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RESEARCH ARTICLE

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The synergy of bicycles and public transport: a systematic literature review

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ABSTRACT

This study is a review of the existing literature on the topic of bike-transit combination. The aim is two-fold: (i) to identify factors that influence its successful uptake, and (ii) to discuss the potential of the bike-transit combination and its impact on urban transport systems. The review showed that the bike-transit integration is complex and can be influenced by a variety of factors. These factors are mainly related to the quality of public transport, the cycling network and the integration of these two. Improving them can have a positive impact on bike-transit uptake. Land use and built environment characteristics also play an important role, suggesting that the local context plays a significant role on its successful uptake. In general, the review reveals that bike-transit has shown potential in improving the performance of existing public transport systems, by expanding catchment areas and improving accessibility, but its impacts on car use have not been explicitly studied. The review concludes that the bike-transit combination shows a promising path to sustainable urban mobility and is a topic worth further investigation. However, it also calls for more integrated research approaches and an explicit focus on which types of travel behaviour are substituted by the bike-transit combination.

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Bicycle; public transport; multimodal transport; integrated transport; transfer

1. Introduction

Motor vehicle traffic contributes to numerous challenges in urban areas, including traffic congestion, serious injuries and fatalities from road accidents, air and noise pollution, and the excessive utilisation of public space to facilitate road and parking infrastructure. Despite successful attempts to reduce car dependency (Kuss & Nicholas, 2022), cars remain the dominant mode of transportation, with high levels of ownership and usage (Eurostat, 2022). This may be due to inherent limitations associated with alternatives, like public transport (i.e. bus, light rail, subway, train etc.) and active mobility, compared to car use (Kager & Harms, 2017). For example, public transport provides low flexibility and limited door-to-door accessibility. Even trips with the fastest forms of public transport, like the train, are often slower than

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those with private cars in terms of door-to-door travel time (Rietveld, 2000). The main limitation of active travel, such as cycling or walking, is the limited catchment radius (Kager & Harms, 2017). People can walk or cycle only up to a certain distance depending on their physical capabilities before it starts becoming unpleasant and inefficient in terms of travel time.

The idea of a synergetic combination between different transport modes is argued to have the potential to mitigate the limitations of each individual mode (Kager & Harms, 2017). For instance, the challenges of first and last-mile trips when travelling with public transport can be addressed by using personal transport, such as the car or the bicycle. At the same time, combining the bicycle with public transport can expand the service area of active travel immensely, as well as address several challenges related to car use, such as car parking scarcity in urban areas. Therefore, the combination of bike-transit is argued to have shown promising potential in competing with car use and providing a more sustainable travel option (Kager & Harms, 2017; Martens, 2004).

The design and implementation of effective policies and practices to achieve the integration of the two systems require a thorough understanding of existing knowledge, as well as a clear identification of gaps and challenges that need to be addressed. Despite the growing interest in this topic, there is still a need for a comprehensive overview of the mechanisms and factors that influence the uptake of bike-transit and its effects on urban transport systems. To our knowledge there is currently no systematic literature review dedicated to this topic. Without a comprehensive and systematic review of the literature, policymakers and practitioners may not have the necessary knowledge to make informed decisions. This review is therefore motivated by the need for an informed and evidence-based overview of the potential of integrating bicycles into public transport systems in order to facilitate more fruitful discussions among policymakers and academics.

2. Method

A literature search has been conducted on existing literature focusing on the combination of cycling and public transport. The review is limited to articles in English that have been published in peer-reviewed scientific journals or conference proceedings, books and book chapters. The papers were identified through a systematic search in the online databases Scopus, Web of Science, TRB-TRID, and Oria, looking for specific keywords in the title, abstract and list of keywords in the databases' records. More specifically, the following Boolean string of search terms was applied:

(bicycle OR bike OR cycl* OR bike shar* OR bicycle shar* OR shared bike* OR micromobility OR micro-mobility OR e-bi* OR electric bi* OR bi* parking)

AND

(public trans* OR rail OR train OR bus OR metro OR tram OR BRT OR Bus Rapid Transit OR light rail OR LRT OR transit OR urban rail OR subway OR station OR transfer OR interchange)

OR

(multimodal* OR multi-modal OR multimodal trans* OR multi-modal trans* OR travel chain OR intermodal trans* OR park and ride OR bike and ride OR multimodal hubs OR mobility hubs OR first mile OR last mile OR access OR egress)

Table 1. Database search results.

Database	Records after initial search	Records after applying field restrictions
Scopus	1842	882 Excluding subject areas: Arts and Humanities, Agricultural and Biological Sciences; Biochemistry, Genetics and Molecular Biology; Computer Sciences; Chemistry; Earth and Planetary Sciences; Energy; Materials Science; Physics and Astronomy; Immunology and Microbiology; Chemical Engineering; Neuroscience; Pharmacology, Toxicology and Pharmaceutics; Nursing.
Web of Science	2304	1033 Including subject areas: Behavioural Sciences; Psychology; Transportation; Engineering; Environmental Sciences Ecology; Business Economics; Science Technology Other Topics; Geography; Urban Studies; Social Sciences Other Topics; Demography; Social Issues; Sociology
Oria.no	4453	328 Excluding subject areas: Logistics; Energy; Supply Chain; Media; Nursing
TRB-TRIS	3348	388 Including subject areas: Design; Environment; Passenger Transportation; Pedestrians and Bicyclists; Planning and Forecasting; Policy; Public Transportation; Railroads; Research; Society; Terminal and Facilities; Transportation (General)

The first two sets of search terms provide articles that contain both synonyms of bicycles and public transport. This way, we managed to automatically exclude a large piece of literature that solely focuses on unimodal transport, which is beyond the scope of this study. The third set of terms ensures that in if they contain at least one synonym of multimodal transport, even if the two first sets of terms are not included, it would be added on the list of literature to be screened. The asterisk (*) is a wildcard that represents any number of characters, including none. Table 1 presents the number of retrieved records from the search in each database.

The total amount of retrieved articles from the four databases was imported in Rayyan (Ouzzani et al., 2016). Using Rayyan, duplicates were removed leading to 1541 unique articles. The titles and abstracts of these articles were screened from the authors to examine whether they mention: (i) factors and challenges related to bike-transit integration and its uptake, or (ii) potential benefits and policy implication from bike-transit integration. This process resulted in 324 relevant articles that were selected for full-text review. After applying the snowballing technique, 17 additional studies were found through the reference list of the 324 articles. This approach resulted in a total of 341 publications to be considered for full-text review. From those, 43 records were excluded because they were either not accessible to the authors or they were deemed irrelevant to the topic after the full-text review. This resulted in 298 being reviewed to synthesise this study. The systematic process of literature search, the criteria of inclusion and the records per step are presented in an adapted version of the PRISMA protocol (Page et al., 2021) in Figure 1.

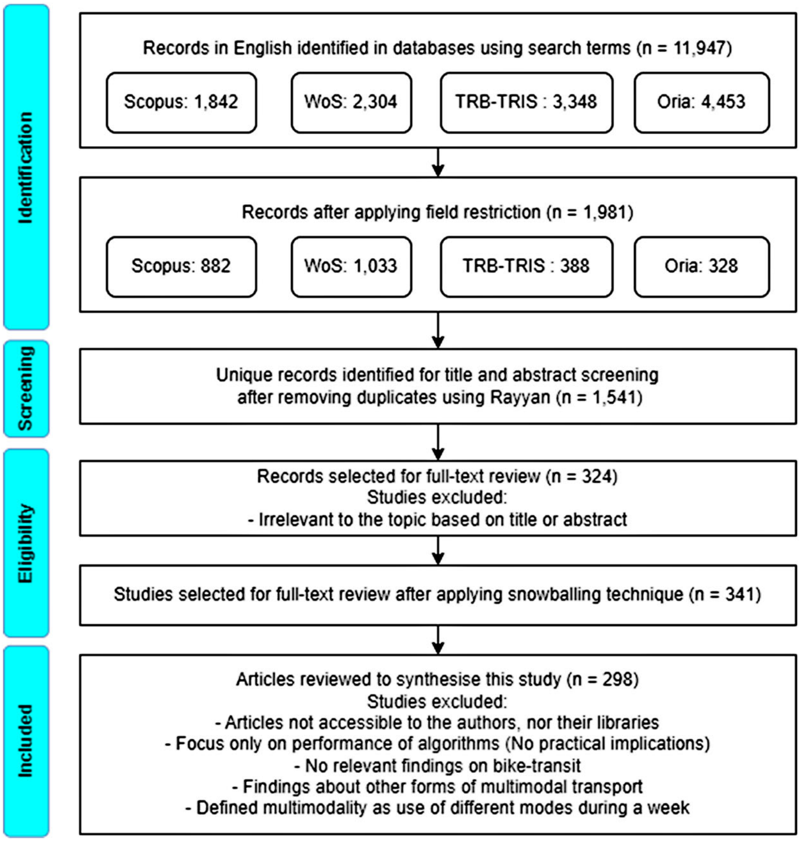

Figure 1. Systematic literature search process.

3. Results

3.1. Trends in literature

Most studies have been published after 2010, with more than half being published after 2019, indicating a growing interest in the topic. Figure 2 shows the number of publications per year.

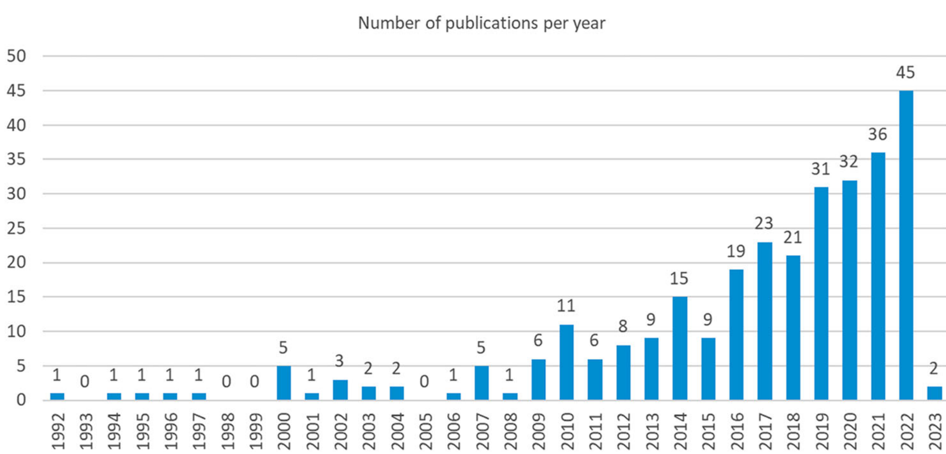

Figure 2. Number of publications per year (by January 2023).

Table 2. Number of times a country appeared in a study ($n = 309$).

Country	Number of studies	Country	Number of studies
North America	**55**	**Europe**	**94**
Canada	7	Austria	2
United States	48	Belgium	4
		Denmark	3
South America	**12**	Finland	2
Brazil	7	France	3
Chile	3	Germany	8
Colombia	2	Italy	5
		Latvia	1
Asia	**120**	Netherlands	53
China	92	Norway	1
India	10	Poland	1
Iran	1	Portugal	1
Singapore	2	Slovenia	1
South Korea	9	Spain	5
Taiwan	3	Sweden	2
Turkey	2	United Kingdom	7
Japan	1		
		Africa	**1**
Oceania	**11**	Nigeria	1
Australia	11		
		N/A	**10**

Around one third of the studies focuses on Europe with approximately half of them being from the Netherlands. The largest proportion of studies focuses on Asian countries, with 30% of all studies originating from China. The main difference in the two cases is that studies from the Netherlands, mainly focus on the personal bike and train integration, while studies from China focus on the integration of shared bike schemes and subways. Finally, most studies from North America are from the USA, focusing mainly on the bike-bus integration. In South America, 7 of the 12 studies are from Brazil, while all 11 studies from Oceania are from Australia. Table 2 shows the frequency of each country being the focus in one of the 298 studies, while Figure 3 displays the country with highest frequency compared to the total number of publications per continent. Note that some studies referred to multiple countries or didn't have a country as a focus.

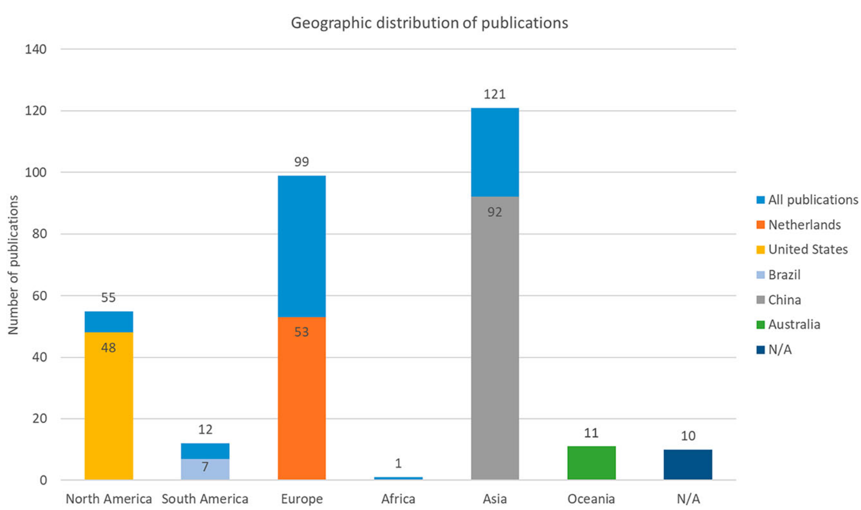

Figure 3. Geographic distribution of publications (by January 2023).

3.2. Methods used in bike-transit studies

The studies included in this literature review, can be divided in two types: (i) system-centric, and (ii) user-centric. System-centric studies focus on the performance of the bike-transit combination as an integrated system, either through a spatial analysis or using existing travel or revealed preference data. Spatial analyses are mostly hypothetical, while the latter are mostly analyses of data from trip observations (Kager & Harms, 2017; Yang et al., 2019) or user surveys (Hochmair, 2015; Keijer & Rietveld, 2000; Martens, 2004).

The most common indicators used are related to performance characteristics, such as travel time reduction (Kager et al., 2016), travel speed (Kager et al., 2016) or travel cost (Li et al., 2020). Several studies also estimate the benefits of bike-transit integration in terms of increased public transport ridership or reduced car use (Tavassoli & Tamannaei, 2020) as well as its expected health benefits (Rojas-Rueda et al., 2012). Moreover, several studies estimate the potential accessibility benefits of this integration and evaluate its contribution to a more equal public transport system using indicators, such as the Lorenz curves and Gini index (Pritchard et al., 2019a, 2019b) or Theil index (Zuo et al., 2020).

User-centric studies, on the other hand, examine factors that influence the uptake of bike-transit combination. These studies can be further divided into two groups: those that use revealed preference data; and the ones that use stated preference. Studies using revealed preference data from retrospective travel survey data, and those that use stated preference data, obtained through hypothetical scenarios. The first category focuses on bike-transit trips and the factors and sociodemographic characteristics associated with them (Böcker et al., 2020; Givoni & Rietveld, 2007; Nello-Deakin & Brömmelstroet, 2021; Radzimski & Dzięcielski, 2021), as well as on policies and measures that led to their increase (Guo & He, 2020; Martens, 2007; Villwock-Witte & Van Grol, 2015). The second category explores the user preferences on trips with bike-transit combination even if it is not currently considered a potential alternative (Arentze & Molin, 2013; Stam et al., 2021; van Mil et al., 2020; Yap et al., 2016), or on different integration strategies (Krizek & Stonebraker, 2011).

3.3. Factors for bike-transit uptake

The efficient integration of the two systems is a vital element in the successful uptake of the bike-transit combination. Therefore, one of the main themes in literature is identifying the factors related to a successful integration of bicycles to public transport systems. In this review we identified several factors related to the uptake of bike-transit. Table 3 presents an overview of these factors.

3.3.1. Trip characteristics and transit system quality

Some of the most influential and more discussed factors for the successful uptake of bike-transit are related to the access and egress part of the trip. Travel distance and time to and from stations by bicycle play an important role on the uptake of bike-transit. Keijer and Rietveld (2000) found that people who live less than 500 m from a train station in the Netherlands are 20% more likely to take the train compared to people living 500–1000 m away and 50% compared to those living even farther, regardless of their access or egress mode. In general, bike-transit seems to be preferred for a range of access distance

Table 3. Overview of factors influencing bike-transit uptake.

Category	Factor	Impact	Source	Country	Findings
Trip characteristics and transit system quality	Access/egress distance	−/+	Florindo et al. (2018)	Brazil	Access distance lower than 1.5 km can increase cycling to train or subway stations
			Giansoldati et al. (2021)	Italy	The average and the maximum cycling distance to a station are 2.1 and 4 km, respectively
			Hochmair (2015)	USA	Access distance ranges between 1.7 km (Atlanta) and 4.5 km (Los Angeles)
			Keijer and Rietveld (2000)	Netherlands	Likelihood to take the train is 20% higher for people living less than 500 m from a station compared to 500–1000 m and 50% compared to >1000 m.
			Martens (2004)	Netherlands, Germany, UK	Access distance range is around 2–5 km
			Sherwin et al. (2011)	UK	The average cycling distance to and from railway stations is 3.7 km
	Total travel distance	+	Krygsman et al. (2004)	Netherlands	Access and egress distance increase proportionally to total travel distance that is up to 60 min.
			Shelat et al. (2018)	Netherlands	The average bike-transit distance trip is 41 km
	Travel time	−/+	Krygsman et al. (2004)	Netherlands	Cycling time is at least 30–50% of the total trip time
			Zhao et al. (2014)	China	Bike-transit users living in the city centre will travel up to 20 min, while in the suburbs up to 35 min
	Travel speed	+	Blainey (2010)	UK	High-speed transit has a negative impact on nearby low-speed transit stations
			Brand et al. (2017)	Netherlands	Higher speed and frequency BRT can attract twice the number of bike-transit users
			Hochmair (2015)	USA	Catchment areas double in radius when high speed transit is available
			Rijsman et al. (2019)	Netherlands	Catchment radius of tram stops by bike in The Hague has been found to be around 1 km
			van Marsbergen et al. (2022)	Netherlands	46% of shared bike trips substituted slower modes (bus and tram), while 9% used them in combination.
			Wang and Liu (2013)	USA	Ridership is not influenced by speed
	Frequency	+	Brand et al. (2017)	Netherlands	Higher speed and frequency BRT can attract twice the number of bike-transit users
			Radzimski and Dzięcielski (2021)	Poland	Higher frequency of public transport resulted in more bike-sharing trips
	Transfer	−	Rijsman et al. (2019)	Netherlands	People are willing to cycle more to avoid a transfer
			van Mil et al. (2020)	Netherlands	Bike-transit user are willing to cycle 6 more minutes to avoid a transfer

(*Continued*)

Table 3. Continued.

Category	Factor	Impact	Source	Country	Findings
Land use and built environment characteristics	Mixed land use	+	Guo and He (2020)	China	Mixed land use is positively associated with use of shared bikes
			Guo et al. (2021)	China	Mixed land use around metro stations is positively related to combined bike-sharing and metro use
			Hu et al. (2022)	China	For trip distances larger than 1.5 km, land use mix is positively associated with bike-and-ride trips
			Weliwitiya et al. (2019)	Australia	The number of cyclists riding to a station is associated with diverse land use mix
	Population and residential land density	−/+	Chan and Farber (2020)	Canada	Proportion of residential land is positively associated with the integration of bike and transit
			Hu et al. (2022)	China	Near city centres the impact of population density is negative, while farther away it is positive
			Wu et al. (2021)	China	Population density has a positive effect on bike-metro trips
			Zhou et al. (2023)	China	Population density has a positive impact on bike-bus integration, but not with subway
	Commercial land density	unclear	Chan and Farber (2020)	Canada	The proportion of commercial land is negatively associated with access to stations by bike
			Cheng and Lin (2017)	Taiwan	Commercial land use has a positive impact on shared bike use
			Zhou et al. (2023)	China	The number of points of interest around stations have a positive effect on shared bike use
	Employment density	−	Guo and He (2020)	China	Employment density is negatively associated with combined bike-transit use
			Ma et al. (2018)	China	Increased job density has a negative impact on shared bike-metro combination
			Zhou et al. (2023)	China	The number of workplaces has a positive impact on bike-bus integration, but not with subway
	Public transport stop density	−	Guo and He (2020)	China	Metro station density is negatively associated with shared bike-metro combination
			Ma et al. (2018)	China	Metro station density is negatively associated with shared bike-metro combination
			Wu et al. (2021)	China	Bus stop density has a significant effect on bicycle-metro trips
			Zhou et al. (2023)	China	Access to more bus stops has a negative impact on the shared bike and subway integration
	Road network density	−/+	Chan and Farber (2020)	Canada	Street density is negatively associated with access to stations by active transport
			Ma et al. (2018)	China	High road density has a negative impact on bike-sharing around metro stations during weekdays
			Weliwitiya et al. (2019)	Australia	The proportion of local low-speed roads influences the number of cyclists riding to a station
			Barajas (2012)	USA	Road intersection density leads to more cycling to stations.

	Cycling infrastructure quality and density	+	Ashraf et al. (2021)	USA	The presence of dedicated bike lanes increased subway ridership
			Guo and He (2021)	China	Lower accessibility of metro stations increases the odds of bikeshare-metro integration
			Liu et al. (2020)	China	Continuous bike lanes in residential areas and workplaces have a positive effect on bikeshare-metro
	Route slope	–	Weliwitiya et al. (2019)	Australia	The number of cyclists riding to a station is associated with low sloping terrain
Quality of interchanges and provided facilities	Allowing bikes onboard	+	Bachand-Marleau et al. (2011)	Canada	The preference for bringing bicycles on transit vehicles was dominant among the respondents
			Ravensbergen et al. (2018)	Canada	22% of cyclists identified the restriction to take the bike on board during rush hour as a key barrier
			Barajas (2012)	USA	On-board bike restrictions lead to less cycling to stations.
	Existence of bike parking facilities	+	Ashraf et al. (2021)	USA	Bike racks attracted increased subway ridership
			Barajas (2012)	USA	Bicycle parking at the station leads to more cycling to stations
			Ravensbergen et al. (2018)	Canada	Both cyclists (34%) and non-cyclist (25%) mentioned bicycle parking as a barrier
	Distance of bike parking facilities	–	Chen et al. (2012)	China	Walking distance between bike parking facility and metro station influences the choice to use a bike
			Geurs et al. (2016)	Netherlands	One of the most important attributes of access to a station is the location of bike parking facilities
			Molin and Maat (2015)	Netherlands	Each additional minute of walking has an increasing negative impact
			La Paix et al. (2021)	Netherlands	Parking distance from the platform is one of the most crucial factors to access a train station by bicycle
	Payment	–	Molin and Maat (2015)	Netherlands	Increasing parking price has a negative impact on cycling to a station
			Geurs et al. (2016)	Netherlands	Free parking can increase the chances of cycling to a train station by 11%
			La Paix et al. (2021)	Netherlands	Parking cost is one of the most crucial critical factors to access a train station by bicycle
	Adequacy (especially during rush hours)	+	Halldórsdóttir et al. (2017)	Denmark	Each 100 additional bike parking spaces can increase the likelihood of cycling to a station by 2.5%.
			La Paix Puello and Geurs (2015)	Netherlands	The availability of bike parking facilities is crucial during rush hours
			Rijsman et al. (2019)	Netherlands	Insufficient bike parking places is a motive not to cycle to a tram stop
	Safety and security	+	Arbis et al. (2015)	Australia	Passive and active surveillance has a positive influence on bicycle parking

(*Continued*)

Table 3. Continued.

Category	Factor	Impact	Source	Country	Findings
			Cervero et al. (2013)	USA	Higher number of secure and protected bicycle parking racks leads to more bicycles at rail stations
			Geurs et al. (2016)	Netherlands	Free guarded bike parking has a positive impact on accessibility of public transport
			Ravensbergen et al. (2018)	Canada	Bicycle security is among the top challenges to cycling to and/or from train stations
			Tobias et al. (2012)	Brazil	One of the most frequent requests is the provision of safe and sheltered bike parking facilities
			van Zeebroeck (2017)	Belgium, Italy, Spain, UK	Providing safe and sheltered bike parking at a convenient place for cyclists is crucial
			Martin and den Hollander (2009)	Australia	Bike storing cages led some public transport users to shift from Park and Ride to cycling to a station
			Panchal et al. (2020)	India	Safety and security of parked bikes is a significant factor to choose bike-transit use
			Rose et al. (2016)	Australia	Secure bike cages showed a 35% increase in utility every year between 2010 and 2015
			Sherwin et al. (2011)	UK	Bike theft experience and low perceived security have a negative influence on cycling to a station
			Halldórsdóttir et al. (2017)	Denmark	Covered bike parking facilities increase likelihood of choosing bike-transit up to 3 times higher
	Cycling infrastructure and traffic conditions around stations	+	Jayarathne et al. (2019)	Australia	Safety is one of the main concerns to access a station by bicycle
			Panchal et al. (2020)	India	Reduced safety from mixed traffic around metro stations has a negative impact on bike-transit use
			Park et al. (2021)	USA	Ridership was higher at stations with dedicated bike routes
			Phan et al. (2022)	Australia	The number of car crashes around train stations is negatively associated with bike use
			Sherwin et al. (2011)	UK	Traffic congestion around stations led more people to avoid driving to a station
			Sherwin et al. (2011)	UK	Better bike access due to improved cycling routes and signage around station is important
			Zacharias and Liu (2022)	China	Directness is a significant factor for bicyclist that access a station
			Zhao et al. (2022)	China	Directness was preferred by most bike users
Access to a bike through bike rental and bike share schemes	Sufficient access to a bike	+	Bi et al. (2021)	China	Bike-sharing in conjunction to public transport is mainly used for distances up to 2 km
			Chen et al. (2012)	China	Share of bikes is 30% for 10-min walking distance and 70% for 15 min
			Guo and He (2021)	China	Sufficient bike availability increases the likelihood of shared bike-metro integration

			Guo et al. (2021)	China	The number of available bikes has a positive impact bikeshare-transit use
			Guo et al. (2021)	China	bikeshare-transit total distance is mostly less than 5 km
			Guo et al. (2021)	China	Most access and egress trips were for a 0.5–2 km distance and a 2.5–10 min travel time
			Kapuku et al. (2021)	South Korea	Bikeshare-transit outperforms unimodal shared bike or bus use in travel time savings by 34% and 33%
			Li and Guo (2022)	China	Travellers residing in suburbs are willing to cycle longer distances to access a train station
			Li et al. (2020)	China	The benefits of integrating shared bikes to high-speed transit are more evident for trips that are longer than 7 km in total.
			Li et al. (2022b)	USA	Small-sized bike share scheme in Arizona had an insignificant impact on ridership
			Stam et al. (2021)	Netherlands	If only shared vehicles are available, bike share is expected to increase on the activity end
			Tarpin-Pitre and Morency (2020)	Canada	The average bikeshare trip distance to and from metro stations was 1.2 km
			van Kuijk et al. (2022)	Netherlands	People have a preference to walk than use shared bike in urban destinations. Shared bikes have a greater potential in suburban destinations.
			van Kuijk et al. (2022)	Netherlands	People showed an equal preference for shared conventional and electric bikes
			Wu et al. (2021)	China	The average catchment radius in urban centres is 1.3 km, while in suburban centres it is 1.6 km
			Zhao et al. (2022)	China	Most shared bike trips were within a 2 km distance
	Attractiveness of PT feeder modes	–	Kapuku et al. (2022)	South Korea	Bike-sharing trips can be more competitive than bus trip, especially during peak hours
			Bai et al. (2019)	China	Long waiting times of other feeder modes can make people choose shared bikes
Availability and competitiveness of alternatives	No access to a car	+	Chan and Farber (2020)	Canada	Low car ownership is positively associated with the bike-transit integration
			Meng et al. (2016)	Singapore	Not having access to a car has a positive impact on bike-transit
	Attractiveness of car	–	Arentze and Molin (2013)	Netherlands	Car users need stronger compensation to shift to bike-transit
			Adnan et al. (2019)	Belgium	Facilities that allow to be escorted by car from a family member or friend have a negative impact on shared bike use for last mile travel
			Chan and Farber (2020)	Canada	The amount of car parking at stations is negatively associated with access by bike

(*Continued*)

Table 3. Continued.

Category	Factor	Impact	Source	Country	Findings
			Midenet et al. (2018)	France	Restricting car parking at stations is essential to shift to bike-transit
			Bergman et al. (2011)	USA	More parking spots at stations lead to more car access trips
			Jayarathne et al. (2019)	Australia	The perception that the car is the fastest option to access a station is one reason to choose Park and Ride
			Rose et al. (2016)	Australia	Lack of available car parking spots at stations had a positive impact on the decision to use the bike
			Sherwin et al. (2011)	UK	Lack of car parking spots at stations lead more people to avoid driving at the stations
	Attractiveness of cycling (for the whole trip)	–	Griffin and Sener (2016)	USA	48% of the bike share users would have otherwise used public transport
			Lee et al. (2015)	Netherlands	40% of e-bike trips would have been otherwise made by car
			Fyhri and Fearnley (2015)	Norway	E-bikes have a positive influence on both number of bike trips and cycling distance of car users
			Kroesen (2017)	Netherlands	E-bike ownership has a larger negative effect than bikes on car and public transport use
			Kroesen (2017)	Netherlands	Car owners are more willing to use an e-bike than a conventional bike or public transport
			Bai et al. (2019)	China	E-bike would replace part of transit public and car-based trips.
			Fan and Zheng (2020)	China	The synergy between shared bikes and subway outweighs any substitution effects
			Saltykova et al. (2022)	China	Around 28% and 8% of bikeshare trips replace bus and subway trips, respectively
	Positive attitude on cycling and public transport and negative on alternatives	+	Heinen and Bohte (2014)	Netherlands	A positive attitude towards the bicycle and public transport has a positive effect on bike-transit uptake, while a positive car attitude has a negative effect.
			Bergman et al. (2011)	USA	Attitude towards the sustainability lead to more bike access trips.
			La Paix et al. (2021)	Netherlands	Attitude towards cycling has a positive impact on accessing a station by bicycle
Sociodemographic characteristics	Age	unclear	Böcker et al. (2020)	Norway	Shared bikes are less used by older age groups either as stand-alone option or together with transit
			Ji et al. (2016)	China	Older rail commuters are less likely to use public bikes to access a station
			Jonkeren et al. (2021)	Netherlands	Bike-train users tend to be young
			Shelat et al. (2018)	Netherlands	Bike-transit users are typically in the 17–27 age group
			Wang and Liu (2013)	USA	Bike-transit users are more concentrated in the age groups of 19–35 and 35–65

			Chan and Farber (2020)	Canada	Age is positively associated with bike-transit integration
			Meng et al. (2016)	Singapore	As age increases so does the likelihood of cycling
			Yang et al. (2014)	China	Age has a significant impact on choosing bike-and-ride
			Molinillo et al. (2020)	Spain	Young (14–24 years) and older people (over 64 years), are more likely to use bike-transit
			Sherwin et al. (2011)	UK	Bike transit users were mostly aged around 30s
			Zhao et al. (2022)	China	Middle-aged and medium-income commuters are more likely to use shared bikes to access the metro
	Gender (male)	+	Böcker et al. (2020)	Norway	Shared bikes are less used by women either as stand-alone option or together with transit
			Ji et al. (2016)	China	Male rail commuters are more likely to use public bikes to access a station
			Meng et al. (2016)	Singapore	Males are more likely to cycle than females
			Ravensbergen et al. (2018)	Canada	67% of those cycling to a train station were male
			Wang and Liu (2013)	USA	Bike-transit user profiles are male-dominant.
			Sherwin et al. (2011)	UK	71% of bike-transit users were male
	Income	unclear	Chan and Farber (2020)	Canada	Median income is positively associated with bike-transit integration
			Ji et al. (2016)	China	Low-income rail commuters are less likely to use public bikes to access a station
			Meng et al. (2016)	Singapore	People with household incomes less than $2000 prefer the bike over the bus for the last-mile trip
			Shelat et al. (2018)	Netherlands	Bike-transit users typically belong in higher income groups
			Yang et al. (2014)	China	Lower income groups are more likely to choose the combined use of bikes and transit
			Rastogi (2010)	India	Commuters with higher income are less likely to walk or cycle to a rail station
			Zhao et al. (2022)	China	Middle-aged and medium-income commuters are more likely to use shared bikes to access the metro
	Education	+	Jonkeren et al. (2021)	Netherlands	On average bike-train users hold university degrees
			Shelat et al. (2018)	Netherlands	Bike-transit users are typically highly educated
			Wang and Liu (2013)	USA	By 2009, there was no longer an apparent pattern in education level
Trip context	Cold or wet weather	–	Hochmair (2015)	USA	Warm weather is a likely factor for increased bike-transit uptake
			Molin and Timmermans (2010)	Netherlands	The probability of choosing a bike as egress mode decreases under wet weather

(*Continued*)

Table 3. Continued.

Category	Factor	Impact	Source	Country	Findings
	Heavy baggage	–	Molin and Timmermans (2010)	Netherlands	The probability of choosing a bike as egress mode decreases when carrying heavy luggage
	Travelling with company	+	Molin and Timmermans (2010)	Netherlands	The probability of choosing a bike as egress mode increases if one travels with company
	Limited daylight	–	Molin and Timmermans (2010)	Netherlands	The probability of choosing a bike as egress mode is increased when travelling in daylight
	Utilitarian trip (Commuting or education)	+	Chen et al. (2012)	China	Bike-transit users choose cycling for time-sensitive trip purposes, such as school (12%) and work (22%)
			Jonkeren et al. (2021)	Netherlands	Commuting was the primary travel purpose for the largest share of bicycle-train travellers
			Martens (2004)	Netherlands, Germany, UK	There is a dominance of daily commuters to school or work among bike-and-ride users.
			Shelat et al. (2018)	Netherlands	Bike-transit is often used for work, business and education purposes
			Wang and Liu (2013)	USA	Commuting trips are the most important trip purpose
			Zhao et al. (2014)	China	Commuters were 79.5% of all bike-and-ride users
			Wu et al. (2021)	China	Bike-transit happens mostly among the working population
			Zhao et al. (2022)	China	Middle-aged and medium-income commuters are more likely to use shared bikes to access the metro
	Route familiarity	+	Molin and Timmermans (2010)	Netherlands	The probability of choosing a bike as egress mode is increased when the route is well known
	Time of the day (peak hours)	+	Gu et al. (2019)	China	Shared bikes served as first-mile solution in the morning and as last-mile in the evening around a new metro station
			Kapuku et al. (2022)	South Korea	Bike-sharing can be more competitive than the bus during peak hours
			Yan et al. (2020)	China	Shared bike use is more evident during the morning and evening peaks of weekdays

Note: -/+: the direction of the impact can be either positive or negative depending on other factors; unclear: contradictory findings in literature.

between 1 and 5 km (Florindo et al., 2018; Giansoldati et al., 2021; Hochmair, 2015; Martens, 2004; Sherwin et al., 2011). The actual distance people are willing to cycle is influenced by its proportion to total travel distance. According to Krygsman et al. (2004), cycling distance increases for total travel distance up to 60 min and consists at least 30–50% of the total trip. According to Shelat et al. (2018), the average total distance of bike-transit trips in the Netherlands is 41 km, suggesting that it is more suitable for longer trips. Below a certain access or total distance, cycling to transit is probably less attractive than walking or using solely other alternatives (Shelat et al., 2018).

The speed and frequency of available public transport are also important factors that influence bike-transit uptake. Bike-transit combination is more attractive when high-speed transit is available (Martens, 2004), while for slower modes, bicycles serve more as a substitute. Only 9% of shared trips in the Hague were in combination with the slower modes like bus or tram, while 46% substituted them (van Marsbergen et al., 2022). Even, when they are used in combination the average catchment radius of tram stops in The Hague has been found to be around 1 km (Rijsman et al., 2019). Although it is around 2–3 times higher than walking (Rijsman et al., 2019), it is lower than the 1–5 km radius of train stations.

However, one interesting observation from the USA is that even though catchment areas double in radius when high speed transit is available, bike-transit ridership is not influenced (Hochmair, 2015; Wang & Liu, 2013). This suggests that high speed transit does not attract new or infrequent travellers, but simply attracts existing public transport users that were previously using nearby stops or stations with slower transit options (Blainey, 2010). The main explanation is that people are willing to cycle more to access a station that offer better service and higher comfort, such as avoiding a transfer (Rijsman et al., 2019; van Mil et al., 2020). More specifically, van Mil et al. (2020) found that bike-transit users in the Netherlands are willing to bike 6 additional minutes to another station to avoid a transfer. In addition, public transport frequency is also important, since as observed by Radzimski and Dzięcielski (2021) higher frequencies resulted in higher shared bike use. Indeed, Brand et al. (2017) observed that higher speed and frequency BRT systems in the Netherlands can attract up to twice the number of bike-transit users compared to normal bus systems.

3.3.2. Land use and built environment characteristics

The urban context plays an important role in achieving an efficient uptake of the bike-transit combination. This is evident from the study of Lin et al. (2018) which explores the association between built environment and bike usage as a feeder to public transport in three cities, i.e. Beijing, Taipei and Tokyo. The results of this comparative analysis suggest that empirical findings from one case study might not reflect reality in another city, even with geographic and cultural similarities.

In general mixing land uses has been found to have a positive impact on bike-transit (Guo et al., 2021; Guo & He, 2020; Hu et al., 2022; Weliwitiya et al., 2019). However, studies from China and Canada observed that population and residential land density have been found to have a positive impact on bike-transit ridership (Chan & Farber, 2020; Hu et al., 2022; Wu et al., 2021; Zhou et al., 2023), while employment density has a negative impact (Guo & He, 2020; Ma et al., 2018; Zhou et al., 2023). As regards population density, Hu et al. (2022) found that it has a negative impact near city centres, and it only becomes positive in farther distances from them. Considering that city centres in China are densely populated suggests that there is an optimal population density where the maximum benefits of bike-transit integration in terms of ridership manifest. As regards commercial land density, the findings are contradictory since Chan and Farber (2020) find it to be negative, while Cheng and Lin (2017) and Zhou et al. (2023) find it to be positive.

Apart from land use, there are several additional characteristics of the built environment that influence the successful integration of cycling to public transport. For example, the slope of the bike route has been found to have a negative influence on using the bike to access public transport (Weliwitiya et al., 2019). The density of public transport stops in an urban area has a negative impact on the combined use of bike and public transport (Guo & He, 2020; Ma et al., 2018; Wu et al., 2021; Zhou et al., 2023). Finally, road network density also has a significant impact, but its direction is not straightforward. Some studies argue that it is negative (Chan & Farber, 2020; Ma et al., 2018), but according to Barajas (2012) and Weliwitiya et al. (2019) if density comes with more intersections or low-speed streets the impact is positive.

3.3.3. Quality of interchanges and provided facilities

The quality of interchanges and provided facilities at stops or stations has been found to reduce the feeling of inconvenience that travellers experience during transfers (Cheng & Liu, 2012; Givoni & Rietveld, 2007; Rietveld, 2000). In general, cyclists prefer to take their bicycle onboard (Bachand-Marleau et al., 2011; Barajas, 2012; Ravensbergen et al., 2018), but this results in capacity issues (Krizek & Stonebraker, 2011; Pucher & Buehler, 2012) and potential conflicts with other transport users (Cheng & Liu, 2012). In most European and North American countries, bikes are generally allowed onboard expect for rush hours where public transport is crowded (Pucher & Buehler, 2012). One solution implemented in North America is installing front-mounted racks on buses, but even those can reach their capacity during rush hours (Krygsman et al., 2004; Pucher & Buehler, 2012).

Using the bike as access mode and parking it before boarding is another solution when taking the bike onboard is not possible (Heinen & Buehler, 2019). Bike parking is one of the most important aspects for the bike-transit integration (Pucher et al., 2010) and has been proven to be more cost-effective than allowing bikes onboard (Krizek & Stonebraker, 2011). Secure bike parking facilities at train stations have a positive influence on the uptake of bike-transit (Ashraf et al., 2021; Barajas, 2012; Cervero et al., 2013; Geurs et al., 2016; Ravensbergen et al., 2018; Tobias et al., 2012; van Zeebroeck, 2017), but bike lockers at bus stops have been observed to be rarely used (Martens, 2007). This suggests that bike parking could be more beneficial for high-speed transit and BRT systems.

In this review, we identified a variety of aspects that would influence the impact of bike parking facilities on bike-transit integration. First, providing an adequate number of parking spaces, especially during rush hours, is an important factor of bike parking facilities (La Paix Puello & Geurs, 2015; Rijsman et al., 2019). The importance of adequate bike parking facilities is even more evident when there are already high levels of cycling and public transport use (Arbis et al., 2015; Molin & Maat, 2015; Pucher & Buehler, 2012). In Denmark, Halldórsdóttir et al. (2017) found that each 100 additional parking spots can increase the likelihood of cycling by 2.5%. Another important aspect is their proximity to the public transport stop or station (Chen et al., 2012; Geurs et al., 2016; Heinen & Buehler, 2019; La Paix et al., 2021). According to Molin and Maat (2015), each additional minute of walking has an increasing negative impact on the probability of choosing bike-transit. A negative impact also exists if payment is required (La Paix et al., 2021; Molin & Maat, 2015). More specifically, Geurs et al. (2016) found that in the Netherlands free parking increases the chances of cycling to a train station by 11%. Covered facilities that offer protection from bad weather conditions increase the likelihood of choosing bike-transit up to 3 times (Halldórsdóttir et al., 2017).

The safety and security of these facilities are also crucial elements. Several studies have found that bike-transit users prefer highly visible or surveilled bike parking facilities (Arbis et al., 2015; Cervero et al., 2013; Geurs et al., 2016; Ravensbergen et al., 2018; Tobias et al., 2012; van Zeebroeck, 2017). For example, Rose et al. (2016) argue that when secure bike cages were installed in stations in Melbourne, they showed a 36% increase in use every year between 2010 and 2015. They also led many park-and-ride users to shift to the bicycle to access their station (Martin & den Hollander, 2009). According to La Paix Puello and Geurs (2015), improving unsurveilled bike parking facilities instead of the surveilled has bigger impact on bike-transit ridership. However, Molin and Maat (2015) argue that improved security through surveillance cannot counteract the impact of longer walking times, meaning that travellers opt for the closest parking to public transport rather than the safest. Therefore, even though it is important to design safe parking facilities, their proximity to public transport needs to be ensured at the same time.

Finally, the quality of cycling infrastructure and the traffic conditions, especially around stations, have been argued by many studies to be important (Cervero et al., 2013; Cheng & Liu, 2012; Geurs et al., 2016; La Paix Puello & Geurs, 2015; Tobias et al., 2012). However, only a few studies discuss specific factors in more detail. One important factor is the safety of bike users around stations. Reduced safety due to mixed traffic conditions, bad signage, or traffic congestion can have a negative impact on the decision to access them by bike (Panchal et al., 2020; Sherwin et al., 2011). More specifically, Phan et al. (2022) found that cycling to a station is negatively associated to the number of car crashes in the surrounding area. Finally, another important aspect is the directness of access to a station (Zacharias & Liu, 2022; Zhao et al., 2022), with separated bike paths having a positive impact too (Ashraf et al., 2021; Liu et al., 2020; Park et al., 2021).

3.3.4. Access to a bicycle through bike rental and bike share schemes

In general, the bike-transit integration seems to have a greater uptake when the bicycle serves as a first-mile solution (Givoni & Rietveld, 2007; Jonkeren et al., 2021; Keijer & Rietveld, 2000; Pucher & Buehler, 2012; Rietveld, 2000). One logical explanation is that most people have easier access to a personal bicycle at the home-end compared to the activity-end (Pucher & Buehler, 2012). Bike rental and bike share schemes offer good potential to fill this gap. Indeed, Stam et al., 2021 observed that if only shared vehicles were available in the Netherlands, bike use would increase on the activity end, while van Kuijk et al. (2022) found that travellers show no preference on whether shared bikes are electric or not. However, one important challenge for bike sharing schemes is providing sufficient access to bicycles (Guo & He, 2021). According to Li et al. (2022b) small-sized bike share schemes in Arizona had an insignificant impact on ridership.

Occasionally, even at the home end access to a personal bicycle is not always possible. Hence, shared bikes can play a vital role in the access part of bike-transit integration too. As walking distance from a station increases bike use increases too. Chen et al. (2012) found that in Nanjing, China or a walking distance of 10 min the share of bikes is 30%, while for 15 min it increases to 70%. Bike-sharing trips can be more competitive than bus trips too as a feeder mode option, especially during peak hours (Kapuku et al., 2022). Kapuku et al. (2021) found that the bike-sharing and transit combination in Seoul, South Korea, outperforms the unimodal use of buses or shared bikes in terms of travel time savings by 34% and 33% respectively. Possible long waiting times of other feeder modes, like the bus, can make shared bikes even more competitive (Liu et al., 2019).

Despite that, Benedini et al. (2020) observed that commuting bike-transit trips mostly happen with personal bikes rather than shared. One reason for this is the rental costs associated with the use of shared bike and could limit their potential compared to personal bikes. This needs to be considered when designing such schemes in order to achieve an efficient integration with public transport. For example, Li et al. (2020) argue that in Xi'an, China the benefits of integrating shared bikes to high-speed transit are more evident for trips that are longer than 7 km in total, but Guo et al. (2021) observed that most shared bike-transit trips are observed for total distances less than 5 km.

In general, shared bikes are mostly used for distances up to 2 km (Bi et al., 2021; Guo et al., 2021; Tarpin-Pitre & Morency, 2020; Zhao et al., 2022), which is shorter than the 2–5 km range of personal bikes to train or metro stations, but similar to that of slower modes, like the tram. This distance differs between urban and suburban centres, with people living in the suburbs being willing to cycle further to reach a station (Li & Guo, 2022; Wu et al., 2021). Consequently, they are willing to accept higher total travel time too. Indeed, Zhao et al. (2014) found that most people in the city centre of Huizhou, China are willing to travel up to 20 min with bike-transit, while people in suburbs up to 35 min. In suburbs, shared bikes have a higher potential in terms of ridership too (van Kuijk et al., 2022).

3.3.5. Availability and competitiveness of alternatives

Apart from having access to a bicycle, another important aspect for the successful promotion of bike-transit is how competitive other available travel options are. Ignoring the competition with other alternatives, like the car, leads to underestimating factors like the value of time for the potential users (van Mil et al., 2020) and thus overestimating the potential of bike-transit. Not having access to a car at all also has a positive effect on bike-transit uptake (Chan & Farber, 2020; Huang et al., 2017; Meng et al., 2016). Finally, if travellers perceive that the car is the fastest and most convenient option to access a station, they will increase the chances that people choose to drive at a station (Jayarathne et al., 2019). To attract people that have access to a car to use bike-transit a stronger compensation in other aspects, such as travel time savings, is necessary (Arentze & Molin, 2013). Moreover, the availability of car parking at stations (Chan & Farber, 2020; Midenet et al., 2018; Rose et al., 2016) and the option to be escorted by a car from a family member or friend have been found to have a negative effect on the uptake of bike-transit (Adnan et al., 2019).

The car is not the only competitor to bike-transit. Promoting cycling can lead to people choosing the bike for the entire trip, especially for short distances (Griffin & Sener, 2016; Pucher & Buehler, 2012), having thus a negative impact on bike-transit uptake. For example, 48% of the shared bike users in Austin, USA would have used public transport if shared bikes were not available (Griffin & Sener, 2016). Similarly, in Chengdu, China, around 28% and 8% of bikeshare trips replaced a bus and subway trips, respectively

(Saltykova et al., 2022). This effect might be more evident if e-bikes become more popular. In the Netherlands, e-bike ownership has been found to have a larger negative effect on both car and public transport use, compared to conventional bikes (Kroesen, 2017). In addition, Huang et al. (2017) found that even though bike ownership is positively associated with metro ridership, e-bike ownerships is negatively associated.

In general, e-bikes have the potential to replace both public transport and car trips (Bai et al., 2019). Lee et al. (2015) argue that 40% of e-bike trips in the Netherlands would have been otherwise made by car. Fyhri and Fearnley (2015) found that the impact of e-bikes on car users in Norway is significant both in number of bike trips and cycling distance. In addition, car owners were found to be more willing to use an e-bike than a conventional bicycle or public transport (Kroesen, 2017). Consequently, even though increased bike use is desirable, the possibility of unimodal bike use being more attractive needs to be considered when designing an integrated bike-transit system. According to Singleton and Clifton (2014) this phenomenon is observable mainly in the short-term, with the benefits on bike-transit integrated manifesting in the long-term. However, the indirect negative impact of promoting e-bikes on bike-transit ridership is understudied.

Finally, attitudes and perceptions of individuals towards different modes of transport also has an influence (Heinen & Bohte, 2014). A positive attitude towards the bicycle and public transport or even the environment and a negative attitude towards car use can increase the probability that an individual chooses to combine them (Bergman et al., 2011; Heinen & Bohte, 2014; La Paix et al., 2021). This suggests that promoting bike-transit in car-oriented and car-dependent urban areas might be a more difficult task compared to ones with an existing cycling culture and good quality public transport system.

3.3.6. Sociodemographic characteristics

The personal characteristics of individuals also seem to influence the choice of bike-transit. The majority of studies has observed that male individuals are more likely to combine cycling with public transport (Böcker et al., 2020; Ji et al., 2016; Ravensbergen et al., 2018; Sherwin et al., 2011; Wang & Liu, 2013). Age is also argued to be an important factor, but there is contradictory evidence regarding the direction of its impact on ridership. Some studies argue that older individuals are less likely to opt for bike-transit (Böcker et al., 2020; Chan & Farber, 2020; Ji et al., 2016; Jonkeren et al., 2021; Shelat et al., 2018; Wang & Liu, 2013), while other studies find that as age increases so does the likelihood to use bike-transit (Meng et al., 2016; Yang et al., 2014), while a third group suggests that both younger and older age groups are less likely to adopt it (Molinillo et al., 2020; Sherwin et al., 2011; Zhao et al., 2022).

Findings on the directionality of income are also contradictory. Some studies argue that higher income is positively associated with cycling in combination to public transit (Ji et al., 2016; Meng et al., 2016; Shelat et al., 2018), while Yang et al. (2014) and Rastogi (2010) found that it has a negative impact. Moreover, both Chan and Farber (2020) and Zhao et al. (2022) found that median income groups are more likely to adopt bike-transit as a travel option.

Finally, several studies argue that highly educated people are more likely to use the bike in combination with transit (Jonkeren et al., 2021; Shelat et al., 2018). However, Wang and Liu (2013) did not find a relationship between bike-transit use in the USA and education, but they did so for housing and race. This suggests that other background characteristics related to an individual's socio-economic status, such as income or residential location, are good predictors of their travel behaviour.

3.3.7. Trip context

The context under which a trip takes place can also play an important role. The bike-transit combination mostly attracts people that travel for utilitarian purposes (commute or education) (Chen et al., 2012; Jonkeren et al., 2021; Martens, 2004; Shelat et al., 2018; Wang & Liu, 2013; Wu et al., 2021; Zhao et al., 2014, 2022), and therefore shows two peaks during the morning and the evening, especially during weekdays (Kapuku et al., 2022; Yan et al., 2020). One reason for this can be that route familiarity is positively associated with bike-transit (Molin & Timmermans, 2010), which is obvious for these trips because they happen almost on a daily basis and between the same origin and destination. One barrier related to commuting bike-transit trips is reduced comfort and the difficulty of maintaining a professional appearance (Ravensbergen et al., 2018). In general, cold or wet weather, carrying a baggage, travelling alone and limited availability of daylight are also important barriers (Hochmair, 2015; Molin & Timmermans, 2010).

3.4. Effects of bike-transit integration

Considering the aforementioned factors allows an effective integration of cycling with public transport, which is argued to have significant sustainability benefits for urban transport systems. In this review, several benefits have been observed. First, the benefits in terms of improving access to public transport are discussed. Then, a focus is given on other sustainability aspects, such as social and environmental implications. The impacts on bike use are also discussed considering that the impacts of this integration are bilateral. Finally, since one of the main arguments for promoting bike-transit is that it performs well as an alternative to the car, we discuss its expected impacts on car use. Table 4 presents an overview of the findings on the expected benefits from a successful bike-transit integration.

3.4.1. Improved access to public transport

The integration of bicycles to public transport systems has been found to complement them by expanding their catchment area (i.e. the geographic area that public transport serves and attracts passengers from). Guo and He (2021) observed that when metro coverage in Shenzhen, China was poor the likelihood of using bike-metro was higher. Catchment areas are one of the most important aspects of public transport systems. Several studies have attempted to estimate the contribution of bicycle in the radius increase of catchment areas of public transport. Kager and Harms (2017) found that cycling serves a four times larger area for train stations in three Dutch cities compared to walking. The BiTiBi project report (van Zeebroeck, 2017), which discusses the outcomes of four pilot studies in Belgium, Italy, Spain and the UK, argues that the expected catchment radius of a train station by bike could increase fivefold. Lin et al. (2019) found that integrating shared bikes to Shanghai's metro doubled its coverage in central areas.

Lee et al. (2016) argue that theoretically integrating cycling to Seoul's public transport system increases the catchment areas of stations 11 times, but in practical terms, due the existence of other stations, catchment areas are actually only 3 times larger. This is because larger catchment areas mean that people have more choices of transit stations. For example, people in the Netherlands mostly have access to one station when only walking is considered, while with cycling most travellers can choose between two or more train stations within a 5 km radius from their origin or destination (Kager et al., 2016). These findings suggest that integrating cycling to public transport could increase catchment areas 3–5 times, but the exact magnitude depends on several aspects.

One important aspect is whether the cycling part is an access or egress trip. Zuo et al. (2018) found that in the USA, access trips near residential areas increase catchment areas by 1.7 times compared to walking, while egress trips near activity destinations by 2.3 times. This suggests that the benefits of bike-transit integration are more evident when it provides connection to activity locations. In addition, Li et al. (2022a) found that people are willing to cycle 1.3 times longer with a private e-bike compared to private regular bikes. Finally, the type of public transport that bicycles are integrated into plays a role too. More specifically, Cao et al. (2019) observed that shared bikes increased the coverage of subway stations by 2.34 times, while for bus stations only 1.33 times. This suggests that bike-transit integration has larger benefits for high-speed transit.

Increasing catchment areas results in more people gaining access to the public transport system. According to Kager et al. (2016), 19% of the population in the Netherlands live within 1 km of a train station. This share rises to 69 and 81% for 5 and 7.5 km of cycling distance respectively. If only main intercity stations are considered, then only 1.1% of the Dutch population lives within a 1 km radius, compared to 16 and 24% that live within the same cycling distances. This means that cycling in the Netherlands connects around 4 times more people to a train station than walking, or 15 times more to intercity stations.

Consequently, promoting cycling to access public transit can lead to an increase in public transport ridership too. According to Singleton and Clifton (2014) improving cycling conditions to achieve better bike-transit integration leads to more trips that substitute public transport in the short-term. However, in the long-term there will be a shift in behaviour leading to more trips that complement public transport. Ashraf et al. (2021) and Ma et al. (2015) argue that a 10% increase on shared bike trips resulted in 2.3 and 2.8% higher subway ridership in New York and Washington DC, respectively. Similarly, Fan and Zheng (2020) observed that subway lines with higher bike-sharing use showed 8% larger growth rate in subway ridership. These findings suggest that the benefits of promoting the bike-transit combination might not be evident from the beginning.

3.4.2. Social and environmental implications

Providing access to transit stations to more people and reducing travel times by providing more choices can increase the accessibility levels offered by public transport systems, giving more people access to opportunities, like jobs, shops, or other activities. More specifically, Bi et al. (2021) observed that integrating bicycles can be more effective at improving job accessibility than policies improving public transport waiting times and frequencies. Yang et al. (2018) also observed that shared bikes improve the transport equity levels of the public transport systems of both Hangzhou and Ningbo in China. In addition, Zuo et al. (2021) found that when bicycles were integrated to the BRT system the part of the population in urban areas of Hamilton County, Ohio that has access to transit increased from 20 to 28.7%, while workplace accessibility increased by 43.7% (Zuo

Table 4. Overview of effects of bike-transit integration.

Category	Impact	Source	Country	Findings
Improved access to public transport	Expand coverage of public transport systems	Kager and Harms (2017)	Netherlands	Cycling serves a 2 km radius of the train stations in three large Dutch cities, increasing catchment areas by four times compared to walking
		van Zeebroeck (2017)	Belgium, Italy, Spain, UK	Catchment radius of a train station could increase five times by bike compared to walking
		Lee et al. (2016)	South Korea	Catchment areas are 3 times higher when cycling is integrated to public transport
		Kager et al. (2016)	Netherlands	Bicycles connect 4 times more people to a train station, or 15 times more to intercity stations.
		Zuo et al. (2020)	USA	The coverage radius of the BRT system in Hamilton County, Ohio got three times higher
		Cao et al. (2019)	China	Shared bikes increased the service areas of subway by 2.34 and of bus stations by 1.33 times
		Guo and He (2021)	China	Poor metro accessibility is associated with high likelihood of shared bike-metro integration, suggesting it contributes to improve accessibility of the metro.
		Li et al. (2022a)	China	Access distance with private e-bikes is about 1.3 times longer compared to private regular bikes
		Zuo et al. (2018)	USA	Cycling increases the catchment area of transit by 1.7 times at the home end and 2.3 times at the activity end
		Lin et al. (2019)	China	Bike-sharing increased the coverage of the metro in central Shanghai by 104%
	Provide more station and route choices	Kager et al. (2016)	Netherlands	With cycling most travellers have at least two train stations within a 5 km radius
	Increase ridership	Ashraf et al. (2021)	USA	A 10% increase on shared bike trips resulted in 2.3% higher subway ridership.
		Fan and Zheng (2020)	China	Subway lines with higher bike-sharing use showed 8% larger growth rate in subway ridership compared to ones with lower bike-sharing use
		Singleton and Clifton (2014)	USA	Commuting by bicycle has a positive impact on transit ridership in the long-term
		Ma et al. (2015)	USA	A 10% increase in shared bike ridership led to a 2.8% increase in metro ridership
		Tarpin-Pitre and Morency (2020)	Canada	Integrating shared bikes to metro can increase the ridership of both systems
		Villwock-Witte and Van Grol (2015)	Netherlands	OV-fiets increased bike-transit users from 30 to 50%
		Pritchard et al. (2019b)	Brazil	If bikes are used to access transit in São Paulo, potential job accessibility increases by 24%

Social and environmental implications	Improve (job) accessibility by public transport	Zuo et al. (2020)	USA	Integrating bicycles to BRT in Hamilton County, Ohio increased workplace accessibility by 43.7%
		Zuo et al. (2021)	USA	By integrating bicycles, the part of population in urban areas that has access to transit increased from around 20 to 28.7%. In suburbs the increase was lower but still significant.
	Improve transport equity	Bi et al. (2021)	China	Changing access and egress mode is more effective at improving access to low-wage jobs than policies that improve waiting times and frequencies
		Pritchard et al. (2019b)	Brazil	Bike-transit benefited all areas, but accessibility mostly increased at already more accessible areas.
		Yang et al. (2018)	China	Shared bikes reduced the Gini coefficient of public transport systems in Hangzhou and Ningbo
		Zuo et al. (2018)	USA	By integrating bicycles, the part of the disadvantages population in suburbs that has access to transit increased from around 27 to 51%
		Zuo et al. (2020)	USA	Increased job accessibility for low-income groups and minorities
		Zuo et al. (2021)	USA	Bicycles increase the accessibility of low-income and zero-car population
	Less emissions	van Zeebroeck (2017)	–	If only 20% of commuters in Europe shift from car to the bike-train combination, it will result in 5000 million less passenger km driven annually, leading to a reduction of 800,000 tons of CO2, 55 tons of PM and 250 tons of NOx emissions per year
	Health benefits	van Zeebroeck (2017)	–	20% of commuters in Europe shifting from car to the bike-train combination results in approximately 1200 lives saved per year
		Rojas-Rueda et al. (2012)	Spain	40% of the car trips starting or ending in Barcelona City to public transport and cycling would result in around 98 deaths avoided per year.
	Economic benefits	van Zeebroeck (2017)	–	20% of commuters in Europe shifting from car to the bike-train combination equals 3 billion Euro per year saved
		Papon et al. (2017)	France	For each passenger that shifts from car park-and-ride to a bike or e-bike to access Amboise station, the estimated socio-economic benefits are around 2000 Euro per year
		Papon et al. (2017)	France	For each passenger that shifts from being dropped-off at Amboise station by car to a bike or e-bike, the estimated socio-economic benefits are around 1000 Euro per year
Impact on bicycle use	Increase ridership	Singleton and Clifton (2014)	USA	Cycling is a substitute of transit in the short-term, but becomes a complement in the long-term
		Pucher and Buehler (2012)	Netherlands	39% of train users reach a station by bike
		Pucher and Buehler (2012)	Denmark	25% of train users reach a station by bike
		Pucher and Buehler (2012)	Sweden	9% of train users reach a station by bike

(*Continued*)

Table 4. Continued.

Category	Impact	Source	Country	Findings
		Pucher and Buehler (2012)	Japan	The integration of bikes to Tokyo's metro and suburban rail systems resulted in 20% of the passengers cycling to a station
		Martens (2004)	Netherlands, Germany, UK	The bike is used four to nine times more for access compared to egress
		Givoni and Rietveld (2007); Heinen and Buehler (2019); Jonkeren et al. (2021); Keijer and Rietveld (2000); Rietveld (2000)	Netherlands	Cycling has a higher share in the home-end. Around 35% of the total access trips to stations are made by bike compared to only 7% of the total egress trips to stations
		Heinen and Buehler (2019); Martens (2004)	Denmark	Bike's modal share is 25% on access trips and 3–6% on egress trips for Copenhagen's suburban train system
		Tarpin-Pitre and Morency (2020)	Canada	Integrating shared bikes to metro can increase the ridership of both systems
Impact on car use	Reduced competitiveness of cars	Pritchard et al. (2019a)	Netherlands	Bike-transit reduces the differences in accessibility with car in the larger cities in the Netherlands, like Rotterdam and The Hague
	Car use reduction	Bachand-Marleau et al. (2011)	Netherlands	Bike-transit can replace car trips even for distances larger than 15 km, if the destination of a trip is a city centre
		Martens (2007)	Netherlands	OV-fiets resulted in an increase in train trips and bike use, and a small reduction in car use
		Nello-Deakin and Brömmelstroet (2021)	Netherlands	A large proportion of bike-train users in Randstad have access to a car preferred not to use it
		Tavassoli and Tamannaei (2020)	Iran	Bike-sharing in Isfahan has higher potential to substitute car use if designed as a feeder mode to public transport rather than as a stand-alone solution
		van Zeebroeck (2017)	Belgium, UK	Bike rental schemes at rail stations resulted in 7-9% of trains users replacing a car trip for the combined rental bike-transit trip
		Villwock-Witte and Van Grol (2015)	Netherlands	Bike rental schemes at rail stations resulted in 10% of trains users replacing a car trip for the combined rental bike-transit trip

et al., 2020). This integration also improved transport equity, by increasing job accessibility for low-income groups and minorities (Zuo et al., 2020). More specifically, the part of the disadvantaged population in suburbs with access to transit increased from around 27 to 51% (Zuo et al., 2018).

Similarly, Pritchard et al. (2019b) estimated an increase of 24% in potential job accessibility if bicycles are used as access mode for transit trips in São Paulo, Brazil. However, even though bike-transit benefited all areas of the city, accessibility mostly increased at the already more accessible areas. Therefore, they argue that while bike-transit combination can benefit all areas of a city, it is not enough to counteract inequalities stemming from land use forces (e.g. high concentration of jobs in specific areas) or the unequal provision of public transportation (e.g. lack of coverage in less urban areas). Sagaris et al. (2017) also support the importance of the land use element when promoting bike-transit to create more socially just cities. Therefore, even though bike-transit can improve access of disadvantaged population groups, the local context in terms of land use and built environment should not be neglected to ensure a more fair urban transport system.

When cycling is efficiently integrated to public transport and substitutes car use, it has several significant environmental and health benefits too. It is estimated that if only 20% of commuters in Europe shift from car to the bike-train combination, it will result in 5000 million less passenger km driven annually, leading to a reduction of 800,000 tons of CO_2, 55 tons of PM and 250 tons of NOx emissions per year (van Zeebroeck, 2017). This reduction, in combination with the physical activity from cycling, results in approximately 1200 lives saved per year, which in economic terms equals 3 billion Euro (van Zeebroeck, 2017).

Papon et al. (2017) estimated that for each passenger that shifts from the car to a bike or e-bike each to access Amboise station in France are considered, the socio-economic benefits are around 2000 Euro per year. For those shifting from being dropped-off at the station by car they are around 1000 Euro per year. To put these statistics in the context of a city, Rojas-Rueda et al. (2012) estimate that a shift of 40% of the car trips starting or ending in Barcelona City to public transport and cycling would result in around 98 deaths avoided per year.

3.4.3. Impact on bicycle use

In general, the relationship between bike use and public transport is bilateral, since promoting the integration of the two systems can benefit both modes (Martens, 2007; Tarpin-Pitre & Morency, 2020). This implies that improving public transport can also have positive impact on the share of cycling, but it can also be the other way around. For example, Yang et al. (2019) and Tyndall (2022) observed that the introduction of the new metro service in Nanchang and a new light rail station in Seattle resulted in an increased demand for shared bikes around the stations. Furthermore, Wang et al. (2020) found that bike-sharing usage in Beijing during peak hours is affected by the station's passenger flow.

In terms of ridership, promoting the integration of bike and transit resulted in 39% of train users in the Netherlands, 25% in Denmark and 9% in Sweden, reaching their train station by bike (Pucher & Buehler, 2012). In Tokyo, Japan, the integration of bike to the metro and suburban rail systems resulted in 20% of the passengers cycling to a station (Pucher & Buehler, 2012). According to Martens (2004), the bike is generally used about four to nine times more for access, compared to the egress part. Indeed, access and egress trips to railway stations in the Netherlands showed a higher share of cycling in the home-end of a multimodal trip (around 35% of the total access trips), compared to the activity-end (7% of the total egress trips) (Givoni & Rietveld, 2007; Heinen & Buehler, 2019; Jonkeren et al., 2021; Keijer & Rietveld, 2000; Rietveld, 2000). Similar patterns have been observed for Copenhagen's suburban train system, with 25% bike share on access trips and 3–6% on egress trips (Heinen & Buehler, 2019; Martens, 2004).

3.4.4. Impact on car use

Even though bike-transit can have significant benefits for the public transport system and is thus argued to offer a competitive alternative to the car, only a few studies mainly from the Netherlands have explicitly focused on its impact on car use. According to Pritchard et al. (2019a), when cycling is integrated to the public transport system, the differences in its accessibility compared to the one offered by car have been significantly reduced in the larger cities in the Netherlands, like Rotterdam and The Hague. This reduction was more evident during the morning and afternoon peak hours, when public transport is more frequent. Therefore, bike-transit can become a competitive alternative to car use in large urban areas with frequent and high-quality public transport. This is also confirmed by the large proportion of bike-train users in Randstad (where The Hague and Rotterdam are located) who have access to a car but prefer not to use it (Nello-Deakin & Brömmelstroet, 2021). Moreover, according to Bachand-Marleau et al. (2011), bike-transit can replace car trips even for distances larger than 15 km, if the destination of a trip is a city centre. This suggests that, as indicated by Martens (2004), having access to a car does not prevent people from using bike-transit when cycling is efficiently integrated to high-speed transit.

The contribution of bike rental and bike share schemes to reduce car use is also evident. The introduction of bike rental schemes at rail stations in the Netherlands, Belgium and the UK resulted in 7–10% of all trains users having replaced a car trip for the combined rental bike-transit trip (van Zeebroeck, 2017; Villwock-Witte & Van Grol, 2015). In addition, Tavassoli and Tamannaei (2020) argue that bike-sharing in Isfahan, Iran showed higher potential to substitute car use if designed as a feeder mode to public transport rather than as a stand-alone solution. However, for slower modes of public transport, like the bus, car availability can have a strong negative effect on the levels of bike-and-ride (Martens, 2004). Consequently, the bike-transit integration has a higher probability to replace car trips when high-speed transit is involved.

4. Discussion and conclusions

The main objective of this study is to provide a systematic review and analysis of the published literature on the combined use of cycling and public transport. Overall, this study provides useful insights into the current state of knowledge about the factors for and the effects of efficiently integrating bicycles into urban public transport systems, as well as the methods used to study them. It is important to note that bike-transit integration is a complex process that is heavily influenced by the local context. Bike-transit uptake is influenced by various factors, such as the quality of infrastructure, built environment characteristics and the availability and attractiveness of alternative options, like the car. Findings in this review are mostly from the Netherlands, which has a well-developed public transport system and a strong cycling culture; China, where the focus is on integrating shared bikes with existing high-speed rail or metro networks; and the USA, where bike-transit mainly refers to the combination of bicycles and buses. Consequently, the findings in this review should be interpreted with caution as their generalisability is limited.

In conclusion, while existing literature shows that bike-transit integration can improve the performance of existing public transport systems and lead to several social and environmental benefits, the impact of this integration on car use and consequently on sustainable mobility is a topic that requires further in-depth investigation. Although several studies highlight the potential of bike-transit combination for recurring trips like commuting and education, there are several empirical and methodological gaps that need to be addressed by future research to gain a clearer understanding of the potential of bike-transit to become an alternative to car use.

Additionally, despite the benefits of promoting the combined use of bicycles and public transport, this synergy does not seem enough to solve major issues stemming from poor public transport provision, lack of proper cycling infrastructure, or from pathologies of decades of car-oriented planning and investing that established the dominance of cars over other more sustainable travel options in most urban areas. Therefore, apart from the integration of the two systems, additional interventions such as car traffic restrictions, changes in land use, or incentives to adopt more sustainable travel behaviour might be necessary to efficiently reduce car use and thus achieve a more sustainable urban transport system.

4.1. Empirical gaps

One major gap that we identified in the literature is that even though there is a common agreement that bike-transit integration has good potential to become an alternative to the car, only a few studies (mainly from the Netherlands) have explicitly focused on its impact on car use. An increase in bike-transit ridership though can be a result of either replacing car trips or of more frequent trips of existing public transport users, shifting from walking to the station or shifting from cycling for the whole trip. Consequently, if the main argument for bike-transit is that it provides an attractive alternative to the car, then car use substitution should always be the main focus.

In addition, improving cycling conditions to achieve bike-transit integration can make cycling a more attractive option for the whole trip, turning the bicycle to a competitor of public transport. Understanding the impact of different interventions on unimodal bicycle use is essential because the level of service offered by other alternatives has been found to influence the potential uptake of bike-transit. The same applies for e-bikes, whose impact on bike-transit uptake is currently understudied. If e-bikes are properly integrated, they can have significant benefits on public transport systems. However, by enabling cyclists to cover longer distances with less physical effort they also provide an attractive alternative to car use as well as to short and medium distance transit trips (Fyhri & Fearnley, 2015; Kroesen, 2017; Lee et al., 2015).

Concluding, investigating the substitution mechanisms behind travel behaviour change can provide a better understanding on what motivates people to substitute car use for the bike-transit combination without compromising active travel options, such as walking and cycling. This is especially vital for car-oriented and dependent areas where car travel has been favoured for decades and promoting bike-transit as an alternative to car use can be a difficult task.

4.2. Methodological gaps

In this literature review two main approaches were identified: (i) the system-centric, and (ii) the user-centric. Combining them can offer a better overview on the factors for and the potential of bike-transit integration. One gap we identified on methods is the lack of qualitative data gathering techniques, such as focus groups and in-depth interviews. These user-centric techniques enable a deeper understanding on the motives behind existing travel behaviour and how to change it. Combining such an approach with existing techniques could offer a more concrete overview of how to promote bike-transit as an actual alternative to car use.

In addition, studies examining the impact of specific measures do not include a control group. Control groups allow to test whether observed behavioural changes are an outcome of the examined intervention, rather than the presence of co-existing measures or phenomena. Using existing travel data or revealed or stated preference data does not allow to consider one. Again, applying more qualitative approaches could be a good solution.

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