
	Bachand-Marleau et al., 2011	x		x	x			
	Böcker et al., 2020	x		x		x	x	
	Cheng and Lin, 2018	x	x	x			x	
	Fan et al., 2019	x	x	x		x		
	Griffin and Sener, 2016	x			x			
	Grosshuesch, 2020	x			x	x		
	Guo and He, 2020	x	x	x				
	Hamidi et al., 2019				x			x
	Ji et al., 2017	x		x			x	x
	Ji et al., 2018	x		x		x	x	
	Li et al., 2020	x						
	Lin et al., 2018		x					
	Lin et al., 2019	x			x		x	
	Liu et al., 2020	x				x	x	x
	Ma et al., 2018a	x		x				
	Ma et al., 2018b	x		x	x	x	x	
	Miramontes et al., 2017							
	Qin et al., 2018	x	x					
	Schröder et al., 2014			x				
	Tavassoli and Tamannaei, 2020	x						
	Wu et al., 2019	x	x			x		
	Yang et al., 2019	x	x					
	Zhao and Li, 2017	x				x	x	x
Private micro-vehicles	Cervero et al., 2013	x			x			
	Chan and Farber, 2019	x	x		x			
	Cheng and Liu, 2012	x	x	x		x	x	x
	de Souza et al., 2017	x					x	
	Geurs et al., 2016	x				x		
	Heinen and Bohte, 2014				x			
	Hochmair, 2015	x	x		x			
	Kager et al., 2016				x			
	Krizek and Stonebraker, 2010	x			x			
	Krizek and Stonebraker, 2011	x		x				
	Lee et al., 2016	x		x	x			
	Marqués et al., 2015	x			x			
	Marqués and Lovelace, 2017	x						
	Martens, 2004							
	Martens, 2007	x			x			
	Midenet et al., 2018	x					x	
	Pritchard et al., 2019	x		x				
	Pucher and Buehler, 2009	x				x		
	Rietveld, 2000	x	x					
	Sagaris et al., 2017	x	x		x			
	Saplıoğlu and Aydın, 2018	x						
	Tobias et al., 2012	x			x		x	
	Weliwitiya et al., 2019	x			x	x		
	Zuo et al., 2020	x	x		x		x	

Particularly in relation to the impacts, it is apt to further analyse the impacts that the integration of micromobility and public transport has on a social, economic and environmental scale. In order to improve and further promote this form of intermodality, it is suggested that the focus should shift to the impacts, in order to understand causalities, reduce negative effects and enhance the benefits where possible. This is particularly relevant for new micro-vehicles that are brought to the market, where the environmental, economic and social impacts are not well known and studied yet and proof of effect could promote modal shifts and change individual's perception of micromobility. For instance, the environmental impact of electric micro-vehicles is a current issue of debate, which requires further investigation, so that the system can be improved and cater for a more sustainable alternative to private motorised vehicles. As presented in a recent report (Holm Møller et al., 2019), the first life cycle analysis of e-scooters has prompted the micromobility provider VOI to reconsider some aspects of production, vehicle requirements and charging processes in order to reduce emissions and improve the overall sustainability throughout the life cycle of the vehicle. Another aspect that is frequently debated in the literature is safety. How safe is micromobility and how should it be regulated in order to guarantee that all road users are safeguarded? This aspect has similarly not been fully addressed in sufficient detail in the 48 articles included in this review and is a topic of debate in many cities worldwide. Several reports on micromobility have addressed the issue and underlined the importance of further research to clarify the questions that remain unanswered regarding regulations and the safety implications of new micro-vehicles (Holm Møller et al., 2019; ITF, 2020). In Section 4.2 the main suggestions and recommendations included in the 48 selected articles will be presented and discussed.

4.2. Review of suggestions and recommendations

The suggestions and recommendations made by the authors of the 48 selected articles have been grouped into six different categories, dependent on the issues they address. As outlined in Table 9, in both groups, for both shared and private micro-vehicles, the majority of suggestions made are in relation to infrastructure. For shared micro-vehicles, suggestions regarding vehicles, technology and data, and about policies, regulations and incentives have been made in several articles, while for private vehicles aspects regarding planning are mentioned frequently. The specific suggestions brought forward in the articles will be presented and discussed in detail in the following.

4.2.1. Infrastructure

Most studies stress the importance of a safe, comfortable and continuous network of dedicated and protected lanes for micro-vehicles (Cervero et al., 2013; Chan and Farber, 2019; Cheng and Liu, 2012; Fan et al., 2019; Geurs et al., 2016; Guo and He, 2020; Hochmair, 2015; Ji et al., 2018; Lee et al., 2016; Marqués and Lovelace, 2017; Midenet et al., 2018; Pritchard et al., 2019; Qin et al., 2018; Saplıoğlu and Aydın, 2018; Tobias et al., 2012; Weliwitiya et al., 2019; Wu et al., 2019; Zhao and Li, 2017; Zuo et al., 2020). This is cited, in the vast majority of cases, as the most important intervention/measure required to promote micromobility and public transport integration. The provision and availability of infrastructure that ensures a safe and efficient use of micro-vehicles should therefore be a priority for municipalities and city officials (Grosshuesch, 2020). Guo and He (2020) mention the importance of improving road conditions and connections of cycling lanes, to reduce the risk of collisions with other road users, and to improve the user experience of micromobility.

Another crucial aspect stated in the literature is the availability of safe, user-friendly and affordable micromobility parking facilities at public transport stations (Adnan et al., 2019; Bachand-Marleau et al., 2011; Cervero et al., 2013; Chan and Farber, 2019; de Souza et al., 2017; Geurs, La Paix, and Van Weperen, 2016; Krizek and Stonebraker, 2011; Liu et al., 2020; Marqués et al., 2015; Midenet et al., 2018; Pritchard et al., 2019; Pucher and Buehler, 2009; Rietveld, 2000; Tobias et al., 2012). This is particularly important when using private micro-vehicles, since parking can affect transfer time and perceived unsafe parking or prior experiences of theft can deter users from choosing private micro-vehicles as access mode to public transport stations.

When using shared micro-vehicles, both station-based and dockless, ending rides in proximity of busy public transport stations can equally be a problem, when there are an insufficient number of spaces available. The availability of both shared bicycles and docks therefore needs to be able to meet the existing demand (Ji et al., 2017; Ma et al., 2018b). This requires a well-functioning redistribution system of shared micro-vehicles, as will be discussed in more detail in the Technology section of this chapter.

With reference to docking stations of shared micro-vehicles, Böcker et al. (2020) and Yang et al. (2019) suggest a distance of 200–220 m from the docking station to the public transport station, which has been found as the maximum distance that users are willing to walk to access public transport after returning the shared micro-vehicle.

Another recommendation that many studies offered is to implement traffic calming measures and regulations to control motorised traffic in order to avoid conflicts and make conditions safer for all road users (Chan and Farber, 2019; Cheng and Liu, 2012; Midenet et al., 2018; Tobias et al., 2012). Particularly in the area surrounding public transport stations, it is crucial to provide safe and pedestrian-friendly environments, so that micromobility users can access public transport safely and quickly (Böcker et al., 2020; Martens, 2007). At the same time, it is also suggested that the availability of car parking spaces and park-and-ride facilities at public transport stations should be limited, since the availability of those amenities may deter commuters from using micromobility to reach the station and are therefore in conflict with the policies in favour of micromoblity (Chan and Farber, 2019; Midenet et al., 2018). Pucher and Buehler (2009) suggest that transit systems should invest in and provide bike-and-ride rather than park-and-ride facilities, as they are not only more cost-effective, but are also a more efficient use of space and are environmentally friendly.

Many studies also suggest implementing sharing services and to increase their convenience and availability (Böcker et al., 2020; Li et al., 2020; Qin et al., 2018;) and to plan them specifically as a services that should be used predominantly in combination with public transport in order to promote modal shifts from private motorised vehicles (Cheng and Lin, 2018; Ji et al., 2018; Lin et al., 2019; Qin et al., 2018; Tavassoli and Tamannaei, 2020; Zhao and Li, 2017). Most sharing services should be expanded to suburban areas outside of the city centres (de Souza et al., 2017; Ji et al., 2018; Ma et al., 2018a), and stations should be made available near commuter destinations such as schools and office locations as well as in residential areas (Ji et al., 2017; Ma et al., 2018b; Martens, 2007). Böcker et al. (2020) found that the allocation of bicycle sharing stations, particularly at the destination locations, can exclude certain population groups and limit equal access to the service, which is a factor that should be considered when the spatial distribution of sharing stations is planned. Some papers suggest that, in countries with high degrees of inequality in terms of access to public transport, in addition to micromobility infrastructure, further investment in transit in low-income and peripheral/suburban areas is required (Bachand-Marleau et al., 2011; Ji et al., 2018; Krizek and Stonebraker, 2010; Pritchard et al., 2019; Sagaris et al., 2017).

Cheng and Liu (2012), Bachand-Marleau et al. (2011) , Krizek and Stonebraker (2010) and Krizek and Stonebraker (2011) focused on the possibility of taking micro-vehicles on public transport and suggested that, in order to improve this service, the infrastructure and facilities at public transport stations should be enhanced and special carriages would need to be provided to facilitate the transport of micro-vehicles.

4.2.2. Built environment

The built environment around public transport stations significantly influences the share of micromobility use in access and egress trips. However, of all the mentioned factors, the built environment is the one that cannot be changed and adapted as easily as the others, and therefore the suggestions given revolve around other aspects of the integration or are limited to strategies for new developments. For example, local authorities should encourage and promote dense and contiguous developments with mixed land-use and micromobility-and pedestrian-friendly environments (Cheng and Lin, 2018; Fan et al., 2019; Qin et al., 2018; Sagaris et al., 2017; Wu et al., 2019; Zuo et al., 2020). The street network structure, such as street intersection density, traffic volumes (Chan and Farber, 2019; Hochmair, 2015;) and the presence of greenery play an important role and significantly influence the modal choice for access and egress trips to and from public transport stations (Cheng and Liu, 2012). These factors should also be considered when choosing the optimal locations of micromobility sharing stations (Griffin and Sener, 2016; Guo and He, 2020). Lin et al. (2018), however, mention that local authorities should be wary of making reference to findings from other cities when it comes to the influence of built environment characteristics and shared micromobility use. Empirical data collection of local knowledge and preferences is suggested as the best option.

Rietveld (2000) suggests that non-residential, high density land-use types should be prioritised in the surroundings or railway stations, such as offices, education, shopping and cultural facilities to promote active travel modes and micromobility as access and egress modes.

4.2.3. Technology (Vehicles/Apps/Real-time data)

Technology plays an important role since it can significantly improve and facilitate the integration of micromobility and public transport. When it comes to designing new concepts and intermodal sharing systems, the alternatives should be evaluated based on different criteria in order to identify the most suitable concepts and the associated vehicle requirements (Schröder et al., 2014). For shared micro-vehicle systems, mobile phone applications and real time data on availability at different locations are crucial in improving the usability and user-friendliness of the service. Real-time information on shared micromobility usage and available vehicles at docking stations is essential, both for users, to plan ahead, and for providers to design a specific and effective redistribution system (Cheng and Lin, 2018; Fan et al., 2019; Ji et al., 2017, 2018; Ma et al., 2018a, 2018b). The redistribution system needs to be flexible, in order to adapt to changes in flows and usage (Yang et al., 2019) and it is a crucial part of the integration of shared micromobility with public transport (Guo and He, 2020), since the availability of vehicles and docking stations is the main factor that influences propensity to use share micro-vehicles to access public transport stations.

For users that want to transport their micro-vehicle on public transport, real time data on available spaces on public transport carriages should also be provided (Bachand-Marleau et al., 2011; Cheng and Liu, 2012).

To improve safety, user satisfaction and ultimately attract new customers, the performance of shared micro-vehicles should be improved by installing bells and antiskid tires, regularly replacing brake-pads, and generally ensuring quality and maintenance of vehicles (Fan et al., 2019; Ma et al., 2018b). Shared micro-vehicles should, whenever possible, be adapted to the needs of different user groups and travel purposes (Böcker et al., 2020; Cheng and Liu, 2012; Ji et al., 2017; Ma et al., 2018b). In general, more data still needs to be collected and made available in relation to micromobility use, transfer practices to and from public transport and public transport ridership in order to better understand the mobility patterns of users and in order to improve the system as a whole (Bachand-Marleau et al., 2011; Böcker et al., 2020; Krizek and Stonebraker, 2011; Lee et al., 2016; Pritchard et al., 2019).

4.2.4. Planning

In order to promote and further improve the integration of micromobility and public transport, the two modes should be considered as one system and accordingly, should be planned and developed together considering the specific dynamics and opportunities that this integration comprises (Kager et al., 2016; Krizek and Stonebraker, 2010; Lee et al., 2016; Marqués et al., 2015; Tobias et al., 2012). In order to successfully do that, it is suggested that all involved stakeholders, including users and local communities, should be included from early on in the planning process (Zuo et al., 2020; Sagaris et al., 2017). Griffin and Sener (2016) suggest that the planning process should be based on a strong collaboration of city officials with the micromobility providers from early on, to define shared goals and work proactively towards them. Performance measurements and annual revisits, paired with public participation should ensure a successful and effective implementation of shared micromobility services (Griffin and Sener, 2016).) Mircomobility-friendly environments should become a priority in master plans and urban mobility plans (Zuo et al., 2020; Hochmair, 2015; Tobias et al., 2012), and guidelines of best practices for the design of high quality infrastructure that facilitates the integration of micromobility and public transport should be shared, promoted and implemented (Zuo et al., 2020). Weliwitiya et al. (2019) suggest that cycling master plans should include specific investment and planning details pertaining to the integration of cycling and public transport. Bachand-Marleau et al. (2011) and Martens (2007) also stress the importance of defining planning objectives and specific measures for the integration of micromobility and public transport, since the availability of infrastructure and services plays such an important role in access and egress mode choice to and from public transport. Heinen and Bohte (2014) found that commuters that use bicycles and public transport have different preferences and beliefs than users that use only one or the other mode. Therefore the specific needs and preferences of integrated transport users should be taken into account when planning and developing measures.

Many studies propose that the evaluations of transport investment proposals and measures should include aspects and parameters concerning equity and social inclusion, in order to prioritise the allocation of resources in areas with low levels of access to services and opportunities by public transport (Hamidi et al., 2019; Lin et al., 2019; Ma et al., 2018b; Sagaris et al., 2017; Zuo et al., 2020). While other papers advise identifying those areas with the highest latent demand for micromobility instead, as a means of prioritising them for measures and investments, since improvements will have the greatest impact on modal shifts in those areas (Chan and Farber, 2019).

4.2.5. Policies and regulations

Policies and regulations play a decisive role in determining user experience, safety and willingness to adopt the mobility practice of integrating micromobility and public transport. This is particularly true of new micro-vehicles that are being introduced in cities worldwide, since many local authorities have struggled to regulate new micro-vehicles such as e-scooters, or have resorted to banning their use (Grosshuesch, 2020). In order to promote and facilitate the regulation of new micro-vehicles, Grosshuesch (2020) suggests that local authorities should refer to regulations already adopted for human-powered micro-vehicles, for example bicycles, and adapt these regulations to electric and shared micro-vehciles, such as e-scooters and dockless shared bicycles. In order to ensure compliance with the regulations on safety and parking, small fines should be introduced (Grosshuesch, 2020). Zhao and Li (2017) state that maintaining road rights and reserving road space for micromobility should be addressed in transport policies, and other studies recommend that illegally parked vehicles on micromobility lanes/infrastructure and around public transport stations should be strictly penalised (Adnan et al., 2019; Ji et al., 2018; Ma et al., 2018b). Furthermore, Fan et al. (2019) and Weliwitiya et al. (2019) state that micromobility users should be given priority at intersections, as a head start at intersections increases visibility and can reduce conflicts with motorised traffic or other road users. Safety and user experience of micromobility users could be improved by reducing speed limits on roads adjacent to or in the vicinity of public transport stations and by changing the street layout (Weliwitiya et al., 2019). Liu et al. (2020) suggest that different policies and regulations are required in different areas of the city and can be used to facilitate and promote the integration of micromobility and public transport. In this regard, regulations and policies should be clear and concise and should be made available for all road users (Cheng and Liu, 2012). Geurs et al. (2016) highlight that policies that seek to improve travel time and cost reductions for users that integrate micromobility and public transport, have a significant effect on public transport ridership and job accessibility. Many suggestions have been made regarding policies that aim at reducing inequality in access to micromobility and increase the modal share of users that integrate micromobility and public transport (Böcker et al., 2020). Liu et al. (2020) suggest that, in combination with directly promoting the integration of micromobility and public transport, a 'second car purchasing limitation' could have a short-term effect in promoting modal shifts away from private cars.

4.2.6. Pricing and incentives

Pricing and incentives such as flexible and integrated ticketing, discounts for specific user groups and incentives for users that integrate frequently are additional instruments that can be used to promote micromobility and public transport integration, to attract new user groups and promote social inclusion and equal access to services and opportunities. The introduction of uniform ticketing systems for micromobility and public transport systems would not only allow for a more user-friendly experience but would also make transfers more efficient, convenient and, moreover, it would provide important insights into mobility patterns and behaviours (Böcker et al., 2020). This in return would provide the basis for improvements and planning guidelines.

Various studies emphasise that a flexible pricing system should be introduced to incentivise rides outside of peak-hours, to spread the demand evenly throughout the day and the free rental period of shared micro-vehicles should be limited to between 30 min and 1 h (Ma et al., 2018b). In order to expand the catchment area around stations, bonuses for longer sharing trips could be offered (Lin et al., 2019). Incentives and subsidies from the government are key in keeping fares low, which reduces inequality in access to micromobility services and addresses transport poverty issues for low-income groups (Ji et al., 2017; Ma et al., 2018b; Zhao and Li, 2017; Zuo et al., 2020).

To attract new users, it has been suggested that discounts could be offered for smart card trips with transfers between sharing and public transport services (Ji et al., 2018) and a loyalty program could be introduced for users that frequently integrate micromobility sharing services and public transport (Cheng and Liu, 2012; Ma et al., 2018b;). Discounts for different user groups and different time periods are also welcomed (Cheng and Lin, 2018; Liu et al., 2020; Ma et al., 2018b) to significantly increase micromobility and public transport integration. Böcker et al. (2020) suggest that certain rental restrictions should be lifted in order to cater to a more varied pool of users and in particular to women and other marginalised groups. In addition, pricing policies that discourage the use of cars for short trips could be examined, for instance a pricing policy for park-and-ride that is proportional to the inverse of the distance travelled by car, to encourage people that live close to the station to choose micromobility as an access mode (Midenet et al., 2018). Alternatively, to promote micromobility and public transport use for trips to work, employers should be encouraged to reward employees that use micromobility and public transport for trips to and from work, via a program that facilitates and subsidises the purchase of a micro-vehicle (Adnan et al., 2019; de Souza et al., 2017; Tobias et al., 2012), and by means of a central government tax rebate for companies that implement this scheme (de Souza et al., 2017). In addition to incentives for employers, Böcker et al. (2020) suggest incentives for bicycle-sharing providers to implement the necessary infrastructure outside of the city centre and in particular to create sharing station pairings at public transport stations and origin/destination locations such as lower income neighbourhoods and 'female-oriented employment centres'. This would help in particular to address inequality and provide a more inclusive service.

Ji et al. (2017) suggest that, in order to increase ridership of shared micromobility services, the use of private micro-vehicles should be discouraged: "*To promote public bicycle usage, cities in China may highlight the costs and responsibilities associated with owning a bicycle, including the financial loss associated with bicycle theft*". This suggestion is not in line with the overarching goal of increasing sustainable mobility by promoting the integration of micromobility – including private micro-vehicles - and public transport. However, it is worth noting that in certain contexts and under specific circumstances, it can be useful to consider the advantages that a shared micro-vehicle system could have compared to the use of private micro-vehicles. For instance, a shared system has the advantage of requiring less vehicles and therefore less space, since vehicles are shared among different users. Nevertheless, it would be prudent to first and foremost promote modal shifts from private motorised vehicles to micromobility and public transport by improving conditions for both shared and private micro-vehicles.

4.2.7. Training and educational campaigns

In order to raise awareness and promote the integration of micromobility and public transport, especially as a viable alternative to private motorised vehicles, educational campaigns and training are useful tools. It has been found that the provision of infrastructure alone often is not enough to compensate for inequalities in access to services as some user groups might face other types of barriers such as poor riding skills, or lack of confidence and experience (Hamidi et al., 2019). Given that many micro-vehicles are novel, training events for all groups should be made available and could be specifically tailored and targeted at different user groups (Cheng and Liu, 2012; Zhao and Li, 2017). For instance, social marketing campaigns and public education efforts could help the elderly to overcome barriers posed by the lack of experience in using the technology of sharing systems (mobile applications, unlocking vehicles, etc.) (Ji et al., 2017). Liu et al. (2020) state that it is important to promote micromobility among the younger generation to change the image of micromobility use, given that many young people use it out of lack of alternatives and for financial reasons and tend to abandon the mobility practice once they can afford a different mode of transport. As an additional effort in order to promote modal shifts away from private motorised vehicles, educational campaigns to increase awareness on the environmental impacts of different travel modes have also been considered in the literature (Cheng and Liu, 2012; Zhao and Li, 2017).

4.3. Main findings and further research

This sub-section presents a discussion of the main findings and gaps identified in the literature reviewed, in addition to the aspects highlighted for examination in further research.

4.3.1. Main findings and gaps in the literature

In the first step of the analysis, the main gaps in the literature were identified: while most studies were conducted to identify the reasons, preferences and mobility patterns of users that combine micromobility and public transport, most articles did not include the impacts that the integration of micromobility and public transport has on society, the economy and the environment. Of the studies observed, few included an examination of an impact in their analysis, quantified by means of modal shifts from private motorised vehicles to micromobility and public transport that can be expected from improvements to the system. A limited number of studies focused on the social impacts that the improved integration of micromobility and public transport have, such as promoting social inclusion, reducing inequalities between and among different population groups and increasing the access to services and opportunities. However, none of the 48 articles selected included and quantified the impacts that an effective and successful integration of micromobility and public transport could have on the environment, on liveability and sustainability and on the economy, and this was found to be the most significant gap. It is vital to include these aspects in future research, to provide evidence of effects, in order to make stronger arguments for the implementation and improvement of such an integrated transport system. While some data may be available on these issues when considered on their own – such as, for example, a life cycle analysis of e-scooters, as presented by Holm Møller et al. (2019) or in the research conducted by de Bortoli et al. (2019), it would be relevant to include them in the discourse about micromobility and public transport integration in order to provide a clearer and more complete representation of the causes and effects surrounding an integrated transport system. De Bortoli et al. (2019) compared the environmental impacts of different micro-vehicles used in Paris and determined that under certain circumstances, the use of shared micro-vehicles can have a negative impact on the environment and contribute to climate change. It was concluded that such findings need to be investigated further and put in the context of other cities and more specifically, in the context of the integration of micro-vehicles with public transport for longer trips. Another evident gap is the lack of research focusing on new and electric micro-vehicles in the context of integrated transport. Due to the fact that these vehicles are new, and data is only scarcely available, analysing the integration of these vehicles with public transport can be a challenge. However, in order to gain a more complete understanding of the potential of such integrations, these micro-vehicles need to be studied in the context of an integrated transport system, as access and egress modes to and from public transport.

In the second part of the analysis, the recommendations and suggestions made by the authors of the 48 articles were collected and grouped into categories in order to create an overview of the main aspects addressed. Almost all articles presented suggestions and recommendations stressing the importance of infrastructure for micromobility. The suggestion presented by most authors is to provide a safe, comfortable and continuous network of dedicated and protected lanes for micro-vehicles. This underlines the significance of adequate infrastructure and how the availability of such infrastructure can promote and result in significant modal shifts. Another aspect that is related to the provision of infrastructure is that it should enhance the safety of all road users and this can be achieved by reducing conflicts with other road users and in particular with motorised traffic, that should be contained and slowed down through traffic calming measures. As also stated in the ITF report on Safe Micromobility (2020), motorised vehicles are involved in 80% of fatal micro-vehicle accidents, meaning that reducing the potential for conflicts between the two modes can drastically improve safety for micromobility users. Given that the goal is to improve and promote the integration of micromobility and public transport, the infrastructure, facilities and amenities for micro-vehicles at public transport stations and stops should be improved and implemented for this purpose, to provide a safe, comfortable and user-friendly service that can compete with private motorised vehicles.

Characteristics of the built environment surrounding public transport stations also significantly influences the modal share of micromobility as an access and egress mode and should therefore be considered when planning and implementing measures to promote the integration of micromobility and public transport. The importance of data collection and analysis to further understand the different aspects of the integrated micromobility and public transport system was mentioned, also stressing the positive impacts that real-time data could have on users' experience and satisfaction of the integrated transport system.

Relevant suggestions were also made concerning planning and implementation of infrastructure, measures and micromobility sharing services. The importance of cooperation and collaboration among all involved stakeholders, including users and local communities, throughout all the planning phases was mentioned as a relevant ingredient for a successful integration of micromobility and public transport, as well as for identifying vehicle requirements and user preferences.

With regards to social inclusion and equity, it is recommended that these aspects are considered from early on, in order to plan and implement a system that guarantees equal access to all population groups, while also improving social inclusion and providing access to services and opportunities to those user groups that tend to be marginalised or excluded. This aspect is relevant when planning new measures or infrastructure, but it can also be improved via incentives and subsidies. It is recommended, that local authorities and service providers attempt to increase ridership among those user groups by facilitating access to the combined use of micromobility and public transport services through incentives and discounts. Additionally, in order to help different user groups to overcome the barriers that hinder them from using the integrated transport system, educational campaigns should be used, and trainings should be provided.

The main findings obtained in this systematic literature review are very much in line with the points of discussion presented in the POLIS Report on Micromobility "Macro managing Micro mobility - Taking the long view on short trips" (2019), and can therefore be considered a relevant and meaningful addition to the on-going discussion on this topic. The systematic literature review conducted in this paper identified gaps in the literature and in the state of knowledge, while also providing recommendations and guidance for planners and practitioners that wish to improve the integration of micromobility and public transport.

4.3.2. Areas for further research

Micromobility has significant potential to contribute to a more sustainable and socially inclusive urban transport system when combined with public transport services. However, to harness its potential benefits, more empirical research is required to address the gaps identified in this systematic literature review. More measures and improvements need to be implemented following the findings that are already available and those that are presented in this article. In particular, the authors suggest three main fields of enquiry that need to be addressed by further research on this topic: (i) the impacts of an integrated transport system that combines micromobility and public transport, in particular the impacts on the environment; (ii) the integration of different types of micro-vehicles and public transport such as, for example, shared and private e-scooters and e-bikes and the implications for infrastructure requirements for these different types of vehicles; (iii) the development and use of specific methods for data collection and analysis of micromobility and transport integration, to better understand the practices and mobility patterns of micromobility and public transport users. These three aspects will be discussed in more detail in the following.

4.3.3. Environmental, social and economic impacts

The main aspects that should be considered in further research pertain to the impacts that an integration of micromobility and public transport would have on the environment, society and the economy. This review has suggested that in particular the impacts on the environment should be examined more closely and in greater detail, specifically in the context of an integrated transport system. The successful integration of micromobility and public transport can promote mode shifts away from private cars in the urban and suburban contexts and can therefore be a valuable instrument to decarbonise transport and reduce the environmental impacts of the transport sector, while also contributing to more liveable and healthier cities. The environmental benefits of integrated transport should therefore be studied and closely monitored, to provide guidance and evidence to support decision-making processes. In addition, clear and quantifiable environmental impacts and benefits of an integrated transport system – such as CO_2-emission reductions or air quality improvements due to mode shifts away from private cars – could be used to promote and incentivise integrated transport systems and encourage even more users to integrate micromobility and public transport in their daily mobility.

In the same way, quantification of the impacts on society would also be a welcome addition to the knowledge base, in particular social equity and accessibility to services and opportunities across different population groups. The contribution of micromobility and public transport integration in this area could further increase the importance and priority given to measures and infrastructure that promote social inclusion and have overall positive impacts on society. Many cities have set themselves goals to become more equal and inclusive and the contribution of micromobility and public transport integration on this matter has to be studied and documented. For this reason it is relevant to analyse and quantify these impacts and address these issues in the planning and development phase of infrastructure and services to integrate micromobility and public transport.

The impacts that the integration of micromobility and public transport has on the economy in a specific urban context could also provide valuable insights and contribute to the current debate in relation to solutions to implement a successful and efficient integrated transport system. In particular when considering the cost-effectiveness of an integrated transport system and of different measures that promote and facilitate the integration of the two modes, it is extremely relevant to quantify and discuss the economic impacts. Such considerations must also include the other impacts listed above, such as environmental and health impacts, as well as social impacts, that can all result in substantial economic benefits for cities.

4.3.4. Different types of micro-vehicles

Additionally, different micro-vehicles ought to be considered and studied in the context of first- and last-mile access to public transport. Standardised assessments considering all relevant aspects of the life cycle of these micro-vehicles are needed, in order to facilitate and inform decision-making processes and implementation when appraising different alternatives. Particularly the environmental impacts and effects of new vehicle types need to be studied and the necessary services and infrastructure required to seamlessly and successfully integrate these vehicles with public transport need to be defined and planned. The integration of electric micro-vehicles with public transport requires additional considerations regarding environmental impacts. While electric micro-vehicles are more energy efficient and use less space than conventional cars and electric vehicles due to their size, there are still aspects that need to be considered, such as the production and end of life phase of such vehicles as well as considerations regarding use of such micro-vehicles in combination with public transport. For shared micro-vehicles in particular, charging and redistribution systems and strategies need to be put in place to minimise environmental impacts and implement a truly sustainable alternative transport system. In order to further reduce the environmental impacts of the combined micromobility and public transport system, also public transport options should be evaluated and promoted based on their energy efficiency and environmental impacts.

4.3.5. Data collection and analysis

Going forward, new methods of data collection and analysis are needed, in order to more accurately model intermodal trip chains, mobility behaviours and patterns and the spatial reach of integrated transport systems combining micromobility and public transport. Furthermore, introducing integrated ticketing systems and improving transfers at public transport stations - through improved parking facilities and services - would make the user experience more convenient, pleasant and reduce overall travel time, while also providing valuable data. User centred research and design should be used to identify the main aspects that require improvement and to obtain insights into the users' experience and practices. These insights could then be used to inform planning strategies and developments to further promote and incentivise modal shifts away from private cars, to additionally reduce the environmental impacts of urban transport systems and improve liveability in cities.

The global pandemic caused by COVID-19 has forced cities worldwide to rethink and reimagine their strategies to promote and enable sustainable mobility also in order to ensure that social distancing can be maintained. With this in mind the process of assessing and regulating the use of new micro-vehicles should be accelerated in respect of the evident demand for such micromobility trips. This review has highlighted that the importance of infrastructure provision for micromobility and active modes and why it should be adapted and improved, while more road space should be allocated to sustainable modes and pedestrians, to ensure compliance with the social distancing requirements.

5. Conclusions and outlook

In this paper, a systematic literature review was conducted, to determine how the integration of micromobility and public transport has been studied to date. Through a systematic approach, 48 articles have been selected and analysed in this study, that specifically focus on the subject of micromoblity and public transport integration. The main goal was to identify the aspects of the topic that have been empirically examined to date, while also discovering the gaps that exist and ought to be addressed in order to fully appreciate the system and further improve it. In a second step, the main recommendations and suggestions from the 48 articles were collected and organised into categories, in order to underline the main issues that could be addressed and to provide some guidance for planners and practitioners, seeking to implement measures to improve the integration of micromobility and public transport. The main gaps that could be identified pertain to the impacts that the integration of micromobility and public transport has on various aspects of society, the environment and the economy. These require further investigation, in order to generate a better understanding of the benefits and limitations of the integration of micromobility and public transport. Moreover, studies which conduct data analysis on how micromobility is used as an access and egress mode to public transport is welcomed, as this was a gap identified in the literature. This is particularly true for new, electric micro-vehicles that have not been extensively studied in the context of an integrated system with public transport yet. The paper also provides an overview of recommendations and suggestions included in the 48 articles reviewed. These recommendations address several aspects of the integration of micromobility and public transport and provide guidance to those seeking to implement measures or improve the conditions that facilitate and promote the combined use of micromobility and public transport.

This systematic literature review was conducted in accordance with a strict methodology, and search and selection process, aimed at identifying the state of knowledge on this topic of micromobility and public transport integration. However, the authors accept that naturally some articles may have been missed and therefore were not included in this review. Nevertheless, the selected articles provide a solid and extensive overview of the subject and how it has been studied to date. The authors are also conscious of the fact that this subject of inquiry is still novel and is at the centre of on-going research in cities all over the world, meaning that many new and perhaps ground-breaking insights will be gained in the coming months and years. However, the authors are confident that this systematic literature review will prove useful in further investigating the subject and will contribute to a timely debate amongst policymakers.

CRediT authorship contribution statement

Giulia Oeschger: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Páraic Carroll:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Brian Caulfield:** Conceptualization, Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing, Visualization, Supervision.

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