

Shared Modes Strategies and Practices

Project deliverable D1.3

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List of abbreviations and acronyms

Acronym	Meaning
AHP	Analytic Hierarchy Process
B2B	Business-To-Business
B2C	Business-To-Consumer
GA	Grant Agreement
GIS	Geographic Information System
HOV	High-Occupancy Vehicles
IRIMS	Institutionella Ramverk för Integrerade Mobilitetstjänster i framtidens Städer, "Institutional Frameworks for Integrated Mobility Services in future cities"
ITDP	Institute for Transportation & Development Policy
LL	Living Lab
LBSS	London Bike-Sharing Scheme
MaaS	Mobility as a Service
MCDM	Multi-Criteria Decision Making
NSM	New and Shared Modes
PT	Public Transport
P2P	Peer-To-Peer
RFID	Radio Frequency Identification
RSA	Revenu de Solidarité Active, "Active Solidarity Income"
SUM	Seamless shared Urban Mobility
TDM	Transportation Demand Management
WASPAS	Weighted Aggregated Sum Product Assessment
WP	Work Package

Project Executive Summary

The objective of the Seamless shared Urban Mobility (SUM) project is to transform current mobility networks towards New and Shared Modes (NSM) integrated with Public Transport (PT) in more than 15 European Cities by 2026, reaching 30 by 2030. Intermodality, interconnectivity, sustainability, safety, and resilience are at the core of this innovation. The outcomes of the project offer affordable and reliable solutions considering the needs of all stakeholders such as end users, private companies, public urban authorities.

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Deliverable executive summary

Key words

shared mobility, mobility hub, bike sharing, micro-mobility, public transport, integration

Introduction

The Seamless shared Urban Mobility (SUM) project aims to transform urban mobility towards seamless and shared solutions integrating public transport with shared and active modes of transport. This deliverable aims to inspire project members by widening and deepening their understanding of shared mobility solutions, allowing them to apply state-of-the-art strategies and guidelines to their Living Labs (LL), and providing recommendations on well-established NSMs for which best practices exist.

Method

This deliverable summarises shared mobility trends, strategies and practices from the transportation literature that have already succeeded or have development potential. The authors searched for articles, studies and reports using the following keywords: shared mobility, mobility hub, bike sharing, micro-mobility, public transport, and integration and included results from 2018 and later that contained relevant empirical data. Due to the limited time available to prepare this deliverable, the authors focused on shared mobility concepts that are sustainable and most relevant to the SUM LLs, such as shared micro-mobility, integration of public transport and new and shared mobility, and mobility hubs.

Main Conclusions

According to the definition of “shared” meaning either “two or more travellers co-exist in space in one vehicle” like in public transport and pooling, or “individual travellers take over an available vehicle from the last user” like in bike-sharing or carsharing, shared mobility services can be categorized into three types: simultaneous shared mobility, sequential shared mobility, and combined shared mobility which is the combination of simultaneous and sequential shared mobility services.

For shared micro-mobility, it is important to consider the existing urban mobility condition and actual public needs as well as institutional support before choosing from different micro-mobility sharing scheme types in order to have long-sighted successful shared mobility schemes. Challenges of the schemes are categorized according to the vehicle riding stages: “Accessing the vehicle”, “Riding the vehicle”, and “Returning the vehicle”, including key strategies to avoid fall-downs and solve operational problems, as well as examples of best practices for relevant strategies. Dock-based sharing schemes need more infrastructural investments while dockless sharing schemes need good strategies for operational issues especially re-balancing issues.

For carsharing, it is not easy to achieve long-term viability, while a conceptual integrated decision-support framework proposed from studies might help the carsharing designing and implementation decision-making process. Depot location and trip selection criteria can be impactful on the profitability of carsharing scheme, and that one-way carsharing system might succeed with a gradual development.

To increase the user-experience of multimodal travel, effective strategies include increasing the reliability of each travel leg with different strategies and integration of different modes, which can be the integration of physical infrastructure like mobility hub, payment and information services like ticketing and travel planning apps, and institutional management. A framework of mobility hub typologies according to urban contexts can be helpful for deciding what type of mobility hub to adopt in a certain context. To maximize the impact of a

mobility hub, the location and the modes accommodated are crucial factors, which also depend on the expected service range.

There are several barriers that need to be overcome to establish a successful mobility as a service (MaaS). Barriers are classified into formal and informal from levels of micro, meso and macro with suggestions provided. In addition to this, the development of the service content, beyond the app and the mobility plans, is also central.

More general take-away strategies to support shared mobility include encouraging public engagement, improving services and maintenance, spotting complementarity between modes, gaining political and institutional support, and learning from each other's experiences. They are supported with relevant studies and examples.

Limitations

Solutions from one city often require localization and adaptation for use in other cities. Each LL should pay careful attention to their local context.

Purpose of the deliverable

The primary objective of the SUM project is to enable the mobility transformation in 15 European cities by 2026, with an extension to 30 European cities by 2030. The transformation involves the integration of new shared mobility modes with public transport, focusing on innovation, interconnectivity, environmental sustainability, safety, resilience, and replicability. This literature review aims to give city LLs within the Seamless shared Urban Mobility (SUM) EU project inspiration about what shared mobility solutions to develop, and knowledge gained from prior implementations.

Existing literature on shared mobility addresses solutions and strategies from a variety of perspectives, encompassing but not limited to: user perspective in terms of needs, perception, daily practice, etc.; designer perspective in terms of physical and digital infrastructures, services, vehicles, etc.; planner perspective in terms of transportation, urban land use, etc.; policy perspective in terms of data operation, transport mode promotion, etc.; service provider perspective in terms of vehicle producer, digital platform operators, transport service providers, etc.

To exhaust all possible solutions and make the reader lost in hundreds of possible paths towards success, is not the aim of this literature review. Instead, it strives to provide a full picture of shared mobility in categories, along with concepts that help to understand what the challenges are and why, so that it becomes clear what needs to be tackled and what the possibilities and limits of these modes are.

There is a dominance of studies in shared mobility based on car-usage-involved practices, while studies show that a car-centric transport system requires significantly more transport spending from governments and individuals than a system based on walking, cycling, and public transport. The focus of this literature review is therefore given to sustainable shared mobility modes that are not car-based. A significant part of this review is related to improving shared micro-mobility services in operation and integrating them with other modes like public transport, due to the fact that many SUM LLs have adopted shared micro-mobility schemes such as bike-sharing and scooter-sharing while a seamless integrated mobility service system is yet to be found.

The ultimate purpose of the deliverable is to present the involved project partners, especially the LLs, with a state-of-the-art review of shared mobility to use as a starting point when deciding on what mobility solutions to implement and test, how to improve existing mobility services, and how to avoid mistakes made previously at other locations.

Attainment of the objectives and explanation of deviations

In the SUM Grant Agreement (GA), task D1.3 is described as follows: best practices and strategic innovations within the field of shared mode mobility will be reviewed. The task will give the project inspiration to what shared mobility solutions to develop within the LLs, it will ensure that the tested shared mobility solutions will be novel and state-of-the-art, and it will further assure that mistakes or fall downs of previous shared mobility implementation will not be repeated. Chalmers will conduct a literature review and also a web search on current shared mobility solutions.

The literature review and web search have been conducted. The coverage of the literature reviewed is supported by the information retrieval strategy and the LLs' current status and needs from Work Package (WP)1, with a focus on shared micro-mobility, mobility hubs, and the integration of different modes. The task provides practices and strategies that will assist the LLs in developing their mobility system, and to be aware of potential mistakes.

Intended audience

The intended audience is mainly the SUM LLs, but practitioners and researchers interested in shared mobility may also find it useful.

Structure of the deliverable and links with other work packages/deliverables

The deliverable introduces the topic, describes the methodology used for the review, and then describes different shared mobility solutions. The choice was made to divide the reviewed mobility solutions regarding how the involved vehicles were shared in a temporal sense.

1 Introduction

The SUM project aims to introduce, test, and evaluate different shared mobility solutions that provide a seamless mobility experience. The outcomes of the project will be affordable and reliable solutions considering the needs of all stakeholders such as end users, private companies, and public urban authorities. To meet this end, an understanding of shared mobility and the pre-requisites for successful implementation is crucial. This review provides a starting point to meet these goals.

1.1 Definition - What is Shared Mobility?

Broadly speaking, shared mobility is an innovative transportation strategy (Shaheen & Cohen, 2021) that allows journeys to be completed without the traveller owning a vehicle, especially a private car. Shared mobility also stands for transportation services or tools that are designed according to this strategy.

Public transport (PT) is the traditional form with the idea of shared mobility, where travellers go on journeys along established routes that operate according to fixed schedules, with shared vehicles including buses, trams, trains, metro, ferries, etc. However, in current research, shared mobility mostly refers to transportation services that fill in the gaps in door-to-door journeys that public transport cannot cover, due to limits of service time and routes, to complete journeys without owning a vehicle. To achieve this, shared mobility enables travellers to have short-term access to a transportation mode on an as-needed basis (Shaheen & Cohen, 2021).

“Shared” in shared mobility implies double meaning. The first meaning is that two or more riders co-exist in space in one vehicle, like in public transport (also known as pooling). The second is that individual travellers take over an available vehicle from the last user, like in bike sharing, scooter-sharing or carsharing. According to the definition of “shared”, inspired by the work of Guyader et al. (2021) who divide shared mobility research papers into three types, shared mobility services can be categorized into three types: simultaneous shared mobility, sequential shared mobility, and combined shared mobility which is the combination of simultaneous and sequential shared mobility services, such as the mobility as a service (MaaS).

Figure 1 summarises the key areas of shared mobility. It is developed by the authors, inspired by the ideas from Shaheen et al. (2020).

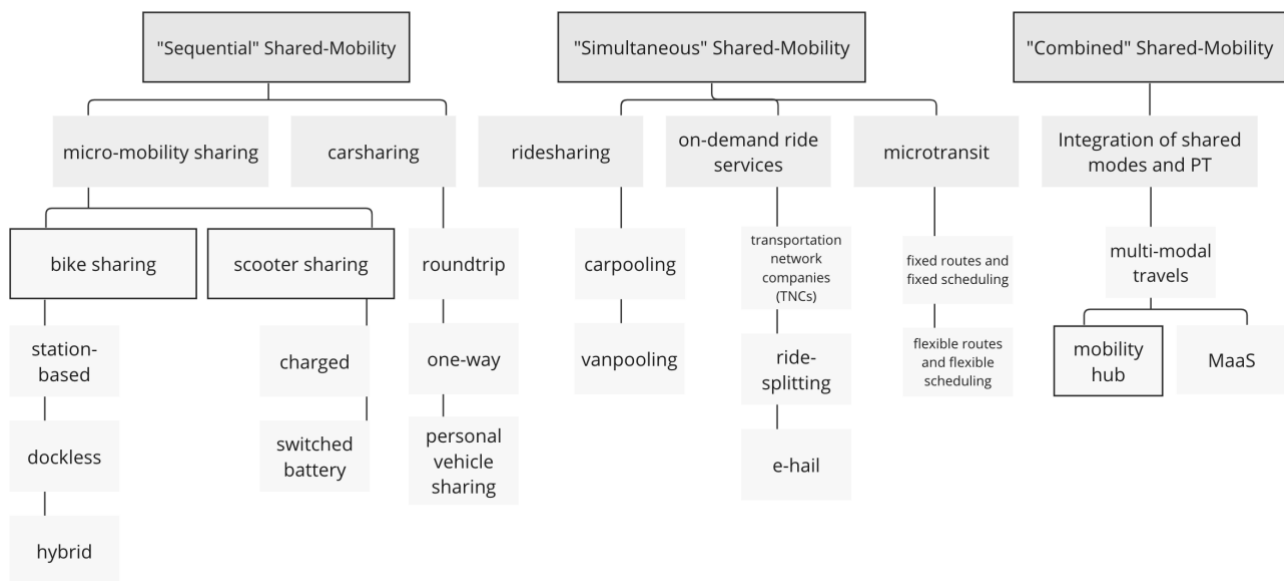


Figure 1 Key areas of shared mobility

Shared mobility is a broad topic covering a complex and heterogeneous body of literature. Guyader et al. (2021) looked at the different modes of transportation that constitute shared mobility from historical perspectives. Overall, there is a dominance of studies based on practices where car-usage is involved, such as carsharing, carpooling, ride-hailing, while studies on non-car-involved shared mobility are lacking. Studies show that the cost of a car-centric transport system is enormous, requiring governments and individuals to spend 50% more than in a system based on walking, cycling, and public transport (ITDP, 2021). The focus of this literature review is therefore given to sustainable shared mobility modes that are not car-based.

Based on WP1 result of LLs' goals, the focus of this review is given to bike sharing, mobility hubs, and integration of different modes, which have the highest frequency of being mentioned. A significant part of this review is related to improving shared micro-mobility services in operation and integrating them with other modes like public transport, due to that many LLs have adopted shared micro-mobility schemes like bike-sharing and scooter sharing while a seamless integrated mobility service system is yet to be found.

1.2 Methodology

In order to fulfill the aim of this literature review, a state-of-the-art type review was chosen since they tend to address more current matters (Grant & Booth, 2009). A state-of-the-art review focuses on the most recent and relevant studies in the field, often including research up to the present year, which contrasts with broader literature reviews that may include seminal or foundational studies from the past.

The focus of the review was decided based on

- reading current mobility status from WP1 1.1
- summarizing LLs' goals within their SUM project planned practices

The database chosen for the literature retrieval is Scopus as it covers a wide range of scientific disciplines, including transportation and mobility studies. Publications later than 2018 with highly relevant "article title, abstract, keywords" were selected for in-depth reading and analyzing. The web-search engine is Google for non-academic literature and examples of shared mobility practice.

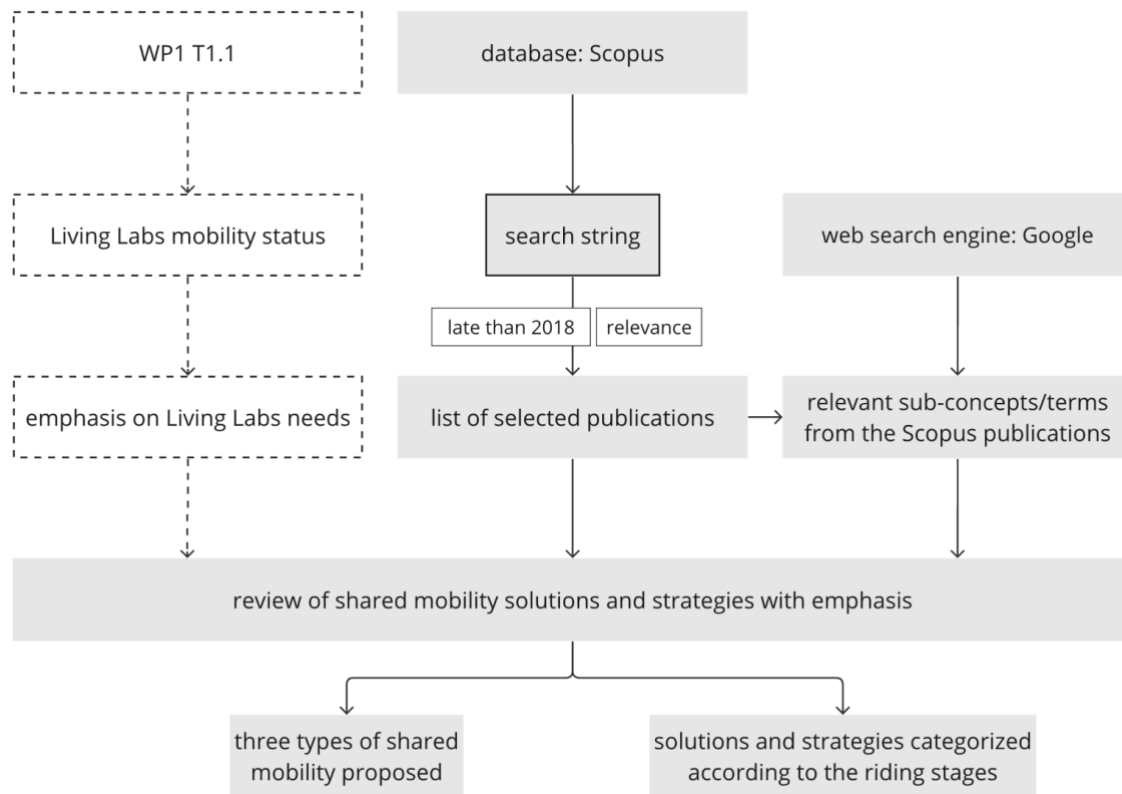


Figure 2 Information retrieval process

Modes Living Lab																	High Frequency Living Lab Goals - in terms of transport mode/infrastructure (based on WP1)			
	bus	tram	light rail	metro	train	ferry	microtransit	ride-hailing	taxi	car-pooling	car-sharing	bike	cargo bike	scooter	moped	MaaS	bike infrastructure	multimodal integration	mobility hub	park & ride
Munich	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	☆	☆	☆	☆
Geneva LL area	✓	✓			✓	✓	✓	✓	✓			✓				✓		☆	☆	
Jerusalem	✓	✓	✓					✓	✓	✓	✓	✓					☆	☆		☆
Penteli	✓								✓		✓			✓			☆	☆	☆	
Rotterdam	✓	✓		✓				✓	✓		✓	✓		✓	✓				☆	
Krakow	✓	✓					✓	✓	✓		✓	✓		✓			☆	☆	☆	☆
Fredrikstad	✓					✓	✓		✓		✓	✓		✓			☆	☆	☆	☆
Larnaca	✓							✓	✓								☆	☆		
Coimbra	✓				✓		✓	✓	✓			✓		✓				☆	☆	

Shared Mobility (broad sense)			
Public Transport		Shared Mobility (narrow sense)	
		Demand Responsive	New and Shared Mobility(NSM)
Simultaneous Shared Mobility		Sequential Shared Mobility	
		Combined Shared Mobility	

Figure 3 Current Status of Living Labs from WP1

Due to the complex and heterogeneous nature of the body of literature under the topic “shared mobility”, a scoping strategy instead of a systematic strategy was chosen as the tool to map the key concepts underpinning this research area and the main sources and types of strategies available. Firstly, literature on the topic of “shared mobility practices and strategies” was gathered by searching for papers in Scopus database using the search string “(“shared mobility” AND review) (solution* OR practice OR strategy* OR concept* OR model OR success*)AND(new* OR “state-of-the-art” OR “state of the art” OR recent*)” to have a holistic view of all relevant topics and sub-concepts within shared mobility best practices. Secondly, important sub-concepts were selected and untangled into eight clusters for more specific searches and screening, with a focus on mobility hub and micro-mobility such as bike-sharing and scooter-sharing. Thirdly, the collected literature was analyzed and reviewed.

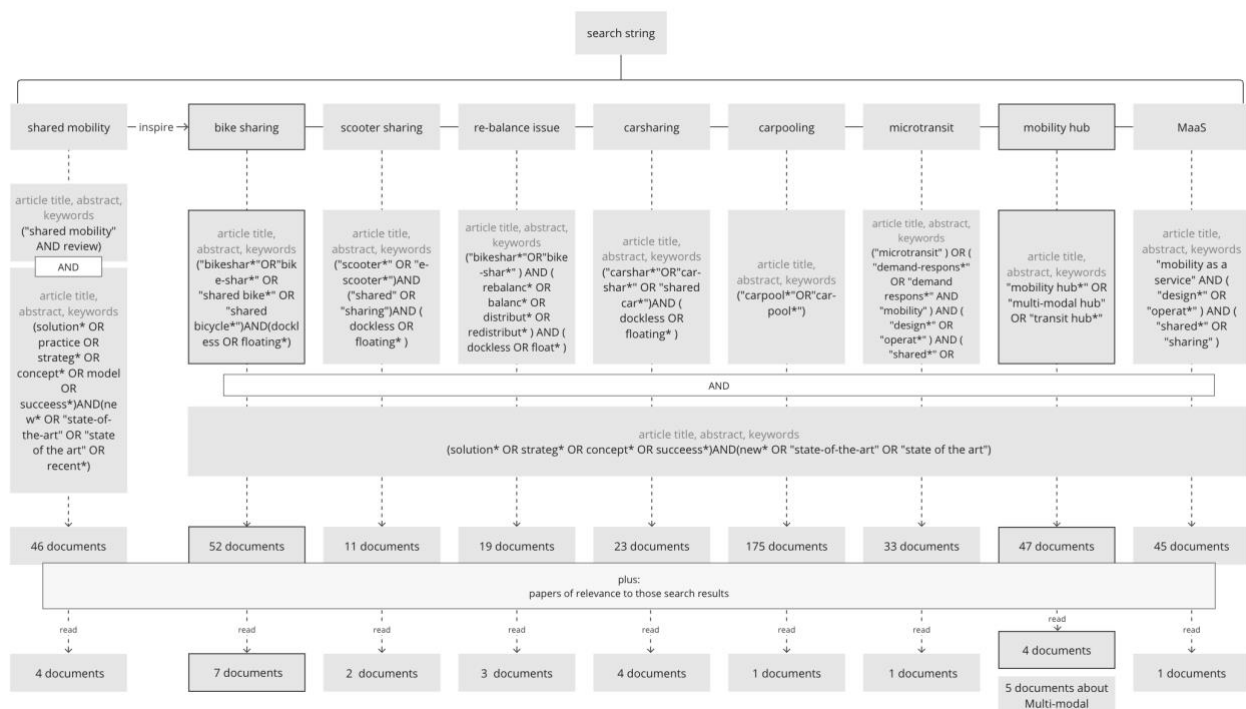


Figure 4 Information retrieval topics & search strings

Further web-search was then conducted based on the relevant key concepts, strategies or challenges and specific shared modes that appear to be crucial within the topic of shared mobility.

1.3 Structure

In this literature review, state-of-the-art shared mobility practices and strategic innovations are reviewed in the order of the above-mentioned three types of shared mobility (sequential shared mobility, simultaneous shared mobility, and combined shared mobility), each featuring relative transportation mode, common challenges, and relative strategies.

2 Sequential Shared Mobility

Sequential shared mobility involves a one-to-one handover of a shared vehicle from one user to the next. In this model, a user utilizes a vehicle (such as a bike, scooter, or car) for a specific duration or distance and then leaves it at a designated location for the next user. This form of shared mobility often relies on designated stations or pick-up/drop-off points to facilitate a smooth transition between users. When the station's location is not pre-defined, as very common in the dockless or floating system of vehicle-sharing, the challenge lies in accessing the shared vehicle. In this section, models and strategies within practices of micro-mobility sharing (such as bike-sharing and e-scooter-sharing), and carsharing are discussed. Among those sequential shared mobility modes, bike-sharing is given the most attention, as it appeared the most frequently in LLs' scheduled and applied practices for shared mobility promotion to achieve the SUM project goals, according to the current mobility status in WP1 T1.1.

2.1 Shared Micro-mobility

Urban transportation policies, investments, and infrastructure have historically prioritized the movement of vehicles without considering broader economic, environmental, and social impacts (The Path Less Travelled: Scaling up Active Mobility to Capture Economic and Climate Benefits, 2023). The cost of a car-centric transport system is enormous, requiring 50% more transport spending from governments and individuals than a system based on walking, cycling, and public transport (ITDP, 2021).

Within the broader shared mobility framework, micromobility and active mobility are two concepts that play integral roles. Micromobility refers to lightweight, often electric, modes of transportation such as bikes and scooters that are well-suited for short-distance travel with a typical speed below 25 km/h, and can be either shared or private, either human-powered or electric. Including light electric vehicles, micromobility excludes mopeds and motorcycles due to their heavier weight and higher speeds exceeding 45 km/h (Yanocha et al., 2021). Active mobility emphasizes human-powered transportation modes, including walking and cycling. Bike sharing, a subset of micromobility and active mobility, specifically focuses on the communal use of bicycles. These concepts are interconnected, contributing to a holistic approach that addresses the challenges of urban mobility by offering flexible, sustainable, and shared solutions that enhance accessibility and reduce environmental impact.

Shared micro-mobility is a term used to describe bike-sharing, scooter-sharing or other low-speed modes. It is an innovative transportation strategy that enables users to have short-term access to a transportation mode on an as-needed basis (Shaheen et al., 2020). The authors consider sequential shared mobility's most essential concept to be shared micro-mobility, among which, the two main sub-concepts are bike-sharing and scooter-sharing.

Bike-sharing has evolved significantly since its inception in Amsterdam in 1965, and has emerged as a pivotal component within the realm of shared mobility, offering a sustainable and flexible solution to address urban mobility challenges. According to research, bike-sharing has experienced the fastest growth in history as a transport mode (Efthimios Bakogiannis et al., 2016). In 2022, around 3,000 cities around the world operated bike-sharing systems (O'Sullivan, 2022). In the context of shared mobility, bike-sharing plays a distinctive role in providing users with a cost-efficient, accessible, and environmentally friendly mode of travel.

Adopting a bike-sharing system can bring many direct and indirect benefits enhancing urban mobility and quality of life according to insights from the CIVITAS (2016). Directly, it promotes health through physical activity, offers additional mobility options, reduces congestion, creates employment, increases the modal share of cycling, boosts tourism, and helps manage public transport demand. Indirectly, bike-sharing amplifies health benefits, increases cycling visibility, encourages the development of cycling infrastructure,

reduces CO2 emissions, enhances the city's image, improves cycling safety, contributes to more livable streets, and leads to cost savings by reducing reliance on car infrastructure. Together, these benefits underscore the significant role bike-sharing can play in creating more sustainable, efficient, and attractive urban environments (CIVITAS Insight 10 - Bike-sharing as a Link to Desired Destinations | CIVITAS, 2016).

Scooter-sharing, emerging in the early 2010s, represents a significant evolution in urban micro-mobility, comparable yet distinct from its predecessor, bike-sharing. The development of scooter-sharing was propelled by advancements in GPS technology, mobile connectivity, and electric scooter design, making it more feasible and user-friendly over the years. One of the significant advantages of scooter-sharing is its contribution to reducing urban congestion and pollution, as these lightweight, electric vehicles produce zero emissions and occupy less space compared to cars.

There are similarities and differences between bike-sharing and scooter sharing systems. Like bike sharing, scooter-sharing leverages GPS technology and smartphone apps for easy rental and navigation. However, electric scooters offer certain additional advantages over bicycles. They require less physical effort, making them more accessible to a wider range of users, including those who may find biking physically demanding. Scooters are also often faster than bicycles for short distances and are seen as more agile in dense urban environments. On the other hand, bike-sharing is perceived as healthier due to the physical exercise involved and generally offers more stability and safety, especially for longer distances. Bikes can sometimes accommodate additional cargo, like groceries or backpacks, more conveniently than scooters. In terms of infrastructure, bike-sharing systems have been around longer and thus having a more established presence in many cities, including designated bike lanes and parking areas, which scooter-sharing systems are still developing.

Among the extensive practices of shared micro-mobility, it has witnessed great success in developments, as well as dramatic stories of misfortune due to financial or operational failures. This section explores the multifaceted bear-in-minds within micro-mobility-sharing system services categorized from the perspective of using process, defining the challenges often faced in the scheme as the operational issues are high, and providing relevant strategies that coped with them successfully.

2.1.1 Models of Shared Micro-mobility Systems

2.1.1.1 Station-based, Free-floating, or Hybrid

Station-based (docking) sharing schemes rely on fixed docking stations strategically placed throughout urban areas. Users access vehicles from these designated stations, ride to their destination, and return the bike to any available docking point within the system. This approach ensures organized vehicle distribution, facilitates maintenance, and provides a reliable structure for users to locate and return vehicles.

Free-floating (dockless) sharing revolutionizes traditional sharing models by eliminating the need for fixed docking stations. In this scheme, users locate and unlock vehicles using a mobile app, and after completing their journey park the vehicles at convenient and permissible locations. The flexibility of free-floating systems enhances user convenience and reduces the scheme's reliance on fixed infrastructure.

Hybrid sharing combines elements of both free-floating and station-based schemes, offering users the flexibility of point-to-point travel without the constraints of fixed docking stations. Users can locate and unlock vehicles using a mobile app, similar to free-floating systems, but they also have the option to return the vehicle to designated docking points if they prefer. This model aims to provide the benefits of flexibility associated with free-floating systems while incorporating the organizational advantages offered by docking infrastructure.

To compare dock-based systems with dockless systems in bike-sharing schemes, according to Nikitas, dock-based systems, until practices then, have been more successful in securing long-term viability than most dockless schemes (Nikitas, 2019).

2.1.1.2 Other types of vehicles in the shared micro-mobility landscape

E-bikes (electric bikes) feature an electric motor that assists riders, offering pedal-assist or throttle-powered options. They provide an efficient and eco-friendly solution for commuting, particularly in hilly areas or for longer distances when cycling seems a difficult choice compared with driving.

Cargo bikes, also known as a box bike, carrier cycle and freight bicycle, designed and constructed for transporting loads, include a cargo compartment consisting of an enclosed or open box. They offer an eco-friendly alternative for deliveries in dense urban environments and transporting children. This type of bike-sharing is growing across Europe. In Germany alone, we count more than 160 cities operating cargo bike-sharing.

Electric mopeds, with more powerful motors and larger batteries compared to e-scooters, offer higher speeds (up to 30-45 mph) and longer ranges, making them suitable for extended urban commuting. They typically feature a comfortable seat, storage space, and require adherence to stricter regulations like licensing and insurance. In contrast, e-scooters are designed for shorter distances and lower speeds (about 15-20 mph). Ideal for quick, convenient trips, e-scooters are less regulated and widely used in shared mobility platforms, whereas electric mopeds, due to their higher capabilities and costs, are more commonly owned for personal use.

2.1.1.3 Bike-sharing Supporting Technologies

Table 1 Key components and relevant technological innovations of a bike-sharing scheme, adapted from "Public Bike-sharing - Final Guidance Note, 2016"

Component	Relevant technologies
Bicycles	- Real-time on-bike information on navigation, public transport schedules, local events, information about the bicycle (such as remaining battery charge) and the availability and location of nearby docking stations - GPS tracking to aid positioning and navigation systems, reduce risk of bicycle being lost or stolen, or reduce the need for docking stations - Solar panels fitted to bicycles to power electronic components - Pedal generators applied to electric bicycles and cargo bikes which reduce the need for batteries and charging infrastructure - Accelerometers to detect a bicycle being moved or interfered without authorisation - Sensors to detect attempts to tamper with or break locks - Better design and use of more advanced materials to make bicycles robust but lightweight 'Smart' bike locks that fit to standard bicycles and connected with smartphone apps, allowing small-scale bike-sharing schemes where individual owners can offer their own bicycles for hire
Docking stations	- Mobile stations that can be relocated by the operator to match demand at short notice - Stations that collect energy generated by cyclists to feed it back to the grid - Free-roaming, GPS-tracked bicycles that do not need stations, improving convenience and reducing installation costs - Designation of areas where users are encouraged to return their bicycles in schemes without fixed stations as a means of reducing unpredictable distribution
User payment and access systems	- Ticketing systems integrated with wider public transport network so that users with smartcards for other modes do not need a separate key or smartcard to access bike-sharing - On-bike payment systems for payment without kiosks or stations - Payment through use of saved account details for other online purchases
ITS Technology	- Integration of data into online journey planners so that details of bike-sharing options appear alongside alternative options for travel by default - Integration of bike-sharing with wider fares system so that multimodal tickets can be purchased which cover bike-sharing schemes - Use of smartphone applications for journey planning and real-time information on the availability of bicycles and stations - Use of smartphone applications to connect individual bicycles owners and users in a peer-to-peer bike-sharing system – negating the need for a single public provider
Bicycle distribution system	Locking technology fitted to bicycles as an alternative to stations, which have limited capacity
Peer-to-peer	- Integration with existing bike-sharing schemes or bike rental - Integration with car sharing or other peer-to-peer services

The table above is adapted from "Public Bike-sharing - Final Guidance Note, 2016", summarising the key components and relevant technological innovations of a bike-sharing scheme.

The "Public Bike-sharing - Final Guidance Note, 2016" outlines key elements and corresponding technological advancements in bike-sharing schemes. Bicycles benefit from real-time information systems providing navigation and event updates, with GPS technology to facilitate positioning and reduce the need for docking stations. Theft prevention is enhanced using accelerometers and smart locks, with some bikes also harnessing solar power to reduce the need for battery charging. Docking stations have evolved with the introduction of mobile variants and energy-generating capabilities. Free-floating bikes with GPS tracking offer flexibility and help manage distribution without fixed stations. User payment and access are streamlined through integrated ticketing systems compatible with public transport smartcards, on-bike payment options, and the use of online purchase accounts. ITS technology includes journey planner integration, ensuring bike-sharing is a visible option in travel planning, and fare systems that support multimodal ticket purchases. The distribution of bikes is improved with locking technologies that mitigate the need for station infrastructure. Peer-to-peer sharing is facilitated through integration with existing bike-sharing schemes or other shared services, expanding the accessibility and convenience of bike-sharing in urban areas. (Public Bike-sharing - Final Guidance Note, 2016)

2.1.2 Strategic Innovation and Best Practice Guide - During Different Stages of Micro-Mobility-Sharing

2.1.2.1 Stage 1: Accessing the vehicle

Location is the primary concern. During the stage when the rider accesses a bike, the bike's location appears important for the convenience and experience of the whole trip.

For station-based bike-sharing systems, whether the stations are strategically located is one key factor in scheme design or operating success. The Institute for Transportation & Development Policy (ITDP) 2018 Bike share Planning Guide suggested some characteristics of an ideal station location as shown in the following chart:

Table 2 Characteristics of an ideal station location, adapted from "Bike share Planning Guide, ITDP(2018)"

Ideal Station Location Characteristics	
On sidewalk	On street
• Sunny, minimal tree cover • At least 2 meters of clear walking space • Close to intersections • Close to public transit stations • High-visibility area and street lighting • Easy access for users, as well as maintenance and rebalancing vehicles • Close to bicycle infrastructure	• Close to intersections • Close to public transit stations • High visibility and street lighting • Low volume of cars, low speed limits • Adjacent to bicycle infrastructure • Not blocking manhole cover, storm drain, etc.

In the guide, an advised process for making station location decisions is firstly creating a first draft of station locations, while engaging community groups to build support and ensure equity, then finalizing station locations through site visits, and lastly revisiting and analyzing station performance in case of the need of resizing or re-locating. It is worth noting that, in planning bike-sharing stations, involving stakeholders like residents and businesses is a good way for community buy-in and equitable access. For instance, New York City and Washington, DC exemplify this strategy by involving local political representatives and citizens in selecting station locations, which fosters transparency and community involvement. Designed by New Yorkers, the Citi Bike share system included 400 meetings and a website that received over 10,000 suggestions and 55,000 clicks of support for station locations to help shape the system (NYC Bike Share:

Designed by New Yorkers | Bike Share, 2013). This method proves effective in ensuring equitable access and quelling fears of bike-sharing as a symbol of gentrification (ITDP, 2018).

The work by Bahadori et al. systematically reviewed station location techniques for bicycle-sharing systems. They found that the initial network design and the operation improvement (where changes in operating a BSS are implemented) were the two primary issues to consider with regards to the location of bicycle stations. In addition to this, they proposed four main criteria for selecting appropriate places for the stations or parking : “bike network”, “operator”, “user”, and “city infrastructure” (Bahadori et al., 2021), and suggested the use of three following modelling techniques to further determine the best locations: “mathematical algorithms”, “multi-criteria decision making”, “GIS”,. The review suggested that for more accurate and practical results, mixed use of the above-mentioned three types of location modelling techniques can be considered, to combine strengths of Geographic Information System (GIS) and multi-criteria decision making (MCDM) to locate bike-sharing stations and excel the location problem resolution. Recent studies also highlighted the value of user locations data and public questionnaires in identifying the most appropriate bike-sharing station location.

The successful examples of the French schemes Vélo’v in Lyon and Bicloo in Nantes, both managed by JCDecaux, have witnessed significant increase in rentals and subscribers (Intelligent Transport, 2019). This can be partially attributed to the increased accessibility of service (in Lyon’s metropolitan area, 4,000 new bikes were installed in seven night-time hours, without influencing normal service), as well as high availability rates (95% for Vélo’v and 99% for biclooPlus), which ensure that users can reliably find a bike when they need one, increasing the attractiveness of the service.

The establishment of station-based bike-sharing systems can be time-consuming and costly in comparison to free-floating bike-sharing systems, where there is no fixed location of bikes in the system. However, free-floating bike-sharing can bring up other challenges such as the accessibility of bikes when the bike distribution is imbalanced in certain urban areas. How to re-distribute and re-balance the bikes is a systematic issue which we address later in this document under section “Stage 3: Returning the bike”.

China, Hangzhou's Public Bicycle sharing scheme provides an alternative solution to some of the challenges of the **free-floating bike-sharing** system. The experience of inconvenient parking due to fixed station locations directly affected the usage rate of public bicycles. In response, Hangzhou Public Transport Group developed geo-fencing, only in which can the bikes be locked. By setting up "electronic station areas" in the urban area, and prompting the user through the mobile application with GPS, the convenience of "parking without dock" can be achieved. At the same time, compared with parking free-floating bicycles at will, the new public bicycles with parking area limits are more friendly for urban management (Beijing News, 2017). Besides their strategy of geo-fencing, Hangzhou's Public Bicycle system stands out due to many other reasons, including its low subscription fee and widespread availability, appealing even to car owners. Supported by subsidies from local authorities, this not-for-profit scheme offers free use for the first 60 minutes. Key to its success is its complete integration with other PT systems, alongside a high-quality real-time information system.

By October 2023, Hangzhou Public Bicycle Transportation Service System had 5,458 service points and 143,700 public bicycles, with the highest daily hiring volume of more than 473,000 trips, and the cumulative hiring volume of more than 1.324 billion trips, with the free usage rate reaching 98%. Due to its convenient, cost-efficient, safe and sharing characteristics, as well as the "self-service operation, intelligent management, through the rent and return, deposit guarantee, overtime charges, real-time settlement" mode of operation, public bicycles have become an indispensable means of urban transportation for Hangzhou's Chinese and foreign tourists and citizens to travel. The system has been recognized by the BBC Travel Channel as "one of the eight cities in the world that provide the best public bicycle service". On September 5, 2021, C40 released five global examples of best-practice cycling cities, and Hangzhou was selected along with Paris

and Copenhagen (Hangzhou Public Bicycle Transportation Service Development Co.,2021). The system has a good strategy for generating revenue thanks to governmental support, further demonstration about this can be found in section “5.4 Political and Institutional Support”.

Another crucial aspect of a bike's accessibility is the ease with which it can be unlocked and paid for. To enhance the accessibility of free-floating bike-sharing systems in urban environments, ITDP (2018) provided some suggestions in the Bike share Planning Guide, including the implementation of alternative payment methods to accommodate users without access to smartphones or credit cards. Possible solutions encompass cash transactions facilitated at local retail outlets or the utilization of preloaded cards. Additionally, there is a focus on developing subsidized fare structures targeted at low-income demographics. This approach may involve the elimination of initial deposit requirements and the provision of unlimited access to short-duration trips at a reduced cost. Furthermore, the integration of bike-sharing systems with existing public transportation networks is being explored. This integration could manifest in the form of reduced fares for multi-modal commutes, thereby promoting seamless transitions between bike share and public transit systems. A potential method for achieving this integration is the adoption of a unified radio frequency identification (RFID) technology, enabling a single card to facilitate access across different modes of transportation, one successful implemented example is the OV-fiets in Netherlands which uses a chip card for convenient experience of unlocking bikes (OV-Fietsslot - Jouw OV-Chipkaart Als Sleutel | NS). The rental process of a OV-fiets bike can be achieved without any internet or app operation. Those above mentioned strategies aim to render free-floating bike share systems more inclusive, thereby expanding their utility and effectiveness as a component of the urban transportation infrastructure (ITDP, 2018).

2.1.2.2 Stage 2: Riding the vehicle

Safety and infrastructure are crucial factors to consider for enhancing the usage of bike-sharing. Two survey-based studies on bike-sharing used in two cities, Drama in Greece and Gothenburg in Sweden, respectively representing the Southern European context and Northern European context, show that the willingness of citizens to have a bike-sharing option in the city is higher than the actual usage. It was found that the two common key usage barriers refer to road safety concerns and the lack of adequate cycling infrastructure (Nikitas, 2019).

In a place-based study of multimodal travel, the importance of safety and infrastructure is discussed. It notes that while cycling infrastructure may be more prevalent in peri-urban areas compared to rural settings, safety concerns, particularly the security at train stations and the safety and comfort of accessing public transport by walking or cycling, are significant. For instance, a journey might begin in a well-lit urban area but end in a poorly lit rural one, which can be a safety concern for travellers. There is an emphasis on the need to improve active travel infrastructure in rural areas. The perception that it is unsafe to travel by bike in such areas hinders the potential to combine bicycle and train travel. “Participants from those areas also cited safety at stations and stops as a greater concern. Information on safety (including, e.g., staffing, lighting, CCTV) could be incorporated into such an app” (McIlroy, 2023). Packaging safety information into MaaS platform to increase transparency can be a good strategy to encourage the usage of stops in periphery locations.

Other than safety, high connectivity and a pleasant environment are also important criteria to improve the riding experience. New York's (US) Citi Bike system is running prosperously with on average 8.3 daily trips per bike and 42.7 daily trips per 1,000 residents (Cripps, 2013). Citi Bike boasts an extensive network, serving NYC boroughs and expanding into neighbouring areas. The city invested in expanding bike lanes, racks, and bike-sharing infrastructure as part of its broader transportation strategy. The service was launched in May 2013, featuring 332 stations and a fleet of 6,000 bicycles. By October 2017, after annual additions, the number of stations reached 706, and the bike count rose to 12,000, establishing it as the biggest bike-sharing program in the United States. (Citi Bike, 2020) The program is set for a significant expansion that will double its service area by 35 square miles and triple the number of available bikes to 40,000. The continuous

infrastructural expansions keep the program relevant and inclusive to the citizens within distinct districts and communities, by achieving higher accessibility and better linkage.

The Qiandao Luneng Resort Greenway, embraced for its "multiple uses" in Hangzhou, China, enhances the city's green infrastructure. Listed among the "best quality experience locations" during the third Hangzhou Citizen Day, it features a versatile route that includes Asian Games Avenue, catering to both slow-paced traffic and competitive sports with a dedicated mountain bike and triathlon running track. It's designed to preserve the natural environment while promoting ecological restoration and forest management. The greenway not only offers changing scenic views but also serves as a testament to the legacy and spirit of the Asian Games. Alongside sporting activities, the greenway is flanked by various service facilities that enrich the visitor experience, such as accommodation, leisure, and commercial areas. Since its inception, the greenway has become a beacon for tourism, drawing in over 130,000 visitors and hosting events like the Ironman Triathlon and mountain bike races. These events, alongside cultural festivals, have significantly contributed to the economic uplifting of the region, boosting sectors such as tourism, hospitality, catering, retail, and transportation. (Hangzhou Daily, 2023)

It is clearly targeted when considering expanding or upgrading bike infrastructures for dock-based bike-sharing schemes. What about the free-floating sharing scheme which does not have nodes and hierarchical bike suitable routes? Zhang et al. proposed the concept of "biking islands" in cities, which means geographical areas of interest with a high concentration of bike usage. By making full use of bike trajectory data from free-floating bike-sharing schemes, biking islands are recognized via percolation theory as it is suitable in describing the formation of clusters and critical road segments that have a significant influence on urban-context biking behaviour. (Zhang et al., 2019) The suggested concept and method are beneficial for analyzing the travel patterns of cyclists and the urban layouts conducive to cycling. They also hold promise for aiding in urban and transport planning efforts. This includes the demarcation of specific non-motorized zones for cyclists and the establishment of biking amenities, as well as identifying key road sections that could enhance the overall efficiency of the cycling network. "Biking islands" can possibly be conceptualized as specialized cycling zones, equipped with ample bike infrastructure and where motorized vehicles are limited or banned, thereby guaranteeing cyclist convenience and safety while fostering the growth of bicycle-centric urban environments.

2.1.2.3 Stage 3: Returning the vehicle

Lessons can be learned from the mismanagement incident resulting in difficulties in returning the bikes in the Paris's Vélib bike share program. Managed by Smovengo, the program has encountered significant operational issues since its expansion in 2017, leading to widespread dissatisfaction and service disruptions. The electrical bikes were introduced when most of the new docking stations were not connected to the electrical grid. That the bikes cannot be charged and used, frustrated the city's 300,000 bike share members. The situation escalated into a labour dispute with workers striking for better pay and conditions, further complicating the service's ability to meet demands. (Lindeman, 2018) To avoid similar situation from happening, efficient staffing, stable technical performance, and patience when establishing new features are important to bear in mind for bike-sharing practitioners.

For bike distribution disparity challenge, **rebalancing or repositioning strategy** can be applied in the stage of returning the bike. For dock-based sharing-scheme, when there are stations at more central locations, there are also stations at less essential districts, leading to the situation that no bike is available in certain areas while too many bikes cannot fit in central area stations. Different strategies can be implemented to tackle the challenge as shown by the two examples of New York City and Lyon.

The New York Citi Bike has successfully coped with the rebalancing issue with the "Bike Angels" concept, winning popularity and user engagement at the same time: The introduction of programs like "Bike Angels" encouraged users to move bikes between stations and earn incentives. The Bike Angels ride bikes from

congested stations to the ones that are short of bikes, to keep the system operating better. A continuously growing “volunteer army” maintains the city’s equality in shared mobility with motivation and gains incentives in the sharing system so that they can bike more and move more, and even contribute with points to users in districts where the sharing scheme is less affordable (Vanderbilt, 2018).

An innovative rental procedure enabled the French scheme Vélo’v users to return bikes in a much more motivated gesture: the inclusion of the first 30 minutes of each rental as free incentivizes users to return bikes to stations promptly, promoting system efficiency. A smart concept “Bonus Stations” was proposed which encourages the subscriber use of less-frequented locations, optimizing bike distribution. Taking a bike from a “full” station also earns points for the rider. Users can drop off and pick up bikes at any station, enabling flexibility for longer trips. On the other hand, Vélo’v users can rent bikes in multiple ways: through terminals, mobile applications, or partner cards, which lowers the rental threshold (MET’, 2019).

For free floating bike-sharing schemes, many of the China-based operations of Mobike and Ofo have experienced problems with the practicalities of rebalancing bikes. Many people complain about bikes causing clutter; as they do not have fixed-station parking locations, users can leave Mobikes where they cause obstruction. In response to these complaints, Mobike has introduced “parking zones” to encourage users to park in specific areas. Geo-fence concept mentioned in the “Stage 1: Accessing the bike” can also be referenced.

In Switzerland, Heitz et al. conducted a study based on free-floating bike-sharing system, and they proposed and tested a user incentive redistribution system with a value co-creation method, aiming to find out solutions for realistic application in Zurich free-floating e-bike scheme.. The tested solution encouraged- riders to drop off bikes to rewards zones which were dynamically changing according to bike distribution and future demand pattern. “Value” here means the increased service level of having a bike available at the place where and at the time when a transportation demand arises (Heitz et al., 2020), which is the initial reason why people choose free-floating scheme over station-based scheme to pick up and drop off bike wherever they want. Users can create this value for other users and benefit from value created by others as well as incentives in the form of free riding minutes. Value created also stands for the saved cost for operators. User needs and behavioural patterns were evaluated for better designing the mechanism. The proposed system allows 30 percent reduction of bike numbers while maintaining the same service level.

2.1.3 Strategies and Solutions that Concern More than One Stage

2.1.3.1 Charging the vehicle

For electric micromobility vehicles, charging is the main issue for operation and maintenance. The New York Citi Bike’s e-bike fleet is facing frequent malfunctions and maintenance issues. Though e-bikes are highly wanted among riders, depleted batteries due to intense usage make the huge fleet insufficient for needs. No e-bike model of theirs can be charged at a dock; employees manually remove dead batteries and charge them at a Citi Bike facility, which is a challenge, due to the city’s traffic and the extensive reach of the bike network. To cope with these challenges, Lyft, the operator of Citi Bike, has employed nearly 250 workers to move bikes and swap batteries across the city. They have increased their mechanic workforce. In addition, they are exploring options to reduce battery swaps by electrifying some stations (Surico, 2023), like Paris, which has installed over 700 charging stations for e-bikes (“Paris E-Bike City Guide 2024”). However, implementing such infrastructure changes is complex and requires city support, as electrified e-bike stations need new hook-ups. For combining existing infrastructure for synergies, the example of LinkNYC kiosks using the existing telephone booth power might be a case to refer to.

For the battery swapping and rebalancing approach, the study of Zhou et al can be referenced, based on Markov chain dynamics considering e-bike number and battery power level (Zhou et al., 2023), which can

make approximately 20% more mean financial gain, compared to the current approach in the industry, based on numerical simulations on an e-bike-sharing system in practice.

For e-scooters, the vehicle needs to be collected to charge instead of swapping battery, which requires higher operational cost. The chargers go to scooters with low batteries by their GPS location and transport them to designated charging stations. Charged vehicles are then dropped off at designated points, usually high-traffic zones. There has been research addressing the improvement of efficiency in this charging process. For example, Masoud et al proposed e-scooter-chargers allocation solution that optimises the chargers' assignment so that the route of collecting vehicles is the most optimal one and that each scooter is visited only once (Masoud et al., 2023). Other efforts in research include exploring the potentials of off-grid solar charging station for urban micromobility services for more sustainable energy supply.

Scooters powered by swappable batteries can be a game changer in urban shared mobility. They can slash operational CO2 emissions by up to 51% according to EY's Life Cycle Assessment tool done for Voi's service (EY, 2020). The saved carbon emission mainly comes from much less logistics trips as only need to change battery instead of transporting the vehicle back to charging stations. Company-wide company emissions of Dott, Tier and Voi were reduced up to 81% (Dott, 2021) compared to the non-swappable model. This also brings other benefits: less wear and tear in the charging transport so longer lifespan of scooters; smaller fleet sufficient for the same mobility demand as every scooter can serve more time on the street with swappable battery.

2.1.4 Conclusion

Micromobility services can help public transport system complete urban trips with flexible solutions and multiple vehicle choices. Dock-based micromobility scheme requires more infrastructure investments and support from the city, which also operates more stably and has a higher tendency to succeed, while free-floating micromobility schemes require less upfront investments but they ultimately require more operational efforts. There have been studies and practices aiming to lower the operational efforts in free-floating micromobility schemes.

Apart from all the above-discussed strategies and practices, other inspirations for a prosperous bike-sharing scheme can be referred to in Nikitas' work where evidence-based survival toolkit for policy-makers and mobility providers was developed aiming to explore a formula of success for bike sharing, as well as a detailed list of key recommendations can be of reference for more insights. Important lessons learned include the need for: tailoring the system design and expansion strategy according to the host city needs, city-operator and commercial partner synergies, more bike friendly infrastructure and legislation, pro-active cultural engagement, anti-abuse measures, enhanced fleet management and realistic profit expectations (Nikitas, 2019).

2.2 Carsharing

Carsharing is a modern transportation trend that offers a practical alternative to private car ownership. This model allows individuals to rent cars for short periods, often by the hour or day, making it an economical and flexible choice for those who don't need a vehicle full-time. Carsharing can potentially reduce the number of cars on the road, thus contributing to decreased traffic congestion and lower urban emissions. Carsharing services often include a variety of vehicles, from compact city cars to larger family vehicles, catering to a wide range of transportation needs while also introducing users to the potential benefits of electric and hybrid vehicles. The costs of carsharing are divided into two parts: membership fees, generally including insurance for the driver; billing for use, based on the duration of the trip and the mileage travelled. According to Shaheen et al. (2018) around 2000 metropolises benefit from at least one carsharing services. However, carsharing has not yet discovered a sustainable business model for long-term viability, resulting in a volatile and

competitive market with many new competitors. These newcomers introduce modified or hybrid business models to disrupt the market and seize market share from established giants (Lagadic et al., 2019).

There are some urban characteristics that are often related to carsharing system's financial success: parking pressure, high density, and mixed uses that carsharing uses can be for business during the day and residential during the night (Celsor and Millard-Ball, 2007; Nobis, 2006).

Lagadic et al. concluded five main types of carsharing services: Business-to-Consumer (B2C) Round-trip, where users pick up and return cars to the same reserved spot; B2C One-way station-based, allowing return to a different reserved spot; B2C One-way free floating, offering flexible pick-up and return anywhere within a service area; Peer-to-peer (P2P), where private car owners rent out their vehicles through a third-party platform, with access either in-person or via remote unlocking; and Business-to-business (B2B), where companies share a fleet, either owned by the firm or a third-party, for internal use. With the premise that business model innovation is crucial for carsharing lasting success, it was concluded that technological tool and user surface innovation is not sufficient for achieving long-term viability; it is necessary that the users get informed of the service and that the service fit users' daily mobility pattern and personal constraints. The case of Paris's Autolib' proves that growth in the number of users does not ensure profitability if the business model is not right, despite the high level of public subsidies (Lagadic et al., 2019).

For reference of carsharing services types, Golalikhani et al. reviewed academic literature and summarised six ways of classification of carsharing service types proposed by different authors. Based on a comprehensive literature review and recent business practices review of carsharing, their work presents a conceptual integrated decision-support framework for carsharing, including important decisions made by carsharing organizations and their users. The proposed framework offers valuable perspective for decision making in the design and implementation of carsharing systems, and revealed oversimplification issues in the literature such as fleet size and pricing schemes (Golalikhani et al., 2021).

Despite many advantages from the clients' perspective, one-way car-sharing had not been very successful due to a major problem related with vehicle stock imbalance issues (Correia & Antunes, 2012). To address this, the authors proposed from an optimization perspective 3 mixed-integer programming models with a depot location feature, varying according to the trip selection scheme. The authors considered three types of schemes, being: controlled service scheme, full-service scheme, conditional service scheme respectively. The first scheme assumes that the carsharing organisation has the full say of whether accept or not a client's request based on the profit-maximization objective; the second scheme assumes that all requests will be accepted and the third assumes that the organization only rejects request when there is no vehicle at the pick-up depot. The three models were applied to the city of Lisbon, where existed one-way carsharing problem. The study results show that the full-service scheme has the lowest profitability and efficiency, requiring more vehicles in the fleet than others. In the unconstrained scenario (when the number of depots is unconstrained and no minimum percentage of demand to satisfy), the first scheme would have a large number of small depots scattering around and the full-service scheme would have a less depots with depots being very big in the central city area, with much higher vehicle idleness rate than scheme 1. In a scenario where 100% demand is satisfied, even if the clients pay a high price rate, a city with trip imbalance situation like Lisbon would suffer from great financial losses, due to the idleness of the large fleet, which suggests that synergies between commuting trips and other trips are difficult to have. The study shows that depot location and trip selection criteria can have a big effect on the profitability of carsharing scheme; one key finding suggests that one-way carsharing system might succeed with a gradual development, as schemes consist of only a few depots in the central business district area that reject undesirable trips have values for return-on-investment indicators similar to schemes with larger networks (Correia & Antunes, 2012). The authors also suggested to look at the effects of a price policy adaptive to prop up or drop-down trips that balance or unbalance the system for higher operational profitability.

Taxi service is a bit different in this context. According to the definition of sequential shared mobility, there is a one-to-one handover of a shared vehicle from one rider to the next. In this context, taxi service can be counted as a sequentially shared vehicle that comes with a driver, and that the rider does not have to approach the vehicle but instead the vehicle approaches the rider. Taxi services offer scheduled and immediate transportation options for a fee, which is determined by agreed-upon rates, designated zone fares, or metered charges. Customers can arrange rides in advance through calls, websites, or mobile apps, hail a cab on the street by signalling a driver, or use designated taxi stands or loading areas. Additionally, e-hailing through a smartphone app can be used to request a taxi's service.

3 Simultaneous Shared Mobility

Simultaneous shared mobility refers to scenarios where multiple users coexist within the same vehicle during a shared trip, like in the PT services. This model is commonly seen in ride-sharing services, where passengers heading in similar directions share the same vehicle. It maximizes the utilization of the vehicle and promotes cost efficiency while challenges also arise with this flexibility referring to decision of the stop's location, routes, etc.

Broadly speaking, among the simultaneous shared mobility modes there is public transport above all, from which a lot of lessons can be learned. It is not included in this shared mobility literature review; however, it is important to integrate public transport with new and shared mobility. Ride-hailing also belongs to simultaneous shared mobility, but it is not addressed here as car-based modes is not the focus of the SUM project.

3.1 Ferry

Ferries are a form of water-based public transport that connect destinations across rivers, lakes, and coastal waters—often offering a scenic and efficient alternative to road travel. Unlike fixed-route land transport, ferries can flexibly navigate waterways, serving communities on islands or across wide rivers. Ranging from small passenger boats to large vehicle carriers, they provide practical commuting options while helping reduce road traffic and support environmental sustainability, particularly in coastal and riverine areas.

Autonomous ferries have seen significant research and real-world implementation in recent years. The Roboat project in Amsterdam has a goal of reducing the traffic on bridges and quays by introducing self-driving boats to transport people, waste, and goods. Small Roboat prototypes have already been developed and tested in 2017. The first large Roboat, featuring 2 by 4 meters is now being tested at the Marineterrein. The self-steering boat can determine the best route and avoid obstacles by estimating whether an object is moving in the water and what the distance to the object is (Hobus et al, 2023). Similarly, the Norwegian University of Science and Technology NTNU researchers have launched an autonomous ferry Milliampere 2 in the Trondheim fjord that provide services as easy to use as if “taking a lift” and “press a button to choose where to go” (Lønnum Andreassen, 2024).

Exploring ways digital technologies support sustainable waterborne passenger mobility ecosystem, Pirrone et al. (2023) examine five Northern European projects that were developed within the last five years—Watertaxi (Rotterdam), Zeam (Stockholm), Medstraum (Stavanger), Hyke (Fredrikstad), Capt'n (Kiel)—with a holistic perspective. In the Rotterdam case, the fleet is powered by renewable energy from solar and wind and the main station is equipped with 190 solar panels providing 50,000 kWh per year (Watertaxi Rotterdam - Snel Vervoer Naar 50 Locaties in Rotterdam En Schiedam, 2024). The system includes both scheduled ferry and on-demand water taxi services across 50 terminals, between which trips can be easily booked by the passengers supported by real-time suggestions. And the DyNaMo Databox (Flying Fish - Watertaxi

Operations System (WOS) in Rotterdam, 2022) supports efficient planning, emissions reduction, and predictive maintenance. Mainly charged by solar panels on rooftop, Zeam in Stockholm is launched in 2023 with an autonomous navigation system (Maritime Autonomy Software - Zeabuz, 2024) watched by an operator on board; developed at similar time, the autonomous Hyke ferry in Fredrikstad also innovated in the automatic wireless charging that reduce the weight of larger batteries and auto-mooring technology that enables stable experience even in bad weather. In terms of intermodality, the Stavanger case shows an example of a mobility hub providing multimodal services including bus, train, bicycle, car-sharing where the ferry is charged (Pirrone et al., 2023).

3.2 Microtransit

Microtransit is an emerging, flexible mode of public transportation that bridges the gap between traditional large-scale transit systems and private individual transport (Balsam & Verrill, 2023). Operating with smaller, on-demand vehicles such as shuttles or minibuses, micro-transit provides a more personalized and adaptable travel experience. Unlike fixed-route buses or trains, these services often use dynamic routing, where the vehicle's path can change based on passenger demand, which is particularly beneficial in sparsely populated areas or during off-peak hours.

Microtransit is proved to be a way towards access equity as it reaches predominantly vulnerable rider groups while rarely competes with traditional fixed-route PT (A.M. Liezenga et al., 2024). Micro-transit aims to make public transport more accessible and user-friendly, often integrating technology like mobile apps for easy booking and real-time tracking. This approach not only enhances the connectivity of existing public transport networks but also promotes a more inclusive transit system by reaching underserved communities and offering first-mile/last-mile solutions that connect commuters to major transit hubs. From the passenger's perspective, study shows that microtransit is perceived as substantially better than both car and PT for PT commuters and perceived as equally good as car for car commuters if the car parking is not guaranteed (Geržinič et al., 2025). This study concludes that the combination of higher parking fees and subsidising microtransit to be the most effective strategy for achieving a modal shift without affecting PT as much. For an ideal scenario for microtransit which is strongly context-based, key elements found include an active involvement and investment from authorities (Oviedo et al., 2023), considering community outreach, and managing the operation cost (Losada-Rojas et al., 2024).

3.3 Carpooling

Carpooling, a form of shared transportation where multiple individuals use one vehicle for their commute, offers an efficient and environmentally friendly alternative to single-occupancy car rides. By pooling resources, carpoolers reduce the number of vehicles on the road, leading to decreased traffic congestion, lower greenhouse gas emissions, and reduced demand for parking spaces. Carpooling also has the social benefits (Shaheen et al., 2024) of reduced vehicle miles travelled, reductions in adverse air pollution impacts on low-income and other environmental justice populations, and cost savings for public agencies and employers. This collective travel method serves different needs, from daily work commutes commonly, school runs, to one-off travel to events. With the rise of digital platforms and mobile applications dedicated to carpooling, finding, and organizing shared rides has become more accessible and convenient than ever.

According to Zafar et al. (2022), there are four types of carpool services: static carpooling, dynamic carpooling, peer-to-peer carpooling, and taxi carpooling. Among those types, static carpooling and taxi carpooling are practiced first. Each type has its benefits, for example, static carpooling solves the daily commute problem while dynamic carpooling and taxi carpooling meet on-demand needs. Scheduling is one of the most important and challenging aspects for both static carpooling and dynamic carpooling, for which Zafar et al. (2022) have summarized 15 scheduling techniques in carpooling with their limitations and possible solutions. Having been on a declining trend in the industrialised countries (Aguilera et al., 2021),

three key areas are highlighted for further research: understanding carpooling for non-work trips, exploring how digital tools are changing carpooling, and examining how new ways of working, consuming, and thinking about shared transport could affect carpooling in the short, medium, and long term.

With technological innovations and socio-economic forces that encourage pooled services, Shaheen et al. (2024) list ways how a variety of public and private stakeholders can support carpooling under those trends. Among those mapped stakeholders, “local and regional government” is the most relevant for SUM project, for whom key take-aways are: implementing parking reforms, including pricing, eliminating minimums, and offering commuter choice and parking cash-out programs; introducing road and curb pricing strategies, such as tolls, congestion fees; enforcing trip reduction ordinances through transportation demand management (TDM); investing in carpooling infrastructure and prioritize high-occupancy vehicles (HOV) with HOV lanes and park-and-ride facilities.

4 Combined Shared Mobility

Combined shared mobility is a term created in this review to define mobility services that include both sequential and simultaneous shared mobility modes as potential options within a comprehensive service offering, for example, multi-modal transportation solutions and Mobility as a Service (MaaS) platforms. In MaaS, which “aims to integrate multimodal transportation options into a single on-demand mobility service accessible via a single digital interface” (Alyavina et al., 2020), users have the flexibility to choose from a range of transportation options, including sequential shared mobility like micro-mobility and simultaneous shared mobility like public transport or ride-sharing, all within a unified platform.

CIVITAS suggested using public transport and shared mobility to reduce private car usage. Being the backbone of local mobility strategies, the public transport system provides an alternative to private car ownership, while cutting down on air pollution, road traffic-related injuries, and congestion (Collective Passenger Transport & Shared Mobility | CIVITAS). Along this scenario, shared mobility supports and complements public transport with its flexibility and adaptability to change. However, having public transport and shared mobility systems is only halfway to reaching the goal, to integrate these two types of systems that differ significantly concerning goals, operations, scales etc. is not easy. Exploring the integration of different modes in one journey, especially public transport, and shared mobility, is the main focus of this section.

4.1 Multi-modal travel and integration of modes

According to McIlroy, “almost any journey not taken by a private vehicle (or only walking) can be considered as multi-modal” (McIlroy, 2023). Multimodal trips are characterized using multiple modes of travel to reach a destination (Yanocha et al., 2021). A substantial amount of research has been conducted on the factors influencing the choice of transportation mode and the decision-making mechanisms involved. However, a big part of this only compares individual modes instead of considering multi-modal travel (Clauss & D’oppe, 2016).

Planning for multi-modal travel can be difficult. Urban and peri-urban dwellers particularly face the challenge of planning multi-modal trips given the variety of transport choices with different prices and varying risks of losing connectivity, as well as navigating the amenities provided at stations and stops.

There might not be any public or shared traffic mode that offers a more flexible and free experience than a private motor vehicle. Understanding the challenges of choosing a public or shared mode, especially the challenges when trying to combine those modes is the first step to creating a better multimodal travel

experience. This table below is adapted from the study of McIlroy who explored the primary challenges people face when going on a multi-modal journey, based on three types of locations where people live, respectively “urban”, “peri-urban”, and “rural”. The recommendations are within the context of aiming to move beyond the current car-focused mobility paradigm to one that combines sustainable, non-car services to fulfil transport needs. (McIlroy, 2023)

Table 3 Key findings and recommendations for non-car mobility transition, adapted from McIlroy (2023)

Key finding	Recommendation	Relevant theme	Most relevant group
Interacting issues of journey time, timetable coordination, and reliability represent major barriers to multi-modal travel.	At the strategic level, mandate timetable coordination between different transport service providers (Liu et al., 2021)	Timetable coordination and coverage; Critical reliability;	Peri-urban (Also urban and rural)
	Implement work policies to accept travel time on public transport as productive (Lyons et al., 2007)	Time	Peri-urban, (Also urban and rural)
The stacking of costs (of multiple services) is perceived as a major barrier when comparing to the perceived cost of car use.	Implement cross-service ticketing (i.e., unification) with price caps (including subsidy) (Horscher & Tirachini, 2021)	Ticketing	All
	Educational / information interventions focussing on revealing the true cost of car ownership (Gossling et al., 2022)	Ticketing	All
People are put off by the complexities of multi-modal journeys and the ticket combinations required.	Implement joint journey planning and ticketing systems (such as MaaS) to support planning and undertaking complex journeys (Hensher et al., 2021)	Route and time planning Ticketing	Urban, Periurban
Difficulties accessing public transport networks hinder non-car travel.	Improve active travel infrastructure connecting rural areas with public transport nodes (Han et al., 2022)	Safety and comfort to reach public transport	Rural
	Expand shared micromobility schemes (including ebikes and e-scooters) beyond the urban realm (Askarzadeh & Bridgelall, 2021)	Geographical network coordination and coverage	Rural
The combination of one controllable leg (i.e., private, on-demand, or share/hire systems) with one uncontrollable leg (e.g., traditional public transport) is highly preferred over combination of multiple uncontrollable legs*.	Ensure secure bike parking is implemented at all public transport network nodes (Heinen & Buehler, 2019)	Bike parking and theft	All
	Provide better on-service facilities for transporting bikes, including by bus (Pucher & Buehler, 2009)	Bikes on public transport	All
	Improve active travel infrastructure connections to public transport nodes (Aldred, 2019)	Safety and comfort to reach public transport	All
	Implement car share and dynamic demand responsive transport schemes to support flexible access to public transport networks in rural areas (Coutinho et al., 2020)	Geographical network coordination and coverage	Rural

4.1.1 Improve Reliability

From a place-based perspective, in terms of urban, peri-urban, and rural distinctions, the overall picture of major challenges for multi-modal travels are synchronizing timetables, and whether each leg (a part of the journey) of the travel is reliable (McIlroy, 2023). Currently the most reliable or controllable leg would be to travel with a privately-owned vehicle, followed by travelling with shared or hired vehicle, and lastly by public transport.

Strategically, to improve multi-modal travel, the paper suggests the need for better timetable coordination between different transport service providers, the implementation of joint journey planning and ticketing systems like Mobility as a Service (MaaS), and improving the active travel infrastructure, especially connecting rural areas with public transport nodes.

On the other hand, if the multi-modal travel consists of several uncontrollable travel legs (such as delayed buses and cancelled trains), the uncertainty of the travel increases. An inference is made that the mix of a controllable travel leg (like privately-owned vehicles) and uncontrollable travel leg can help to tackle challenges associated with timing, schedule synchronization, and service coverage, as well as crucial dependability and the uncertainty of waiting periods. These challenges are particularly relevant when combining various standard public transport modes, such as buses and trains. The paper also argues for expanding the availability of shared micromobility options, like e-scooters, or bike safety and infrastructure connectivity to have one controllable transport in the multi-modal, to help tackle this control issue as users much prefer to combine a reliable mode, for example a private or shared vehicle, with an uncontrollable mode such as the trains, rather than to combine two uncontrollable transport modes (McIlroy, 2023).

4.1.2 Micromobility Integration with PT

Public transport can provide a fallback choice that improves the reliability of shared mobility and reduces the barriers for adoption (Liao & Correia, 2022). Liao & Correia reviewed existing literature of electric shared mobility modes on their usage pattern and potential impacts, and concluded that all shared electric mobility modes are mostly used for short distance trips. As every shared electric mobility mode has its own specific use case, each mode also has its own inconveniences, which makes integration with public transport beneficial. The authors suggested a diverse set of shared mobility modes to be coordinated and integrated with public transport, to maximize the potential of non-private mobility to reduce car dependency.

Micromobility can yield benefits such as improved air quality and health outcomes, pollution reduction, last mile connectivity, and economic development (ITDP, 2021a). However, cities have adopted diverse regulatory measures in response to the swift uptake of private shared micromobility services in 2017 and 2018. Micromobility often occupies a legal grey area. Many cities have opted for stringent regulations without leveraging these regulations to advance wider urban transport, environmental, or social objectives, a stark contrast to city-managed bike share programs where cities own the infrastructure and collaborate with a private entity for operations, incentivizing them to integrate services with municipal goals.

Private micromobility operators typically work under temporary permits or pilots without city ownership, leading to less municipal investment in their success or integration with long-term city initiatives. Although micromobility has the potential to contribute to sustainable transportation, most regulatory frameworks have not fully promoted its incorporation into broader transport networks, often focusing on immediate operational challenges like managing public space and ensuring safety. As cities continue to establish usage and service quality standards, there is a growing need to progress beyond more operational regulation and to position micromobility as an affordable, efficient, and accessible transport option that complements other transportation modes.

In “Maximizing Micromobility”, the Institute for Transportation and Development Policy defines “multimodal integration” as the integration of physical infrastructure, payment, information, and/or institutional management across multiple modes to improve the multimodal journey’s user-experience. Four types of integration strategies are proposed: physical integration, payment and fare integration, informational integration and institutional integration. Common examples are (Yanocha et al., 2021):

- Physical integration - micromobility parking, protected micromobility lanes, bike repair kiosks, charging stations for devices etc. Special attention should be paid to the connection between those integrations and public transit services, for example, to locate bike repair kiosks at transit stations.
- Payment and fare integration - SMART/RFID cards for integrated payments, mobile payment apps, have one mode for free (such as bike share), fare based on time or distance instead of based on modes, “smart fare discount” activated when several modes are used together etc.
- Informational integration – way-finding signage, mobile apps and QR codes. London’s signage system includes cycling travel time to nearby transit stations to encourage more cycling
- Institutional integration – setting multi-municipal service areas, managing multi-modal with a single governmental entity etc.

4.2 Mobility Hub

Why the concept of a mobility hub? The ambition is: “to replace parking with packaging” by creating a travel offer that is perceived to be as easily accessible as owning your own car (Berglund-Snodgrass & Mukhtar-Landgren, 2023). On the other hand, by reducing private vehicle usage and giving equal priority to all mobility modes, including walking, cycling, and other active forms of transport, i.e. public transport, ridesharing, taxis and private motor vehicles, mobility hubs help to lessen greenhouse gas emissions (Aydin et al., 2022).

Hub can be understood as a “package” of different modes. The most frequent type of package is transit-oriented, including trains and buses for a longer journey. Other choices can be mainly two-wheeled micromobility vehicles like shared bikes and scooters, or involving shared cars and perhaps electric charging infrastructures in the package. Mobility hub usually means a physical integration of transport modes and services, for example co-locating. Nevertheless, it is also important to integrate physical infrastructures with digital solutions. Some “smart mobility hubs” incorporate platform-based solutions (Berglund-Snodgrass & Mukhtar-Landgren, 2023).

4.2.1 Hub Typologies

In the study of Roukouni et al., after systematically identifying and analyzing existing definitions and typologies of shared mobility hub from existing studies and reports, a shared mobility hub typology was suggested for the practitioners to know which type of hub is needed for every specific case, in response to the city’s needs, strategies and policies etc (Roukouni et al., 2023). The proposed new framework uses dimensions selected suitable for the European context, categorized in a more clear and logical way compared to existing typologies. The paper also applied the proposed hub typology classification to six shared mobility hub examples in Netherlands, Spain and Portugal and see how they fit each city context, allowing planners and policy makers to apply the proposed shared mobility typology based on their own context.

Table 4 Proposed shared mobility hub typology framework, adapted from Roukouni et al. (2023)

Hub Type / Urban Context	City Centre	Suburban	Emerging Urban Growth Centre	Historic Centre	Key (Standalone) Destination
Transportation function					
Origin/Destination	X	X	X	X	X
Transfer	X	X			
Mobility spatial scale					
Neighbourhood		X	X	X	
City	X		X	X	X
Region	X	X			X
Shared mobility services					
Mini		X	X	X	X
Light	X	X	X	X	X
Medium	X	X	X	X	X
Large	X	X			
Proximity to public transport					
Yes	X				X
No (not necessarily)		X	X	X	

There are five types of shared mobility hubs identified using five dimensions. Urban context is the only fixed dimension that also defines the hub type. The flexibility of the framework lies in that each type is a dynamic combination of the remaining four dimensions (transportation function, the mobility spatial scale, shared mobility services provided, proximity to public transport). For instance, a “historical center” hub can be “light”, “medium”, or “large” in terms of how many shared mobility services is offered, instead of being only one of them. It might start as “light”, and grow into “medium”, and change again due to operational issues.

4.2.2 Hub Location and Accommodated Modes

The location of mobility hubs is crucial for their success in attracting travellers and promoting the use of sustainable mobility options. In order to optimize the hub’s location and shared vehicle distribution and maximise citizens’ benefits, Xanthopoulos et al developed a multi-stage model for multi-modal travel that can measure the hub’s demand and optimize hub capacities. They applied this to the case of Amsterdam and found that a network of higher number of hubs, each with a smaller fleet of shared vehicles– provides more advantages than having a smaller number of hubs with larger fleets. This is due to the significant reduction in travel time when investments help achieve full coverage of the area by the network of hubs (Xanthopoulos et al., 2024), which might be of value for stakeholders considering the distribution of mobility hubs.

The study of Aydin et al. explores an integrated fuzzy multi-criteria decision-making methodology, combining interval type-2 fuzzy Analytic Hierarchy Process (AHP) and interval type-2 fuzzy Weighted Aggregated Sum Product Assessment (WASPAS), to identify the optimal location for a new mobility hub on the Anatolian side of Istanbul (Aydin et al., 2022). The most influential criteria for designing a mobility hub are: the accessibility to city centre, public interest, structural suitability, and demographic patterns. A major transit station, Kadıköy, was found to be the best location for designing a mobility hub to support shared-use mobility and public transport options, as it is not only the main connection point between the Asian and European sides of the city, but also because of its good access to public transit services and highways.

The focus of locating a hub extends beyond merely identifying locations in the city centre or outskirts, affluent or socioeconomically challenged areas. It also includes aspects of regulation and land ownership. In some instances, it may be necessary to navigate specific requirements between public land, which should be accessible for everyone (for example, according to the Swedish Plan and Building Act (PBL 2010:900), a public place may not be closed off to the public, and may only be temporarily leased for an individual activity, unlike neighborhood land). For individual business such as carpooling, existing street parking spaces cannot always be reserved, instead they are deployed in parking lots or parking areas. In Germany, a new law has been adopted by some states that enables the government to purchase carpool companies and hence park the pooled cars in public lands, like in the case of Dresden Mobipunkt or Switch points in Hamburg (Berglund-Snodgrass & Mukhtar-Landgren, 2023). This can be a good strategy to support shared mobility hub implementation with more permitted modes infrastructure in the package.

The strategy from Amsterdam to locate mobility hubs can inspire other cities. Aiming to be the first smart mobility city according to Gemeente Amsterdam Programma Smart Mobility 2019-2025, the transition from car ownership to the use of shared electric vehicles has been strongly encouraged and facilitated in the city's planning. Many mobility hubs are appearing on the streets with a hierarchy of positioning in terms of service scale. BuutHubs refer to the small-scale hubs serving the neighbourhoods; bigger hubs are placed close to public transit stops and mega hubs functions in the scale of city perimeter. Among those, as part of the Programma Smart Mobility 2019-2025, an existing gas station located in Stadionplein in Amsterdam Zuid will be transformed into a new mobility hub: "E-lympic Mobility Hub", which would be very sustainable concerning construction. By implementing a smart energy management system, optimum use of energy will be made of locally generated energy. This hub will provide fast charging for vehicles and rent out electric shared micromobility vehicles and cars, where electricity is generated, stored, and consumed most efficiently. There will also be supporting services like catering, retail and other services, and possibly logistics functions (Hobus et al., 2023). Upcoming plans to further include local residents in the design of the mobility hub will feature surveys and public meetings. The results are to be included in the design of the public procurement.

4.2.3 Hub Operating and Ownership

According to Berglund-Snodgrass (2023), the operation and ownership of mobility hubs can be categorized into three types of models. Firstly, there are those initiated and managed by public actors, typically situated in densely populated cities with well-developed public transport systems. These hubs often rely on a combination of funding sources, including EU, national, and municipal contributions. Each funding source may target different aspects of the hub, with varying innovation programs, time horizons, and objectives, possibly resulting in a challenge of reaching the same project goals. In the second model, hubs are born from collaborations between public and private entities, managed by companies jointly owned by both sectors, where municipalities or municipal companies join together with property owners and property developers and possibly other actors. These typically emerge alongside new, larger urban development areas within cities. The primary aim of these companies is to manifest the mobility visions of the area, fostering long-term collaboration among property developers and clarifying roles and responsibilities. The third model involves hubs initiated and managed by either non-profit associations/cooperatives or individual property developers and managers. These hubs are generally smaller in scale and scope, often linked to

specific residential buildings, for example, “car-free” residential areas, where individual property developers and managers offer a range of mobility services to residents, integrating them with their living spaces.

4.2.4 Hub Users

An alternative way to look at mobility hubs is by considering them as nodes for a shared parking service, such as those found in newly constructed parking facilities designed for shared bicycles and vehicles, exemplified by Hafencity in Hamburg. In instances where the use of the hub is restricted to the residents of the affiliated residential building, one can broaden the access by allowing non-residents to utilize the services for a fee, a practice implemented in AspernSeestadt in Vienna. In the Aspern-Seestadt project, station-based rental bike system with bikes and cargo bikes plus package delivery in a public place in a new urban development area that is being developed in accordance with the “15 minutes city principle” and short distances to public transport and services. The rental bike system is accessible through a card and is free for all residents in the area. Visitors can use the system for a small fee. In AspernSeestadt, 12,000 homes are planned. In 2022, approx. 10,000 people live and 4,000 work in the area (Aspern Die Seestadt Wiens).

4.2.5 Hub Actual Impacts

In a case study in the metropolitan region of Rotterdam and The Hague, solutions to maximize the impact of sustainable mobility strategies whilst reducing private car ownership, have been explored. The authors concluded that “based on the case study, we find that the introduction of mobility hubs alone has limited impact. However, combining this with making sharing services available to the public through MaaS subscriptions, there is a potential to reduce the number of car trips significantly, while the number of trips undertaken by a more sustainable (shared) e-bike increases as well as the number of so-called multi-modal mode trips.” (Zhou et al., 2023) Additionally, the paper suggests that enhancing public transportation services and expanding the network for micro-mobility can further improve the impact of mobility hubs in promoting sustainable transport options.

In order to better integrate operators and modes and relieve the cognitive effort in the inter-modal trip, mobility hubs provide a one-stop location that offers a wide range of mobility options (Liao & Correia, 2022). The authors suggested a future research avenue worth investigating, especially if the hub involves different shared electric modes, to measure how charging infrastructure as an added value of mobility hubs can influence traveller’s behaviour.

4.3 Mobility as a Service (MaaS)

There are many ways to define MaaS.” MaaS is a type of service that through a joint digital channel enables users to plan, book and pay for multiple types of mobility services (Smith & Hensher, 2020). Compared with MOD (mobility on demand), MaaS is mainly centered on aggregating passenger mobility and offering subscription-based services. A key feature that sets MaaS apart is its approach to broker travel with suppliers, repackage, and resell these services as bundled packages (Shaheen & Cohen, 2021). According to Lyons et al., “MaaS is an evolving phenomenon centred upon achieving increased operational, informational and transactional integration in order to provide a user experience of MaaS to rival that of the private car” (Lyons et al., 2020).

4.3.1 Barriers and Enablers

There have been several pilots and trials of MaaS in multiple locations, with early pilots in Sweden, Austria, and Germany (Hensher et al., 2020), more recent ones in Australia (Smith et al., 2023), and some commercial operations like Whim in Finland, the UK, and Japan (whimapp.com), or Jelbi in Germany (jelbi.de). However, the concept of MaaS has been seen to be more complicated to realise in practice than was initially acknowledged (Karlsson et al., 2020; Smith et al., 2019). Several barriers need to be overcome

first before a successful MaaS can be implemented. Karlsson et al. (2020) present a framework of barriers and enablers at the macro, meso, and micro levels.

At macro-level, the main barriers concern policy and legal support for MaaS solutions. Comparing experiences from Sweden and Finland, Karlsson et al. (2020) find issues in taxation laws, regulations defining public transport scope and mandate, and procurement mandates in Sweden, but a more supportive and united legislative landscape in Finland. To overcome macro-level barriers, political will and a strong vision shared between the government, the public authorities and the service providers are identified as key enablers to facilitate the development of both formal and informal structures and support.

At the meso-level, many of the identified barriers relate to the complexity of MaaS developments, and multi-actor processes, where no organisations exercise complete control (Hirschhorn et al., 2019; Meurs et al., 2020). One category of barriers here relates to how different actors perceive their roles and mandates in relation to MaaS (Karlsson et al., 2020), where MaaS can be seen to disrupt the current established mobility service system (Lyons et al., 2020), and where established public sector actors respond to the threat of disruption by attempting to maintain existing institutionalized ways of doing and prevailing logics (Hirschhorn et al., 2019).

The need to collaborate among multiple actors also gives rise to many barriers. For example, collaboration between public actors and private actors presents issues in relation to the macro-level legislative challenges surrounding procurement, innovation, and profit (Smith et al., 2019). Additionally, when united under one service and brand (the MaaS or intermediary brand) the collaboration between different mobility service providers can also be hindered by fears of losing customers, brand protectionism, and a reluctance to adopt new roles, responsibilities, and mandates within MaaS initiatives (Smith et al., 2019). Mobility providers fear being dominated by other actors and losing control over development (Karlsson et al., 2020).

To enable the effective operation of MaaS, this cooperation must be brokered, to overcome resistance and inertia (Lyons et al., 2020). To support the collaboration between partners, Meurs et al. (2020) identify alliance formation as a key process. They suggest that shared goals between partners are fundamental, as well as complementarity between the offerings of the different partners involved, along with several other facilitating factors such as trust and supporting public actions.

Alongside the collaboration barriers, there are further barriers identified by Butler et al. (2021) including lack of business support or low return on investment, problems with service coverage in low density areas without already established mobility providers, and finally barriers related to data. Various forms of personal, business, and open data and its integration into software platforms is central to the operation of MaaS, but also comes with challenges in relation to breached intellectual property, cyber-security and privacy concerns.

Finally **at the micro-level**, barriers have been identified in relation to user adoption, and attracting customers (Butler et al., 2021). Much research has been devoted to stated preference studies in relation to pricing and mobility bundling (which services to include and to what extent). Experiences from high-level MaaS pilots have shown that users have been generally satisfied with the service bundle. Nevertheless, the pilots have attracted early adopters who already have a multimodal behaviour (Smith et al., 2022). It appears important to understand the user mobility needs and the context of the current mobility service landscape to be able to tailor the included mobility services, see for example how Esztergár-Kiss and Kerényi (2020) tailor mobility bundles to different cities.

The development of the service content, beyond the app and the mobility plans, is also central. As many of the early adopters are multimodal travellers who are tired of juggling between several mobility apps simultaneously. This convenience-enhancing service content is one of the factors that makes MaaS competitive (Smith et al., 2023). Several studies have identified that the service content including support

and feedback features, onboarding processes, and the physical and practical manifestations of the service such as vehicle stations and unlocking procedures is as important, or even more appreciated than the mobility services themselves (Karlsson et al., 2016; Smith et al., 2022, 2023). Pilot setups of such service element have been seen to be labour-intensive, so resource-efficient ways of providing this functionality is necessary (Smith et al., 2023). Utilising service design methodologies to design the service is a fruitful way forward (Sarasini, et al. 2022).

Hensher et al. (2020) summarized the key institutional barriers that hinders MaaS development in Sweden in respectively macro, meso, micro levels, and categorized them as formal and informal barriers, to be in line with the “Institutionella Ramverk för Integrerade Mobilitetstjänster i framtidens Städer” - Institutional Frameworks for Integrated Mobility Services in future cities (IRIMS). Both institutionalised structures and practice-based elements were covered in order to bring institutional change. The analysis is summarized in Table 5.

Table 5 Key institutional barriers to MaaS developments in Sweden, adapted from Hensher et al. (2020).

	Formal barriers	Informal barriers
Macro-level i.e. the larger social scale and the state	B1. Laws, regulations and reforms that limit the perceived action spaces of public transport authorities B2. No explicit sectorial responsibility for national public transport developments B3. Taxation schemes that create lock-in effects for private car use	B4. Lack of shared understanding of vision and targets for MaaS
Meso-level i.e. the operational actors and the interactions between	B5. Lack of tools and processes for public-private collaboration B6. Separation of land-use and public transport planning B7. High levels of bureaucracy and political control within public transport authorities	B8. Low levels of trust and understanding across public and private sectors B9. Risk averseness amongst both public and private actors B10. Ambiguities regarding prioritisation and lack of innovation culture within public transport authorities
Micro-level i.e. the individuals as users and citizens	B11. Miss-matches between MaaS offering and perceived mobility needs/problems B12. Tedious on-boarding processes and complex systems to learn	B13. Current travel habits and vested interest, especially in private car use B14. Low awareness of current transport related costs, especially related to private car use

For barriers 4,6,8,9,10, it is suggested that a vision and a principal strategy for MaaS based on policy objectives should be established first so that tactical and operational activities can be aligned. For barriers 1,2, it is suggested to establish new public authorities with a sectorial responsibility for both transport generally and land-use planning within a given geographical area, to strengthen structural links between transport and land-use planning. To address barriers 3,13, the first step suggested is to scrap excessive subsidisation of car ownership and use. To address barriers 5,8, the advice is to implement more

collaborative models for public innovation to build trust and jointly create value across public and private sectors. For barrier 11, it is suggested that urban and sub-urban riders who are already capable and willing to adopt MaaS should be targeted first for MaaS solutions development.

5 To initiate or support Shared Mobility

5.1 Public Engagement

Goodman and Cheshire examined the changes in user profiles in the London bike-sharing scheme (LBSS) in its first three years of operation. The research shows that users from “highly deprived areas” accounted for 12% of the users in the third year compared to 6% at the beginning. This is attributed not just to the expansion of LBSS into some of London’s most deprived districts in 2012 but also to a consistent rise in usage by inhabitants from deprived areas within the original LBSS zones. However, circumstantial evidence points to the price increase in January 2013 potentially causing a disproportionate drop in casual-use trips among residents from poorer areas. The findings suggest that bike-sharing systems are utilized progressively by residents in financially disadvantaged areas when these systems are accessible within their neighborhoods, but only if the services remain affordable relative to other modes (Goodman & Cheshire, 2014).

P’tit Vélib is Paris’ bike-sharing programme for children. It exemplifies an inclusive approach to urban mobility by extending the successful Vélib bike-sharing scheme to children (P’tit Vélib, Paris’ Bike-sharing Programme for Children, 2015). It offers Parisians children with bicycles of various sizes: the model for 3–5-year-old children has two small wheels and two 12-inch wheels. For older children, there are two models with 16-inch or 20-inch wheels available. Strategically placed in green spaces and pedestrian areas, the program encourages outdoor family activities as well as ingrains sustainable travel habits in the next generation, making it a pioneering initiative in promoting inclusive and engaging urban mobility.

The pricing structure of French scheme Vélo’v encourages usage with affordable options. Users can opt for short-term tickets or long-term subscriptions with reasonable fees. The inclusion of partner cards and special rates for specific demographics, such as young adults and RSA (Revenu de solidarité active, “Active Solidarity Income”) beneficiaries, enhances accessibility for a diverse user base.

The New York Citi Bike scheme’s phase 3 expansion has already begun with new stations in East Williamsburg and Bushwick, alongside a \$300,000 grant program sponsored by Healthfirst to increase ridership in lower-income neighbourhoods. Additionally, a handcycle pilot is being launched to make the service more accessible to the disability community. Mayor de Blasio sees this as a step towards creating a fairer city, emphasizing that more communities will have access to this sustainable transportation. (Major Citi Bike Expansion Map Revealed!, 2021)

5.2 Improving Services and Maintenance

There have been studies exploring why some bike-sharing stations are more attractive and frequently used than others. In Nogal & Jiménez’s research, with a non-data-extensive methodology to unite all independent topics within existing literature, the attractiveness of a bike-sharing station is defined as the set of physical, environmental, and service-related features, among which subjective and objective features are differentiated to make the features more applicable (Nogal & Jiménez, 2020). Bike stations in Dublin were compared and assessed according to their relative value, relating to their neighboring stations, instead of absolute value. The application of this method to the local bike-sharing scheme, Dublinbikes, received good results. The bike station attractiveness method is suggested to be a tool for new bike-sharing scheme layout

refinement, regarding the distance between stations and attraction areas etc, and to be a diagnosing tool for improving existing bike-sharing scheme usage, for knowing which less-attractive station should be acted over. The best scenario is that all stations have similar attractiveness so that no station eclipses the others. With a lower cost, user satisfaction can be increased and the re-balancing budget can be decreased.

5.3 Complementarity between Shared Modes

Using detailed data on free-floating bike-sharing and e-scooter-sharing schemes from Seattle, Washington, it is found that micro-mobility vehicles tend to cluster in proximity to Seattle's rail transit stations. Based on this finding, further study during a new rail system expansion in Seattle proves the complementarity between public transportation and shared micro-mobility, as the use of micro-mobility vehicles surged notably within a five-minute walking distance from the new light rail station (Tyndall, 2022). This suggests that relating free-floating sharing with rail transit can be a promising strategy when integrating PT with NSM.

LocoMotion, is a neighbourhood vehicle sharing digital platform that includes micromobility sharing and carsharing in Montreal, which emerged as a transformative initiative. The platform makes it easy for people to reserve or borrow e-bike, bike trailer or cargo-bike within a few clicks, and it is for free. It also offers the option of renting a neighbor's car, or LocoMotion's zero-carbon vehicle, which is less expensive than the normal carsharing service. The project aims to facilitate neighborhood mobility, create ties and solidarity. It also allows users directly contributing to the code and functions and reporting bugs in the systems (Montréal, V. de., 2021).

Liao & Correia discussed about the research agenda of studying relations between different modes. Different shared modes are likely competitive instead of complementary to each other as all of them are used for short trips and share a similar user group. Examples can be that e-scooters replace free floating shared bikes use. Or that shared e-mobility modes replace trips by active mobility and public transport which is more sustainable and healthier. It is worth exploring further how traveller behaviour changes when more than one electric shared mode exist (Liao & Correia, 2022).

5.4 Political and Institutional Support

From a strict usage rate perspective, it is suggested by studies on bike-sharing "scheme success" to policymakers and scheme suppliers that citizens hope to see systems that deliver sustainability benefits being supported by the local authorities (Nikitas, 2019). The observed underuse of bike-sharing schemes, which challenges their profitability based solely on user fees, highlights the necessity for establishing strong partnerships links with city authorities and private industries which are willing to associate their brand with the bike-sharing scheme. Municipal backing may include infrastructure investments, bike friendly laws, and even direct funding, provided that the bike-sharing services align with public and local government expectations.

Studies also suggest the role of the government can be crucial for the success of a shared mobility scheme. In a study about e-carsharing scheme, VAMO, in Brazil, researchers found that the incentive policy is an important factor to decrease carbon emissions and increase public awareness of electric cars. The government as an institutional entrepreneur significantly stimulated the e-carsharing scheme in terms of carbon emissions and e-vehicle adoption, compared to the business-as-usual scenario (Luna et al., 2020).

The success of Hangzhou Public Bicycle sharing scheme depends greatly on institutional support at both the city level and national level. Hangzhou Public Bicycle Company has gradually become a typical system supplier, with products and services covering 21 provinces and cities in China, and sales reached 350 million yuan in 2014. In November 2015, Hangzhou Public Bicycle System Research and Development Company (Hangzhou Jintong Public Bicycle Science and Technology Co., Ltd.) was listed on the "New Third Board",

and has customized public bicycle system solutions for 292 cities nationwide. In November 2015, Hangzhou Jintong Public Bicycle Technology Co., Ltd. was listed on the "New Third Board", and has customized public bicycle system solutions for 292 cities across the country, allowing more cities to share the "Hangzhou Wisdom" of free bicycles. At the end of 2017, the company made a breakthrough across the country, exporting its services to Malaysia (Wu, 2019). At the main meeting of C40 Global Mayors Summit on October 10, 2019, Hangzhou Chen Weiqiang, vice mayor of Hangzhou, mentioned that Hangzhou Public Bicycle is the only public bicycle service project in the world that realizes public welfare services through government coordination and market-oriented operation, which not only realizes perfect unity of economic, social and ecological benefits, but also successfully replicates and extends the Hangzhou model to 292 cities in China, building a service system consisting of 2.5 million public bicycles with an annual rental volume of 3.5 billion passenger trips. The company also generates revenue through public bidding for advertising space on public bicycles and kiosks, as well as relying on bicycle service kiosks' services such as charging, beverage sales, stroller rental, courier storage etc and has achieved a break-even in its mode of operation (Ruan, 2022). Very detailed and innovative experience has been accumulated in the Hangzhou Public Bicycle system over its operation of 16 years, which can be very helpful for the LLs to reference.

5.5 Learning from Each Other

"When it comes to mobility innovations, some municipalities are ahead of the game. They have already wrestled with issues and found answers, so our idea is to foster the transfer of knowledge from one city to another." Said Anne-Charlotte Trapp, the FastTrack Project project officer at Eurocities. FastTrack is a CIVITAS project that work with 24 urban and peri-urban areas to accelerate the roll-out of their sustainable mobility innovations, by bring together local areas with experts and solution providers to surmount the obstacles to innovation deployment (FastTrack | State-of-The-Art Cases, 2022). An online tool was developed to help local areas learn from each other and speed up the implementations, featuring four cluster labels and four cross-cutting themes labelling each project. The cross-cutting themes include Sustainable & Clean Urban Logistics, Cycling in the Urban & Functional Urban Area, Integrated Multi-modal Mobility Solutions, Traffic & Demand Management. For the readers of this review the FastTrack tool from their website can be a very convenient and efficient way for valuable information about the most recent sustainable mobility projects.

The evolution of European urban mobility systems is intricately complicated, owing to the multitude of involved stakeholders, the extensive array of impediments to execution, and the swift pace of technological and societal advancements. Today's knowledge may become outdated by tomorrow's innovations. Therefore, we need a process of "learning by doing" with multi-stakeholder learning ecosystems that shares lessons learned about what works and what went wrong (Smart, Sustainable, Connected and Shared Mobility | CIVITAS).

6 Conclusions

The SUM project aims to transform urban mobility towards seamless and shared solutions integrated to public transport. The purpose of this deliverable is to present to the involved project partners, and specifically the LLs, with a state-of-the-art review of shared mobility to use as a starting point when deciding on what mobility solutions to implement and test, how to design these solutions, and how to avoid fall-downs.

This deliverable included studies of shared mobility to explore state-of-the-art trends, strategies, and practices in the literature that have succeeded or have a potential for development, with a scoping strategy. Shared mobility was categorized into three types, respectively sequential shared mobility, simultaneous

shared mobility, and combined shared mobility. Strategies and practices most relevant to the SUM project were demonstrated with suggestions for practitioners of supporting and maintaining shared mobility. When looking to successfully implement shared micro-mobility, it is important to consider the existing urban mobility context, actual public needs as well as the institutional support before choosing from different micro-mobility sharing scheme types. Challenges of the schemes are categorized according to the vehicle riding stages: “Accessing the vehicle”, “Riding the vehicle”, and “Returning the vehicle”, including key strategies to avoid fall-downs and solve operational problems, as well as examples of best practices for relevant strategies. This literature review highlights for example that dock-based sharing schemes need more infrastructural investments while dockless sharing schemes need good strategies for operational issues especially re-balancing issues.

Achieving long-term viability of carsharing schemes is not necessarily guaranteed by increased user amount and high public subsidies. A conceptual integrated decision-support framework proposed from studies might help the carsharing designing and implementation decision-making process. Depot location and trip selection criteria can be impactful on the profitability of carsharing scheme, and that one-way carsharing system might succeed with a gradual development.

To increase the user-experience of multimodal travel, effective strategies include increasing the reliability of each travel leg with different strategies and integration of multimodal travel, which can be the integration of physical infrastructure like mobility hub, payment and information services like ticketing and travel planning apps, and institutional management etc. A framework of mobility hub typologies according to urban contexts can be helpful for deciding what type of mobility hub to adapt to a certain context. To maximize the impact of a mobility hub, the location and the modes accommodated are crucial factors, which also depend on the expected service range.

To successfully establish MaaS, practitioners need to pay special attention to barriers at the micro, meso and macro levels. Suggestions to overcome these issues are provided in this literature. Besides these, the development of the service content beyond the app and the mobility plans, is also central.

More general take-aways to support shared mobility include encouraging public engagement, improving services and maintenance, spotting complementarity between modes, gaining political and institutional support, and learning from each other's experiences.

Despite the solutions and strategies provided in this review, one must be cautious about their replicability due to the complex nature and several constraints of each city. Cities consist of numerous physical or abstract systems that connect to, overlap with, and impact each other. Thus, cities as the “outer” environment where shared urban mobility operates and performs as an “artefact”, would experience system effects from local interventions. This means the evaluation of shared mobility solutions is a posteriori, as it is difficult to claim any perfect strategy has been the determinant of success within the sophisticated mechanisms of a functioning city. Hence it is important to bear in mind when applying above strategies that successful implementation come from careful localization and adaptation to the context.

7 References

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