A multidimensional mobility hub typology and inventory.

SmartHubs Deliverable D 2.1

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SUMMARY AND CONCLUSIONS

The concept of “mobility hub” builds upon earlier concepts used in the academic literature and planning practice focussing on physical transfers in the passenger transport domain (e.g. park and ride facilities, multi-modal transfer points) and freight logistics domain (e.g., urban and regional distribution centers). The main value added of the mobility hub concept is that it can help to provide an integrated planning approach, involving integrating between policy instruments involving different modes, infrastructure provision, management and pricing, transport and land use measures and other policy areas. A mobility hub can serves the following aspects: a) Provides efficient and seamless integration of sustainable transportation options, b) Focuses on improving user experience of different transportation options, c) Ensures safety and security for all travellers, d) Creates a sense of place through effective and meaningful placemaking strategies, e) Allows for flexibility to embrace technological innovations and foster resiliency, f) Addresses equity by considering accessibility to and availability of transportation options in different neighborhoods, and g) Creates opportunities to form effective partnerships.

This document is the first deliverable (D2.1) of SmartHubs WP2 “Review of the state of the practice”. This report has two main objectives. The first objective is to define mobility hubs and provide a literature review on the impact and practices of mobility hubs around the world from different viewpoints and create a framework for a multidimensional mobility hub topology. The second objective is to create an interactive open data platform that allows an easy “expert crowd” mapping of operational and planned mobility hubs.

There is a large variety in different operationalizations of mobility hub all fitting under concept of mobility hub. A common element in the definitions of mobility hubs is the presence of shared mobility services, e.g., shared bikes, shared scooters, and shared cars. Most definitions focus on the mobility and transfer components of hubs and include the presence of multiple modes and transfer between modes as requirements for mobility hubs. From these definitions we can derive the following definition of a mobility hub (minimal requirements): a *mobility hub is a physical location where different shared transport options are offered at permanent, dedicated and well-visible locations and public or collective transport is available at walking distance.*

The literature distinguish different integration aspects which influences the use and societal impact of mobility hubs. Firstly, the core idea of behind mobility hub concept is physical integration - the physical connection of multiple mobility modes including shared mobility, offering a physical location for users to switch between modes. Secondly, the mobility hub concept also relates to digital integration as a hub involves app-based forms of mobility. Digital integration describing how well information from various mobility offerings are integrated into a single digital platform. Thirdly, the literature identifies the need for mobility innovations to be inclusive and cater for the needs of a wide variety of different users. There is a rich literature on user and stakeholder participation processes in mobility planning and there are well established principles for inclusive design. Based on this literature, a multidimensional typology for mobility hubs has been developed, i.e. the SmartHubs integration ladder, based on three dimensions: the physical, digital and democratic integration dimensions. Each dimension has 5 levels. Furthermore, universal design principles are embedded in the SmartHubs physical, digital and democratic integration ladders as a common threshold to enhance broader usability, accessibility. Universal design, digital and democratic (participation) integration are typically missing in mobility hub concepts and definitions in the literature and planning practice.

The integration ladder enables the comparison of different hubs with different services, understanding potential effects, and aiding the integration of societal goals into mobility hub developments. The levels of the integration ladders help distinguish Smart Hubs from the pool of mobility hubs**.** A mobility hub should offer a minimum level of integration and has at least level 1 on physical integration, digital and/or democratic integration. We define a *Smart Mobility Hub* as a mobility hub which offers advanced levels of physical, digital and democratic integration (i.e. minimum level 2 on physical, digital and democratic integration). The higher up the physical, digital and democratic ladders, the “smarter” the mobility hub becomes. The hypothesis is that the “smarter” the mobility hub, the more user value is created, higher usage and user satisfaction levels are achieved and increased societal impacts can be expected (in terms of reduced car use and ownership levels, accessibility impacts, impact transport emissions, etc.). In other words, smart mobility hubs with high levels of integration are more likely to become a game changer game-changer towards inclusive sustainable urban mobility and accessibility.

There is very little research in the literature on the impacts of existing mobility hubs. Some studies on mobility hub networks in Germany showed, via user surveys, that after the introduction of the hubs networks, people became more aware of the sharing transport systems and after the introduction of mobility stations, both car-sharing and public transport use increases.

A web-based and interactive Open Data Platform (ODP) has been developed that makes a collection of datasets on mobility hubs (among other features) available for users and allows the visualisation of its components. The most important purpose of the ODP is to get a single point of access and overviews of the datasets to the consortium members, which have been and will be collected under common rules. The multidimensional mobility hub typology developed is used to classify existing mobility hubs in the SmartHubs living labs and elsewhere in Europe is made accessible in the open data platform (ODP) which allows an easy “expert crowd” mapping of the operational/planned mobility hubs. At the time of writing this deliverable, the Open Data Platform is under development. The platform has been made available to the researchers of the SmartHubs project and includes at the moment of writing this report (27.01.2022) already has 68 Hub descriptions, 10 of which are Case Studies in the SmartHubs Project. In the following years of the SmartHubs project (up to mid 2024), the set of mobility hub descriptions will be expanded.

1. INTRODUCTION

In many cities across Europe, attention for shared mobility and mobility hubs is growing among both policymakers and businesses. Many different forms of mobility hubs are being developed, ranging from small neighborhood hubs to large hubs at railway stations with hundreds of shared vehicles. Some hubs focus on passenger mobility only, whereas others also integrate urban logistics using cargo bikes and/or parcel storage and pickup facilities. Mobility hubs are a new emerging trend that could be a game-changer affecting urban mobility behavior and logistics choices and, in the longer-term, more strategic choices such as activity places and residential/location choices.

Previous research has addressed mobility hubs as multimodal interchanges of traditional transport modes (Monzon-de-Caceres and Ciommo, 2016) or consolidators of shared transport modes (mainly car sharing) (Liao and Correia, 2020). The emergence of new modes such as shared e-bikes, micro-mobility, autonomous shuttles, and the deployment of mobility as a service (MaaS), however, requires a comprehensive (re-)evaluation of the role of mobility hubs in the future mobility system. Most mobility hub implementations have been top-down and scientific evidence is missing for the advantages and disadvantages of a bottom-up co-creation approach (van Gils, 2019). To date, different guidances for the development of mobility hubs exist, including the ShareNorth Mobility Hubs guidance (CoMoUK, 2019) and the Los Angeles Department of Transport developed Mobility Hubs guide (LADOT, 2017). However, those guidances provide limited evidence of whether mobility hubs serve the needs of their target users. They also do not explore their impacts on sustainable urban mobility and accessibility.

The overall objective of the SmartHubs project is to assess whether a co-designed, user-centric development can enable mobility hubs to act as a game-changer towards inclusive sustainable urban mobility and accessibility (SmartHubs, 2021). The SmartHubs project is organized around six work packages: Project and data management and quality control (WP1), Review of the state of the practice (WP2), Development of co-creation and participatory planning tools (WP3), SmartHubs Living Labs (WP4), Impact Assessment (WP5) and Governance, policy guidelines and knowledge exchange (WP6).

This document is the first deliverable (D2.1) of SmartHubs WP2 “Review of the state of the practice”. This report has two main objectives. The first objective is to define mobility hubs and provide a literature review on the impact and practices of mobility hubs around the world from different viewpoints and create a framework for a multidimensional mobility hub topology. The second objective is to create an interactive open data platform that allows an easy “expert crowd” mapping of operational and planned mobility hubs.

The remainder of this report is structured as follows. Section 2 describes the literature review on definitions, categorizations, and typologies, users, and impacts of mobility hubs, and presents a multidimensional hub typology. Section 3 describes the development of the SmartHubs Open Data Platform to collect information on mobility hubs realised across Europe.

2. LITERATURE REVIEW: DEFINITION AND CATEGORISATION OF MOBILITY HUBS

2.1. Introduction

This chapter provides a literature review on the definitions, categorizations, and typologies of mobility hubs. The literature review is conducted to answer two main research questions:

1. How are mobility hubs defined and characterized, what are the dimensions to describe and categorize mobility hubs?
2. What are the goals, users, and impacts of mobility hubs as identified in the literature?

The review includes academic literature, grey literature, and planning documents available in English, German and Dutch language. To review academic literature, Science Direct and Scopus were used as main databases. We combined a literature review with expert knowledge on available literature from the SmartHubs partners. The review did not follow a systematic review process (Moher et al., 2009) as the term “mobility hub” is relatively new. Only 24 academic papers listed in Scopus have this term in the article title, abstract or keywords, and only 7 academic papers are listed in Science Direct. To add papers to the review, other keywords such as “intermodal hub” and “multimodal hub” and forward and backward snowball reviews were conducted on the papers found.

In total over 230 references were stored in an online library available for all SmartHubs project partners. The literature was categorised using the keywords and explanations as shown below on Table 2.1. These keywords were used to select literature for the different parts of the literature review: definitions (section 2.2), categorisations (section 2.3), physical, digital and social integration (section 2.4) and the users and impacts of mobility hubs (section 2.5). Finally, the chapter sums up the discussed information with a conclusion section (section 2.6).

Table 2-1 Literature search keywords

Keyword	Explanation
Definition	If the reference gives a definition for mobility hub
Categorization	If the reference describes a categorization or typology of mobility hubs
Physical integration	If the reference is on the topic of physical integration, like seamless mobility, public transport transfers or on multimodal/intermodal mobility
Digital integration	If the reference is on the topic of digital integration, like MaaS or other platform/digital services connected to mobility
Social integration	If the reference is on the topic of social integration, like co-creation, participatory planning
Use	If the reference contains information on users or usage of mobility hubs
Community	If the reference contains information on the community of mobility hubs, community-led initiatives for hubs or inclusion of specific groups.
Impact	If the reference contains information on the impact or performance of mobility hubs
Governance	If the reference contains information on governance or organization aspects of mobility hubs such as who initiates hubs, collaboration of stakeholders, the financial structure around hubs, business models for hubs and roles and responsibilities taken by stakeholders
Policies	If the reference contains information on policies or regulation for mobility hubs and which goals policy makers have with developing hubs or how mobility hubs are integrated in urban policy

2.2. Mobility Hub Definitions

The concept of “mobility hub” builds upon earlier concepts used in the academic literature and planning practice focussing on physical transfers in the passenger transport domain (e.g. park and ride facilities, multi-modal transfer points, transit oriented development) and freight logistics domain (e.g., urban and regional distribution centers) (see Witte et al., 2021). The mobility hub concept essentially addresses the general principles of integration in urban transport strategies as described by May et al. (2006). According to these authors, integration of policy instruments can occur in four broad ways: (1) integration between policy instruments involving different modes, (2) integration between policy instruments involving infrastructure provision, management, and pricing, (3) integration between transport and land use measures and (4) integration with other policy areas such as health and education. The main added value of the mobility hub concept is that it targets a transport planning approach integrating across these four dimensions.

In the academic literature and planning practice documents, a large diversification of what is understood under the term mobility hub (or mobility station, mobility point) leads to varied definitions in the literature. What they have in common however is the core idea behind mobility hubs which is the spatial connection of multiple mobility modes including shared mobility, offering a physical location for users to switch between modes. The concept also relates to digital integration of mobility offerings in Mobility-as-a-Service (MaaS) platforms. Mobility hubs, however, can vary in size, layout and orientation. The offer of services may also differ from place to place. Small hubs e.g. offer small carsharing vehicles and bikesharing. Larger hubs at railway stations, for example, provide access to public transport, a taxi stand, bike parking facilities and often offer a mix of shared mobility service types (shared bicycles, scooters, etc). Table 2.2 gives a (non-exhaustive) overview of definitions used in academic research and planning practice. Annex 1 provides a list of 29 definitions found in English, German and Dutch language documents.

Table 2-2 Examples of mobility hub definitions

Examples of definitions used in academic publications	
An intermodal hub can be defined as a place where transportation networks are organized to facilitate intermodality between different modes. Intermodal hubs should intrinsically have an urban dimension and be globally designed as "plug flows", being interfaces between transport networks and territory, being an element to create "urbanity". Intermodal hubs focus technical, social, urban, transport, service aspects and they play a multi-modal, multi-service, multioperator role.	Amoroso et al., 2012
Mobility hubs are agglomerations of transportation modes that concentrate emerging shared mobility services in well-defined locations, delivering several benefits to users.	Anderson et al., 2017
Multimodal mobility hubs, commonly known as 'Mobility Stations' in Germany, are multimodal transport nodes that facilitate intermodal transfers by providing different mobility options in close proximity. Public transport (PT) plays a central role usually in connection with an additional shared mobility service.	Miramontes et al., 2017
A point in the transport network where different mobility services are provided. Public transport stops are within walking distance (approx. 800 meters radius). Linking mobility chains.	Rehme et al., 2018
A location where shared mobility is concentrated. The shared mobility hub clusters different new and conventional mobility services at a physical location. Its functions, services, facilities, and infrastructure requirements depend on the local urban context, including the policy goals of the different stakeholders.	Coenegrachts et al., 2021
Examples of definitions used in the planning practice	
At multimodal nodes, the broadest possible spectrum of the city's mobility offer is made available in a spatially concentrated manner. Easy access to the various modes of transport should be made possible and transfers between the various modes of transport should be made easier. Multimodal nodes are also preferred locations for bike rental offers.	Fallast & Huber, 2015
Mobility Hubs provide a focal point in the transportation network that seamlessly integrates different modes of transportation, multi-modal supportive infrastructure, and place–making strategies to create activity centers that maximize first–mile last mile connectivity.	Department of City Planning Los Angeles, 2017
A mobility station is a physical place where different mobility offers and services are linked and easy access to them is granted. By bundling and networking several mobility offers, multimodality and intermodality are promoted and a mobility guarantee is created (even for those without a private car).	Zientek et al., 2018
A mobility hub is a recognisable place with an offer of different and connected transport modes supplemented with enhanced facilities and information features to both attract and benefit the traveller. A mobility hub is designed and is spatially organised in an optimal way to facilitate access	CoMoUK, 2019

to and transport between modes, including human-powered and shared modes, as well as provide extra transport-related and digital services.	
(author's own translation to English) A high quality physical location with a varied offer of sustainable and active transport modes, combined with pleasant places to stay. Travellers can choice options and can easily transfer modes. A hub is an attractive and recognisable place which is comfortable and safe. It is pleasant for users to stay and transfer, it is also pleasant for citizens and others. It is at walking distance towards a public transport stop (maximum distance to a public transport stop is 500 meter and to high quality public transport 1 kilometer).	Natuur & Milieu, 2020
A transport hub on neighbourhood level, where different sustainable and shared transport modes are linked with each other. Preferably, a mobility hub includes carsharing. Moblity hubs provide an easily accessible, visible and recognisable offer for end users. For policy makers, they offer a tool to enhance a shift towards sustainable transport and more efficient use of public space. Mobility hubs have essential elements (shared mode, bicycle parking, proximity to public/collective transport, easy access, branding) and optional elements (e.g., storage facilities, meeting point for neighbourhood activities).	Advier, 2021
Electric mobility hubs (e-hubs) are dedicated on-street locations, where citizens can choose from different sustainable electric transport options for shared use. eHUBS can vary in size (minimalistic, light, medium, large), type of location, and type of offer. They can be small and located in residential areas, with just one or two parking spots, or bigger and positioned close to stations and major public transport. The characteristics of the eHubs (modes offered) in some cities also depend on public participation processes.	ehubs (2021a)
(author's own translation to English) A hub is more than a transport node where people can transfer between modes. The emphasis is on experience: living climate, recognisability, information, time saving, positive surprise and integration with the environment. It is the ideal place to link several facilities together.Think of facilities for travelers only; such as a kiosk, water tap, WiFi or transfer point for the hub taxi.But also think of general facilities such as a health center, a community school or a shop.In short;a place where everything comes together. A hub can develop into a socio-economic hub of the village, district or region.	reisviahub.nl, 2021

A common element in the definitions of mobility hubs is the presence of shared mobility services, e.g., shared bikes, shared scooters, and shared cars. Most definitions focus on the mobility and transfer components of hubs and include the presence of multiple modes and transfer between modes as requirements for mobility hubs. From these definitions we can derive the following definition of a mobility hub (minimal requirements). **A mobility hub is a physical location where different shared transport options are offered at permanent, dedicated and well-visible locations and public or collective transport is available at walking distance.**

Table 2.3 shows essential and optional characteristics of mobility hub as mentioned in the literature: availability of or proximity to public transport, availability of shared mobility, availability of multiple modes, transfer between modes, non-mobility related facilities (e.g., lockers, activity centers), digital integration (e.g., digital pillar with services and ticketing, integration multimodal route planners, Mobility-as-a-Service platforms), physical and visual integration (e.g., recognisable place with signage and branding, integration in urban fabric) and social integration (e.g. co-creation, user involvement in service offerings). Aspects of visibility in public space and digital integration are also only considered in some of the definitions of mobility hubs. Simirarly, digital integration is described as an add on in the ShareNorth planning guide (CoMoUK, 2019).

Involvement of users or participatory planning receives little attention in mobility hub research and planning. Exceptions are the hub development strategy for a network of bus and train stations in the Provinces of Groningen and Drenthe in the Netherlands, where public and social services are to be integrated with mobility services (reisviahub.nl, 2021). And the Interreg eHUBS project, in which the municipality of Amsterdam is using a participatory planning process that enables citizens of the neighbourhoods to determine together with the municipality what the neighbourhood hub will look like and what the mobility offers will be (e.g., shared cars, electric cargo bikes, e-bikes, scooters) (eHUBS, 2021a).

The literature shows that although public transport and shared mobility are often part of mobility hubs, there is no agreement whether their integration is required for mobility hubs. Mobility hub definitions often, but not always, include public transport services or include proximity/walking distance to a public transport stop as an essential hub component. This implies that high quality public transport stops such as train, tram, metro, which in European cities often have shared mobility services in walking distance are defined as mobility hubs.

Beyond the presence of multiple forms of mobility, there is less agreement in mobility and non-mobility characteristics or elements which are considered essential for a hub (see Table 2.3). Additional mobility-related or non-mobility related facilities provided at mobility hubs or extra functions of mobility hubs are included in some definitions as essential elements (e.g. pillar or sign) whereas in others as optional elements (e.g., parcel storage, activity centers) (e.g., Department of City Planning Los Angeles, 2017; CoMoUK, 2019; Karbaumer and Metz, 2021). See Figure 2.1 as an example.

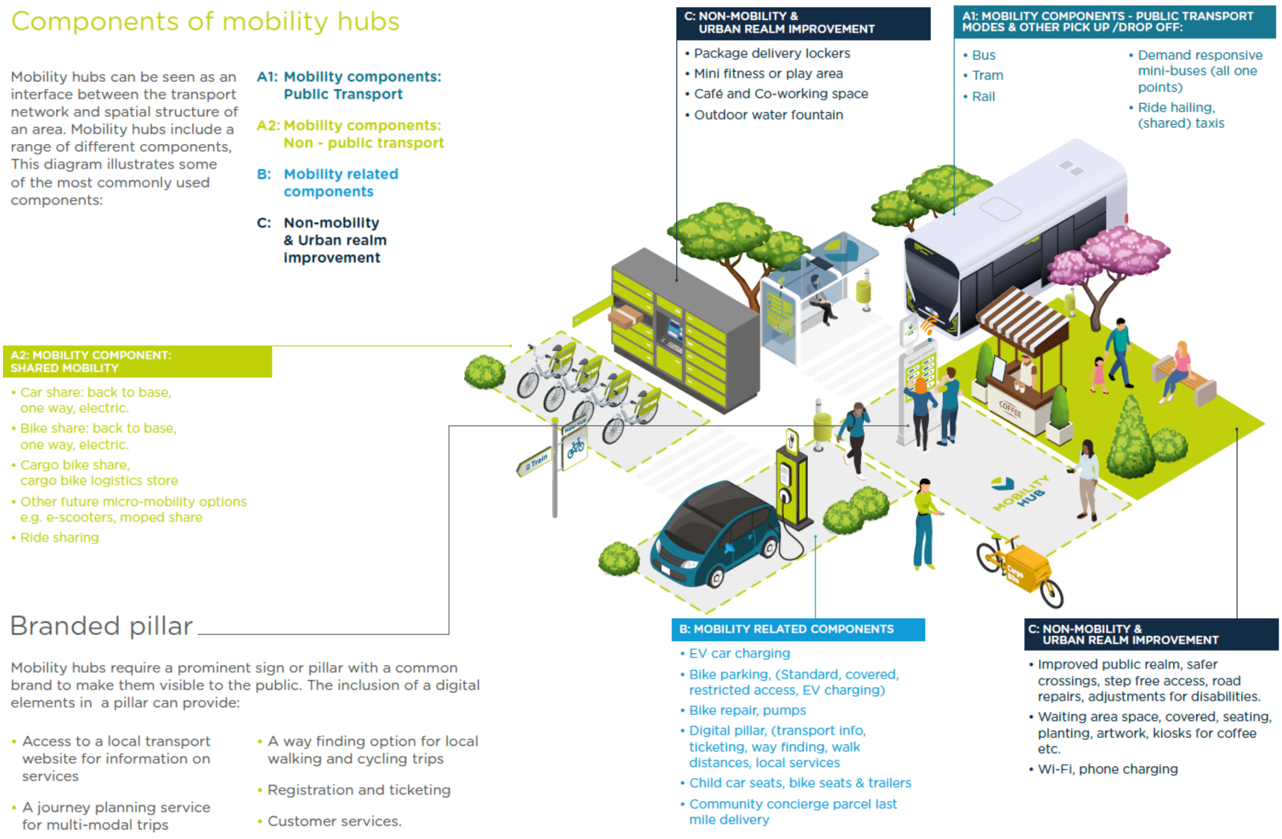


Figure 2-1 Components of mobility hubs (CoMoUK, 2019)

Table 2-3 Mobility hub characteristics used in the literature

	PT	Shared Mobility included	Multiple modes	Transfer between modes	Non-mobility related facilities	Digital integration	Physical/ visual integration	Democratic integration
Advier (2021)	(x)	x	x	x	(x)	(x)	x	-
Amoroso et al. (2012)	-	-	x	x	-	-	-	-
Anderson et al. (2017)	x	x	x	x	-	-	-	-
Coenegrachts et al. (2021)	-	x	x		-	-	-	-
CoMoUK (2019)	(x)	x	x	x	x	x	x	-
Crow (2021)	-	-	x	x	x	-	-	-
DELVA et al. (2019)	-	-	x		(x)	-	-	-
Department of City Planning Los Angeles (2017)	x	-	x	x	-	-	-	-
eHUBS (2021a)	-	x	x	-	x	-	-	(x)
Garde et al. (2014)	x	-	x	x	-	-	x	-
Gemeente Utrecht (2021)	-	x	x		-	-	-	-
Gemeente Utrecht et al. (2021)	-	x	x	x	x	-	-	-
Goudappel et al. (2021)	-		x	x	(x)	-	-	-
Fallast & Huber, 2015	-	-	x	x	-	-	-	-
IGES Institut (2021)	x	x	x		-	-	x	-
Jansen et al. (2015)	x	-	x	x	-	x	-	-
KiM (Witte et al., 2021)	-	-	x	x	x	-	-	-
Metrolinx (2011)	x		-	x	-	-	x	-
Miramontes et al. (2018)	x	x	x	x	-	x	-	-
Mobiliteitsalliantie (2020)	-	-	-	x	-	-	x	-
Natuur & Milieu (2020)	(x)		x	x	x	-	x	-
Navrátilová et al. (2021)	x	(x)	x	x	-	-	x	-
Rehme et al. (2018)	-	-	x	x	-	-	-	-
Reisviahub.nl (2021)	(x)	(x)	x	x	x	-	-	x
Rube et al. (2020)	-/x	x	x	x	-	-	x	-
Schemel et al. (2020)	-	-	x	x	-	-	-	-
van Gils (2019) (eHUBs)	(x)	x	x	x	-	-	-	-
Zientek et al., 2018	-	-	x	x	-	-	-	-
Zukunftsnetz Mobilität NRW(2017)	-	-	x	x	-	-	x	-

x= explicitly mentioned in the definition/essential elements; (x)PT: walking distance to PT; other characteristics: optional element; (-/x) score depends on the type of hub

2.3 Mobility Hub categorisations and typologies

This section identifies relevant characteristics of hubs that are used in the academic and planning practice literature, including policy documents and grey literature. There is a large variety in the service offer of mobility hubs. However, mobility hubs are typically categorized by their location or area characteristics, by size and by the functions they try to fulfill. In some cases, another differentiation is done on the higher level between transportation of goods and person transportation. An example of a visualisation of the categorisation of mobility hubs based on location and function is from VenhoevenCS (2020) (see figure 2.2), in which (passenger) mobility hubs are categorised based on their geographical location within the built-up area (urban/ suburban/ at a motorway corridor) and their function within the transport network (local/regional). Other studies add interregional connections (Van Gils, 2019) or (inter)national connections such as airports or high-speed train networks (Witte et al., 2021), or add specific functions such as tourism hubs (CoMoUK, 2019) or business park hubs (Provincie Gelderland, 2020). Some studies also offer typologies for freight transport hubs (Witte et al., 2021).

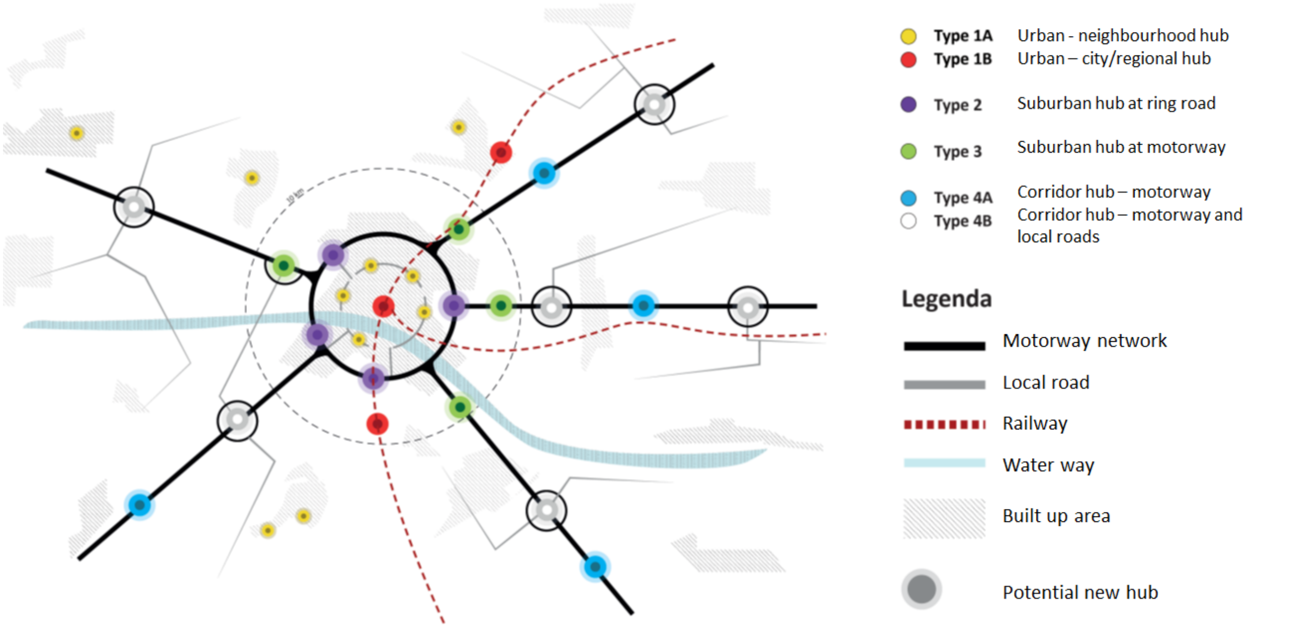


Figure 2-2 A categorization of mobility hubs based on location and function (VenhoevenCS, 2020)

Apart from the categorization, the different types are often described furthermore on the transport modes available at the hubs, the physical and design characteristics, and the level of integration.

It should be mentioned that although only a few academic publications exist on the categorization of mobility hubs, in practice-oriented reports categorization seems more relevant and is described more often, also to give guidance on the development of new hubs. Table 2.4 shows the mobility hubs typologies found in the literature.

Table 2-4 Existing mobility hubs typologies

		Characteristics			
Reference	Typology	Location / area	Size	Person / Goods	Functions
Academic literature categorisations					
(Bell, 2019)	Urban center of cities; Suburban mobility hubs; Regional center hubs; Public transport gateway hubs	x	x		
(Coenegrachts et al., 2021)	First-/Last-mile HUB network; clustered shared (e-)mobility network, POI HUB network, Hybrid HUB network, Closed HUB network				x
(Garde et al., 2014)	Mobilstationen Size S, M, L differing on number of vehicles/lines per mode		x		
(IGES Institut, 2021)	Zentral-Hub ; Transit-Hub ; Peripherie-Hub ; Dezentral-Hub Quartiers-Hub	x			x
(Jansen et al., 2015)	Mobilstationen Size S, M, L differing on number of vehicles/lines per mode		x		
Categorisations in planning/policy documents					
(Arcadis et al., 2019)	Parking hub, sharing hub, street hub				x
(CoMoUK, 2019)	Large interchanges / City hubs; Transport corridor, smaller interchanges / Linking hubs; Business park/new housing development hubs; Suburbs / Mini hubs ; Small market town, village hubs; Tourism hubs	x			x
(Crow, 2021)	Regional/city/city district/neighbourhood hub	x	x		
(Department of City Planning Los Angeles; 2017)	Neighbourhood Mobility Hub; Central Mobility Hub Regional Mobility Hub	x			
(Goudappel et al., 2021)	Urban hub, city hub, motorway hub, urban fringe hub, regional hub, local hub	x			x
(Hoekstra et al., 2020)	Type 1 urban / neighbourhood hub; Type 1B urban | City/regional hub; Type 2 suburban/motorway Type 3 suburban | Type 4A corridor |major road; Type 4B corridor | minor road	x	x		x
(Metrolinx, 2011)	Central City Hub; Urban Transit Node; Emerging Urban Growth Centres; Historic Suburban Town Centres; Suburban Transit Nodes; Unique Destinations	x			x
(Mobiliteitsalliantie, 2020)	Freight: regional/city/local hub Passenger: Regional/Transfer/City Centre/Business/residential/combined Hubs/ national Hubs	x	x	x	x
(Natuur & Milieu, 2020)	parking hub, neighbourhood hub, street/minihub, central PT hub, business park hub	x			x
(Provincie Gelderland et al., 2020)	Urban hub, suburban hub, regional hub, rural hub, neighbourhood hub, business park hub	x	x	x	
(van Gils, 2019)	Interregional/regional/Local/neighbourhood connections	x			
(Witte et al., 2021)	Passenger hub: neighbourhood hub, district hub, regional/rural hub, suburban hub, urban fringe hub, corridor hub, city hub, (inter)national hub. Freight: city/regional/(inter)national distribution center	x	x	x	x

Based on the typologies described in Table 2-4, we will use the following location and functional typology for a passenger mobility hubs in the Open Data Platform (see section 3):

- central urban hub - a large hub in the city center, e.g. railway station
- urban neighbourhood hub – small (a couple of shared vehicles)

- urban neighbourhood hub – large (a substantial number of shared vehicles)
- suburban / urban fringe hub - a hub at a motorway and/or railway near a city
- rural hub - a hub in a rural area
- (inter)national hub – airport
- Other, e.g. business park hub

2.4 Literature on mobility hub integration principles

As noted in section 2.2., the mobility hub concept essentially addresses the general principles of integration in urban transport strategies. The literature distinguish different integration aspects which influences the uptake and societal impact of mobility hubs. Firstly, the core idea of behind mobility hub concept is physical integration - the physical connection of multiple mobility modes including shared mobility, offering a physical location for users to switch between modes. Secondly, the mobility hub concept also relates to digital integration as a hub involves app-based forms of mobility. Digital integration describing how well information from various mobility offerings are integrated into a single digital platform. Thirdly, the literature identifies the need for mobility innovations to be inclusive and cater for the needs of a wide variety of different users. There is a rich literature on user and stakeholder participation processes in mobility planning and there are well established principles for inclusive design.

The following subsections provide an overview of the literature on the inclusive design principles (section 2.4.2), the physical (section 2.4.3), digital (section 2.4.4) and democratic integration (section 2.4.4). The inclusive design principles are considered across all three dimensions (physical, digital and democratic). We incorporate these dimensions to develop a *SmartHubs Integration ladder*, which will be presented on Section 2.4.5.

The SmartHubs integration ladder enable the comparison of different hubs with different services, understanding potential effects, and aiding the integration of societal goals into mobility hub developments.

2.4.1 Inclusive design of mobility hubs

The accessibility and inclusiveness of mobility hubs is a central concern of SmartHubs and especially in the context of vulnerable persons (e.g. older persons, people with reduced mobility, vision or cognitive abilities, people having no access to the internet, persons with low income, women, ethnic minorities, caregivers, children, foreigners), who might experience barriers to using mobility hubs. Thus, the physical elements of the hub (infrastructure such as stops, stations, waiting areas, shops or parcel lockers), the digital navigation and information features (such as online and traditional information boards and screens, wayfinding, booking, payment and ticketing systems) as well as the different services that are offered at the hub (transport services, retail, etc.) should be as accessible and usable as possible by all citizens.

Design of mobility hubs that are accessible for all

The individual attributes affecting a person's ability to move, as well as age or other physical characteristics is highly suggested to be taken into account when designing the mobility center to ensure proper integration. The design must meet the applicable accessibility codes (CoMoUK, 2020; Urban Design Studio, 2016; Aono, 2019; Chidambara, 2019; Nielsen, 2005; Indrakesuma, 2018; Conticelli et al., 2020; Borger et al. 1992.; Mather, 1983). Although it is sometimes not included in the codes, Urban Design Studio (2016) states the importance of designing spaces, such as waiting areas, to satisfy the needs of older users (a relevant social group when talking about accessibility for all).

Among the most frequently mentioned examples of features that must be accessible for all, are barrier-free designs for the mobility hub itself and pedestrian network (Schemel et al., 2020, Wright and Hook, 2007, Hasan and Al-Khafaji, 2020, and Nielsen, 2005). In this regard, Contilcelli et al. (2020) listed specific relevant elements for creating an accessible environment; this includes "boarding equipment, ramps, escalators, staircase aids for bikes, wheelchairs, strollers, etc.". Additionally, Aono (2019) also considers elements such as wheelchair access, the provision of tactile information, walking surface guidance, and priority shelter areas. Wright and Hook (2007), who also agree on the importance of incorporating those elements, consider ramps, escalators, and elevators as further critical components. Similar is the case of Conticelli et al. (2020), who recommend having assistance personnel during the operation of the mobility hub to help users who may encounter difficulties and, thus, complement the previously mentioned elements. The integration of such elements should be extended into the adjacent areas of the hub. Chidambara (2019) considers it a relevant aspect when addressing the accessibility and walkability of the first and last mile sections. Table 2.12 summarizes the main recommendations to plan hubs accessible to all in terms of the physical elements.

Table 2-5 Main recommendation to make hubs physically accessible to all

Integration	Mobility Hubs																		Public transport					Seamless /Multimodal/ Intermodal					Bike & Ride	Park & Ride	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
Accessibility for all segments of the population	x		x		x										x		x			x			x		x			x		x	x
Barrier free, universal gates and tactile information and guides					x							x	x							x	x		x		x		x	x			
Waiting areas (sheltered)		x	x				x			x	x	x						x	x			x		x	x			x			x
Gentle ramps, escalators, and elevators																			x				x		x			x			
Assistance staff (to help users)																												x			

A:(CoMoUK, 2019), B:(Schelling, 2021), C:(Studio, 2016), D: Mobility hubs (Shared-Use Mobility Center, 2019), E:(Aono, 2019), F: (Pfertner, 2017), G: (Miramontes, 2018), H: (Silva & Uhlmann, 2021), I: (Coenegrachts et al., 2021), J: (Cui, 2021), K: (Metrolinx, 2011), L: (Monzon-de-Caceres & Ciommo, 2016), M: (Schemel et al., 2020), N : (Mouw, 2020), O: (Frank et al., 2021), P: (Petrović et al., 2019), Q: (Anderson et al., 2017), R: (Blad, 2021), S: (Wright & Hook, 2007), T: (Chidambara, 2019), U: (Miller, 2004), V: (Nag et al., 2019), W: (Nielsen et al., 2005), X: (Preston, 2012), Y: (Indrakesuma, 2018), Z: (Luo et al., 2021), AA: (Hasan & Al-Khafaji, 2021), AB: (Conticelli et al., 2021), AC: (Tavassoli & Tamannaei, 2020), AD: (Bolger et al., 1992), AE: (Mather, 1983).

Apart from physical accessibility, digital accessibility is becoming more and more important as mobility services increasingly rely on digital interfaces for the planning, booking, payment of services as well as information provision (see section 2.4.3). Digital mobility solutions assume that an interaction takes place between the user and a digital interface (smartphone, screen, computer, electronic display). While these services are becoming increasingly widespread, certain socio-economic (income, place of residence, education, ability to use technology), demographic (age, gender), and functional barriers (limited sight, hearing, movement or cognitive capabilities) may prevent people from using digital interfaces and services in general (Lucas et al., 2016.) Often, a combination of these dimensions is present within one person, making it more difficult to create a solution that fits all. As digital technologies are progressively becoming indispensable to navigate the world of transport services, low levels of digital engagement may create a new layer of transport disadvantage, possibly on top of existing ones (Durand et al., 2021a). Therefore, besides designing physically accessible mobility hubs, it is essential that digital accessibility is also considered.

In SmartHubs, therefore, we distinguish between three levels of accessibility and inclusion at the level of the physical design of hubs and digital accessibility of hub services:

- Level 0: No consideration of the needs of vulnerable users.
- Level 1: The minimum legal requirements are considered to make the infrastructure, the services and the digital interface accessible to persons with physical or mental impairments. These legal requirements differ from country to country. At the European level, the European Accessibility Act (EAA), which came into force in 2019, has set new EU-wide minimum accessibility standards for a range of products and services including computers and operating systems, ticketing and check-in machines, services related to air, bus, rail and waterborne passenger transport as well as e-commerce, among others (European Commission, 2019). The EAA has established the fundamental accessibility requirements and clear-cut obligations for operators and manufacturers with regards to creating accessible products and services. All EU member states will have to create new national legislation or adapt existing legislation that considers this directive. EU countries must apply the directive from 28 June 2025.
- Level 2: The principles of **universal design** are considered to make the hub accessible to the general population as well as vulnerable users with physical and mental impairments or social or economic vulnerabilities.

Universal design goes one step further than complying with current and upcoming legal requirements as access should be provided to everyone without requiring specific groups to use specially adapted infrastructure or services (e.g. all bus stops should be accessible to all visitors rather than providing special assistance for people with disabilities that needs to be requested in advance). Universal design refers to the creation of products, environments or interfaces that can be easily used by all people, to the greatest possible number, considering the diverse range of needs and avoiding adaptation. Furthermore, to achieve universal design and integrate the needs of all users, it is necessary to adopt a user-centred perspective in the conception and maintenance of mobility hubs.

The application of "universal design" is facilitated through seven principles that must be considered throughout the design process (Story, 2001) (see Table 2-13).

Table 2-6 The principles of Universal Design, Version 2.0 (reproduced from Connell et al., 1997 in Story, 2001)

<u>Principle 1: Equitable use</u> The design is useful and marketable to people with diverse abilities. Guidelines: 1a. Provide the same means of use for all users: identical whenever possible; equivalent when not. 1b. Avoid segregating or stigmatizing any users. 1c. Make provisions for privacy, security, and safety equally available to all users. 1d. Make the design appealing to all users.
<u>Principle 2: Flexibility in use</u> The design accommodates a wide range of individual preferences and abilities. Guidelines: 2a. Provide choice in methods of use. 2b. Accommodate right- or left-handed access and use. 2c. Facilitate the user's accuracy and precision. 2d. Provide adaptability to the user's pace.
<u>Principle 3: Simple and Intuitive use</u> Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. Guidelines: 3a. Eliminate unnecessary complexity. 3b. Be consistent with user expectations and intuitions. 3c. Accommodate a wide range of literacy and language skills. 3d. Arrange information consistent with its importance. 3e. Provide effective prompting and feedback during and after task completion.
<u>Principle 4: Perceptible information</u> The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities. Guidelines: 4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information. 4b. Maximize "legibility" of essential information. 4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions. 4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.
<u>Principle 5: Tolerance for error</u> The design minimizes hazards and the adverse consequences of accidental or unintended actions. Guidelines: 5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded. 5b. Provide warnings of hazards and errors. 5c. Provide fail-safe features. 5d. Discourage unconscious action in tasks that require vigilance.
<u>Principle 6: Low physical effort</u> The design can be used efficiently and comfortably and with a minimum of fatigue. Guidelines: 6a. Allow used to maintain a neutral body position. 6b. Use reasonable operating forces.
<u>Principle 7: Size and space for approach and use</u> Appropriate size and space are provided for approach, read, manipulation, and use, regardless of user's body size, posture, or mobility. Guidelines: 7a. Provide a clear line of sight to important elements for any seated or standing user. 7b. Make reach to all components comfortable for any seated or standing user. 7c. Accommodate variations in hand and grip size. 7d. Provide adequate space for the use of assistive devices or personal assistance.

In the context of the mobility hubs, the universal design principles can be understood in the following way:

- Universal design principle 1 - Equitable use
  - The design of the hubs is equally useful for people with diverse abilities.
- Universal design principle 2 - Flexibility in use
  - The design of the hubs accommodates a wide range of individual preferences and abilities.
- Universal design principle 3 - Simple and Intuitive Use
  - The use of the physical and digital elements of the hub is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
- Universal design principle 4 - Perceptible Information
  - The design of the different elements of the hub communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
- Universal design principle 5 - Tolerance for Error
  - The design of the physical and digital elements of the hub minimizes hazards and the adverse consequences of accidental or unintended actions.
- Universal design principle 6 - Low Physical Effort
  - The different elements of the hub can be reached and used efficiently and comfortably and with a minimum of fatigue.
- Universal design principle 7 - Size and Space for Approach and Use
  - Appropriate size and space are provided for approach, manipulation, and use of the different physical and digital elements of the hub, regardless of the body size of users or their mobility.

These seven universal design principles are embedded in the SmartHubs physical, digital and democratic integration ladders as a common threshold to enhance broader usability, accessibility, starting at level 2.

- Level 0 does not entail the application of any principle or other accessibility considerations
- Level 1 involves the minimum accessibility criteria that are legally required.
- Levels 2,3 and 4 consider the universal design principles

In order to facilitate the principle of universal design in the planning and design process of smart mobility hubs, it is pivotal that the needs and skills of the vulnerable groups are known before or discovered during the development process, so these needs and skills can be taken into account (Kedmi-Sahar et al., 2020). Two questions need answering to bridge the gap between the skills required to access a mobility hub and the skills vulnerable groups currently have. First, which groups in society currently have issues accessing smart mobility hubs and how can we reach them? Second, what barriers do these groups experience and what skills do they have? (Tyler et al., 2007).

2.4.2 Physical integration

Based on the previous definition of mobility hubs, the question is now how to physically integrate different transport modes (at least in vicinity of each other) in one dedicated location, including at least one shared mobility option (e.g., shared (e-)bike, cargo-bike, e-scooter, carsharing) and one public transport opportunity? Therefore, this chapter examines key aspects for physical integration of mobility services in mobility hubs. As smart mobility hubs are a relatively new concept, precursors of mobility hubs such as public transport stations with interchange facilities, parking spaces for shared mobility vehicles in the immediate vicinity of a public transport facility and also Park&Ride and Bike&Ride facilities may serve as examples of the spatial connection of several mobility modes (multimodal and intermodal).

One of the purposes of mobility hubs is to provide a seamless transition between different modes of transport (Metrolinx, 2011). This is only possible with proper physical integration of the essential elements of each transport mode. The aspects to be detailed in the upcoming paragraphs are some recommendations from different pertinent sources to efficiently integrate the mobility hubs and all their elements into the built environment.

Five main characteristics are identified in the literature for physically integrating mobility hubs:

1. Search for potential locations of mobility hubs.
2. Placement different modes of transport in the vicinity of each other.
3. Design of mobility hubs that are accessible for all.
4. Design of mobility hubs that are clearly visible with information and common logos.
5. Design of mobility hubs as a placemaker.

Built environment considerations when searching for potential locations of mobility hubs

From a spatial perspective, there are characteristics and elements from the built environment that should be taken into account when determining the location and physical integration of mobility centers. Most of the included elements are related to land use, activities, demographics, and the current public transport and cycling infrastructure (see Table 2.6).

Although several of the sources consulted explain that density considerations depend on the specific functionality, type, and scale of the desired mobility center (e.g., Aono, 2018; Blad, 2021) in general, it is recommended that the location has a sufficient density of potential users. As pointed out in the CoMoUK guideline (2019), potential users' density can be related to residential densities, businesses, or to areas where the number of passengers is high. Therefore, both the population density, as well as the density and diversity of the land-use (mixed-use development) could influence the function and coverage of the multi-modal hub (Nielsen et al., 2005; Urban Design Studio, 2016; Metrolinx, 2011).

The proximity of the mobility hub to essential services, such as education facilities and hospitals (Anderson et al., 2017; Blad, 2021), can significantly increase the accessibility levels. Other points of interest (POIs) that increase the diversity of opportunities available for the users, as mentioned in the literature, includes convenience stores, drug stores, coffee shops, food markets, shopping centers, sports facilities, entertainment venues, multiple retail, and pick-up/storage stations (Urban Design Studio, 2016; Coenegrachts et al., 2021; Cui, 2021; Metrolinx, 2011; Monzón, Hernández., and Di Ciommo, 2016; RISE/ARUP, 2020; Frank, Dirks, and Walther, 2021; Petrović, M., et al., 2019; Anderson, et al., 2017; Blad, 2021; Wright, 2007; Chidambara, 2019; Nag, et al., 2019; Indrakesuma, 2018; Hasan and Al-Khafaji, 2020; Conticelli, et al., 2020). In addition to this, the provision of an attractive open space is recommended. Parks, plazas, engaging streets (Metrolinx, 2011; Urban Design Studio, 2016; Cui, 2021) where people can gather and interact between themselves and the space, complement the diversity of opportunities within the catchment area of the hub. Short distances between these spaces and multi-modal transit stations, together with an attractive and secure pedestrian and cyclist infrastructure and services (including the connection between the network and the hub), can increase the walkability and cycling share in the area (Tavassoli and Tamannaei, 2019; Aono, 2018; da Silva and Uhlman, 2021; Urban Design Studio, 2016; Metrolinx, 2011; Monzón, et al., 2016; Indrakesuma, 2018; Chidambara, 2019; Miller, 2004).

These location characteristics are more commonly found in more densely populated urban spaces where land availability is scarce. Therefore, in some cases, infill development might be the most suitable approach (Aono, 2018). In this regard, Cui (2021) discusses the potential to use leftover spaces in cities. These are caused by urban infrastructure and are typically underused but have the potential to improve the public realm when used efficiently.

Another aspect that must be considered is the provision and frequency of public transport options in the area. While high public transport supply is desirable for seamless mobility and Transit Oriented Development (TOD) (Metrolinx, 2011., Aono, 2018., Mobility Center, n.d., Frank, et al., 2021., Nag, et al., 2019., and Nielsen et al., 2005) the mobility hubs are also thought to fill mobility gaps (RISE/ARUP, 2020). Therefore, multiple sources explain the importance of focusing also on underserved areas and areas which suffer from traffic congestion problems (Miramontes, 2018., da Silva and Uhlman, 2021., Coenegrachts, et al., 2021., Mouw, A. 2020., Frank, et al., 2021., Blad, 2021., Anderson, et al., 2017., and Nielsen, 2005). Regardless of which of the past approaches the mobility hub complies with, Urban Design Studio (2016)- supported also by the already mentioned authors Nag et al. (2019) and Nielsen (2005)- recommends that hubs should be located close by the end and/or start of bus lines. This will encourage the users to reduce car dependency and increase the use of active modes especially for the first/last mile tracks (Anderson, et al. 2017).

Table 2-7 Recommended spatial factors for allocating mobility hubs

Integration	Mobility Hubs																		Public transport					Seamless /Multimodal/ Intermodal					Bike & Ride	Park & Ride	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
High population density	x			x	x					x				x	x		x	x					x			x					
Central location			x																			x	x						x		
Attractive routes increase			x								x									x			x								
High number of amenities			x						x	x	x	x	x		x	x	x	x	x	x		x			x		x	x			
Public gathering spaces,			x							x	x																				
High-frequency (major) transit service.				x	x		x	x	x						x				x			x	x								
Mixed-use development			x	x	x						x																				
Cycling and pedestrian infrastructure					x	x		x			x	x				x		x	x	x		x			x						
University campuses, schools, and the hospitals						x											x	x													
Tourist attractions						x																									
Central areas							x	x	x																				x		
Residential areas with low public transport coverage							x	x	x					x	x			x					x								

A:(CoMoUK, 2019), B:(Schelling, 2021), C:(Studio, 2016), D: Mobility hubs (Shared-Use Mobility Center, 2019), E:(Aono, 2019), F: (Pfertner, 2017), G: (Miramontes, 2018), H: (Silva & Uhlmann, 2021), I: (Coenegrachts et al., 2021), J: (Cui, 2021), K: (Metrolinx, 2011), L: (Monzon-de-Caceres & Ciommo, 2016), M: (Schemel, 2020), N : (Mouw, 2020), O: (Frank et al., 2021), P: (Petrović et al., 2019), Q: (Anderson et al., 2017), R: (Blad, 2021), S: (Wright & Hook, 2007), T: (Chidambara, 2019), U: (Miller, 2004), V: (Nag et al., 2019), W: (Nielsen et al., 2005), X: (Preston, 2012), Y: (Indrakesuma, 2018), Z: (Luo et al., 2021), AA: (Hasan & Al-Khafaji, 2021), AB: (Conticelli et al., 2021), AC: (Tavassoli & Tamannaei, 2020), AD: (Bolger et al., 1992)., AE: (Mather, 1983).

<u>*Placement of different modes of transport in proximity to each other*</u>

Regarding the placement of modes close to each other, the main considerations found in the literature are 1) maximum walking distance and travel time between the different transportation alternatives, 2) avoid conflicts between modes, and 3) wayfinding. The recommended acceptable distance in the literature is generally between 300 and 500 meters, while the travel time is about 5 minutes (see Table 2.7). Longer walking distance are accepted to large public transport stops such as railway stations (500 meters to max. 1 kilometer) (Rehme et al., 2018; Natuur&Milieu, 2020). Moreover, wayfinding signs can inform people where the different options are located. Specially, close to the distance limits, wayfinding signs can help inform people where the different options are located.

When different mobility options and services are located near each other or share paths, it is highly recommended to avoid conflicts between the different modes (Urban Design Studio, 2016; Aono, 2019; and Wright, 2005). First, it should be considered that pedestrians come first in terms of design, security convenience and comfort (Manoj, Goswami, and Bharule, 2019.; Hasan and Al-Khafaji, 2020.; Koen, 2021.; Metrolinx, 2011). As the Mobility Hubs Guide created by the Urban Design Studio (2016) raises, walkable paths must be always free of barriers and must provide easy access; therefore, none of the elements from the hub itself shall act as an obstacle. In addition, active mobility should be not only separated from motorized vehicles, but also smoothly integrated with traffic through ramps, intersections, traffic signals, etc. (Chidambara, 2019; Tavassoli and Tamannaei; 2019; Wright, 2007). When possible, crossing streets to reach different mobility options should be avoided (Wright, 2007). Pavement markings can help avoid conflicts by indicating the space designated for each option, and people can be informed where their needed option is located (Urban Design Studio, 2016).

To continue further under the scope of active transport modes, the integration of high-quality and diverse infrastructure to increase opportunities and enhance the cycling share, is also one of the most mentioned aspects in the consulted literature. This covers the variety of bike-share programs and parking offers. As an example, one of the best practices explained by Aono (2019) and the ARUP/RISE (2020), as well as suggested by studies such as Mouw (2020), and Miramontes (2018), is the integration of multiple options of available bikes (cargo, electric, trikes). A distinction should be made between parking for private bicycles and for shared bicycles, and it should be as close as possible to bike lanes.

Public transport should have priority over private transport, and bus transport should be separated from the general traffic (Monzón, Hernández, and Di Ciommo, 2016). In addition, traffic calming in the area can help integrate the different modes of transportation. For example, angled or parallel on-street parking could slow motorized traffic. According to parking criteria, reserved parking spaces should be available for more environmentally friendly vehicles. Whenever possible, carsharing vehicles (and EV charging stations) should be grouped in "pods" of at least two or three vehicles per location (Aono, 2019; Pfertner, 2017). Typically, EV charging stations are located adjacent to parking lots (Coenegrachts et al., 2021).

Table 2-8 Recommended maximum walking distance and time between transport means

Reference	Max. distance	Max. walking time
(CoMoUK, 2019)	400 - 800 m	
(Bolger et al., 1992)	125 m - 250m	
(Mouw, 2020)	300 - 500 m	
(Wright & Hook, 2007)	500 m	
(Indrakesuma, 2018)		5 min
(Luo et al., 2021)		5 min
(Nielsen et al., 2005)	300- 400 m	3 - 5 min
(Blad, 2021)	400 m	5 min

Table 2.8 summarizes the main recommendations aimed at locating different modes close to each other.

Table 2-9 Main recommendations to place different transport modes in the vicinity of each other

Integration	Mobility Hubs																		Public transport					Seamless /Multimodal/ Intermodal					Bike & Ride	Park & Ride	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
Avoid conflict between modes			x	x	x	x	x			x	x	x				x			x				x						x		
Pedestrian first	x		x	x	x	x										x											x	x			
Wayfinding signage			x	x	x		x				x	x							x				x		x		x	x			x
Pavement markings			x		x	x																			x				x		
Reserved parking for cleaner vehicles			x		x	x																						x			
Bike parking next to bike lanes (difference private vs shared)					x							x				x		x					x				x	x			x

A:(CoMoUK, 2019), B:(Schelling, 2021), C:(Studio, 2016), D: Mobility hubs (Shared-Use Mobility Center, 2019), E:(Aono, 2019), F: (Pfertner, 2017), G: (Miramontes, 2018), H: (Silva & Uhlmann, 2021), I: (Coenegrachts et al., 2021), J: (Cui, 2021), K: (Metrolinx, 2011), L: (Monzon-de-Caceres & Ciommo, 2016), M: (Schemel, 2020), N : (Mouw, 2020), O: (Frank et al., 2021), P: (Petrović et al., 2019), Q: (Anderson et al., 2017), R: (Blad, 2021), S: (Wright & Hook, 2007), T: (Chidambara, 2019), U: (Miller, 2004), V: (Nag et al., 2019), W: (Nielsen et al., 2005), X: (Preston, 2012), Y: (Indrakesuma, 2018), Z: (Luo et al., 2021), AA: (Hasan & Al-Khafaji, 2021), AB: (Conticelli et al., 2021), AC: (Tavassoli & Tamannaei, 2020), AD: (Bolger et al., 1992), AE: (Mather, 1983).

<u>*Design of mobility hubs that are clearly visible with information and common logos.*</u>

The aspects to be discussed in the following paragraphs are considered key elements of a mobility center. They contribute not only to ensuring visibility and clear recognition but also to increasing safety levels, comfort, and information among users of the space.

First, a recognizable logo is one of the most recommended practices. Creating a branding logo and increasing the visibility of the mobility hub as a landmark can attract users and increase the sense of proximity and integration to other transport modes and points of interest (Urban Design Studio, 2016). The recognition of a specific symbol/brand is particularly useful when considering a network of mobility hubs of multi-modal stations as it makes them more recognizable for the users (Blad, 2021; CoMoUK, 2019; Shared-Use Mobility Center, 2019). Some of the recommended practices include using similar colors and a design that informs the users of the multi-modal transport options they have access to (Miramontes, 2018; Mouw, 2020; Silva and Uhlman, 2021. Other authors that recognize this practice as a convenient marking strategy are Nielsen (2005), Wright and Hook (2007), and Aono (2019).

An attractive design of the mobility hub should include the branding logo and aesthetically pleasing scheme. Miramontes (2018) points out that an aesthetically pleasing design makes the space more visible for the users. Mobility hubs should be easy to recognize from the nearby public transport stations and adjacent streets (Urban Design Studio, 2016). Since the infrastructure will be visible to all, Schelling (2021) states the importance of providing coherent furniture in the mobility hub. In this regard, the term furniture can refer to the infrastructure that the hub is equipped with to enhance and ease mobility and increase comfort and security conditions for the users (Aono, 2019).

Regarding the design characteristics that are not strictly related to mobility, some authors (Indrakesuma 2018., Urban Design Studio, 2016., and Shared-Use Mobility Center, 2019) argue that areas visible from the surrounding space can provide the users a safer environment. A higher sense of insecurity among the users is more common during the evening hours. Spaces with good illumination and surveillance systems can make them feel safer and protected (Blad, 2021., and Urban Design Studio, 2016). Furthermore, providing sufficient lighting beyond the physical limits of the mobility hub into the street level is especially relevant to increment the share of active mobility. As Chidambara (2019) points, it is one of the aspects influencing the walkability levels of the first/last mile. The lighting quality in those spaces and the cycling network is equally important (Tavassoli & Tamannaei, 2020).

Part of the visibility elements that significantly influence the user experience is the provision of informative components such as digital boards, maps, information kiosks, and other sorts of assistance. As authors like Indrakesuma (2018) and Conticelli, Gobbi, Saavedra Rosas, and Tondelli (2021) point out, real-time information is particularly relevant for interchange purposes as it eases the trip planning process. The users should have access to understandable information showing public transport arrival times, delays, route choices, ticket fare information, weather information, and status about the different modal options (Nielsen, 2005, Coenegrachts, Beckers, Metrolinx, 2011; Aono, 2019; Shared-Use Mobility Center, 2019; Vanelslander and Verhetsel, 2021; Blad, 2021; Nag, Manoj, Goswami, and Bharule, 2019). Urban Design Studio (2016) mentioned that whenever charging stations for electric vehicles are installed, it is suggested to integrate information about the status of the station as well as cost details and other related information. Other relevant information includes the location and availability of shared vehicles.

Relevant information should be available in multiple areas of the hub. It could be present in various forms and formats (digital and analogue). It should also be available in an audible and tactile form to increase equal access (Wright and Hook, 2007; Urban Design Studio, 2016; Shared-Use Mobility Center, 2019). Additionally, making the same information available online, together with the provision of Wi-Fi access within the hub facilities, might further ease the process of trip planning for the users (Shared-Use Mobility Center, 2019; Schemel et al., 2020)

Table 2.10 summarizes the sources of the main recommendations for designing mobility hubs clearly visible with information and common logos.

Table 2-10 Main recommendations to design mobility hubs clearly visible with information and common logos

Integration	Mobility Hubs																		Public transport					Seamless /Multimodal/ Intermodal					Bike & Ride	Park & Ride	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
Visibility of the station to passengers	x		x	x				x						x				x							x						
Visible from stations			x		x		x							x													x				
Signage & branding	x					x		x						x				x	x				x				x				
Digital information or information pillars	x		x	x	x	x			x		x		x	x				x	x		x	x	x	x	x			x			
Stations must be well lit at night			x										x							x					x			x	x		x
Coherent furniture		x			x																										

A:(CoMoUK, 2019), B:(Schelling, 2021), C:(Studio, 2016), D: Mobility hubs (Shared-Use Mobility Center, 2019), E:(Aono, 2019), F: (Pfertner, 2017), G: (Miramontes, 2018), H: (Silva & Uhlmann, 2021), I: (Coenegrachts et al., 2021), J: (Cui, 2021), K: (Metrolinx, 2011), L: (Monzon-de-Caceres & Ciommo, 2016), M: (Schemel et al., 2020), N : (Mouw, 2020), O: (Frank et al., 2021), P: (Petrović et al., 2019), Q: (Anderson et al., 2017), R: (Blad, 2021), S: (Wright & Hook, 2007), T: (Chidambara, 2019), U: (Miller, 2004), V: (Nag et al., 2019), W: (Nielsen et al., 2005), X: (Preston, 2012), Y: (Indrakesuma, 2018), Z: (Luo et al., 2021), AA: (Hasan & Al-Khafaji, 2021), AB: (Conticelli et al., 2021), AC: (Tavassoli & Tamannaei, 2020), AD: (Bolger et al., 1992), AE: (Mather, 1983).

Design of mobility hubs as a placemaker

To strengthen the connection between people and the hubs, placemaking can potentially maximize the shared value and increase acceptance and usage among the inhabitants. Placemaking can increase the feeling of belonging and comfort, i.e., safe, secure, in a clean, nice-looking area, where they can meet other people and carry out activities (Table 2.11). Urban Design Studio (2016) includes within its recommendations the possibility of implementing tree canopies as an enclosing feature but also extending into adjacent streets. Regarding the design of these street areas, Aono (2019) presented case studies where the sidewalks were enlarged to create parklets and attractive and recognizable waiting areas. A highly attractive space design can enhance walkability (Chidambara, 2019), as explained in other sections of this document. Besides the architectural design, incorporating these features is relevant for creating a pleasant environment for the users. Public furniture such as benches, planters, bicycle racks, sheltered waiting areas, and pedestrian lighting elements are encouraged by the experts (CoMoUK, 2020; Urban Design Studio, 2016; Metrolinx, 2011; Monzón et al., 2016; Mouw, 2020; Wright and Hook, 2007; Chidambara, 2019; Nielsen, 2005, Preston, 2012; and Mather, 1983). Once again, Aono (2019) further remarks on the integration of these aesthetic and functional features as a way of placemaking. He also emphasizes that the furniture design should be flexible enough to adjust to future changes in demand and usage, adhere to universal design guidelines to ensure accessibility for all, and must not create conflict on the pedestrian paths. Several other authors also addressed the importance of using flexible and convenient designs and materials, among those modular approaches that allow easy disassembly of the infrastructure (Schelling, 2021, Metrolinx, 2011, Schemel et al., 2020, Blad, 2021, and Nielsen, 2005).

Complementary elements that encourage the active use of the space as well as enhance the public realm should also be considered. For example, green and blue infrastructure, permeable materials for paved surfaces, public bookshelves, artworks, and artistic designed infrastructure, drinking water fountains, and attractive landscape, among other visually appealing features (Urban Design Studio, 2016; Aono, 2019; Wright and Hook, 2007; and Chidambara, 2019).

The design of the mobility hub must also go beyond and tackle security issues. First, considering traffic security, part of the recommendations includes improving surrounding street crossings, adding traffic calming and management infrastructure, and avoiding locating waiting areas in isolated sections (CoMoUK, 2020; Urban Design Studio, 2016; Shared-Use Mobility Center, 2019; Aono, 2019; Metrolinx, 2011; Mouw, 2020; Nag et al. 2019; Indrakesuma, 2018; Conticelli et al., 2020). Secondly, security can also be enhanced by providing safe storage facilities. Multiple sources encourage the provision of closed and secured parking areas reserved for private bicycles, especially if there is a higher incidence of stolen or damaged bikes in the region (Urban Design Studio, 2016; Aono, 2019; Metrolinx, 2011; Wright and Hook, 2007, Conticelli et al. 2020; and Mather, 1983). The consulted guidelines and authors recommend providing storage for personal belongings or packages (e.g., lockers). The Shared-Use Mobility Center (2019) especially encourages the latter for the users' comfort when dealing with heavy packages and to support retail services that might be accessible in the facilities.

As one of the main objectives of mobility hubs is to minimize the environmental footprint (Metrolinx, 2011) and simultaneously maximize other benefits, consulted sources recommend applying more sustainable construction practices. Wright and Hook (2007) explained in their BRT (Bus Rapid Transit) guideline that passive climatic techniques can be implemented in stations to increase comfort to the users by efficiently regulating indoor temperatures. This previous statement is also supported by Urban Design Studio (2016) guidance, where the authors prioritize the efficient use of energy. They claim that transit facilities should meet high energy standards for conservation and retrofit. The sustainable building practices they addressed agree with the passive design mentioned before, for instance, strategic building orientation, landscape design, and adaptable roof surfaces. Although the installation of solar panels is not included within the passive strategies, it is recommended by various sources (CoMoUK, 2020; Aono, 2019). Furthermore, another subject addressed by multiple literature sources concerns rainwater management to reduce run-off volume related to a high percentage of impermeable surfaces (Metrolinx, 2011 and CoMoUK, 2020). Following the suggestions of Urban Design Studio (2016), bio-retention areas and bioswales could contribute to this regard as well as for water recycling purposes. The inclusion of green spaces and greenery elements can play a significant role in both water management and temperature regulation. However, as Urban Design Studio (2016), Wright and Hook (2007) and a vast number of literature sources of sustainable construction practices point out, it is essential to prioritize indigenous species.

As already mentioned, considering the dynamic behaviour intrinsic to transportation matters, Schemel et al. (2020) focused on exposing the importance of a flexible and easily disassembled design. Such a strategy might contribute to avoiding premature obsolescence and might have multiple benefits in terms of material consumption and the lifespan of the facilities. All the strategies and considerations described above are, naturally, subject to and must always be in line with the respective land use plans in addition to other development plans or projects from the local authorities

(CoMoUK, 2020; Urban Design Studio, 2016; Schemel et al., 2020). Particularly, the guidelines created by CoMoUK (2020) advise to always consider any potential space limitation and local permit regulations and to prepare for any design modification (most likely scaling down the initial proposal) that might be required. Lastly, none of the previously described elements will accomplish the goal of attracting users if the hub operates under unhealthy or polluted conditions. Hence, Wright and Hook (2007), Chidambara (2019), Nielsen (2005), Indrakesuma (2018), and Conticelli et al. (2020) refer to cleanliness as a fundamental characteristic of mobility hubs. A clean and appealing environment can be critical in attracting or repelling users.

Table 2-11 Main recommendations to implement hubs as placemakers

Integration	**Mobility Hubs**																		**Public transport**					**Seamless /Multimodal/ Intermodal**					**Bike & Ride**	**Park & RIde**	
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**	**Y**	**Z**	**AA**	**AB**	**AC**	**AD**	**AE**
Safety and Security surveillance	x		x	x	x						x	x		x					x	x		x			x			x	x		
Environmental building	x		x		x						x		x						x												
Supported by the local land use plan	x		x										x																		
Visually interesting places			x		x							x							x	x											
Green furniture			x		x															x											
Landscape and street furniture			x		x						x	x							x	x											
Drinking fountains and/or bathrooms			x	x	x														x												
Storage and/or urban freight facilities			x	x	x				x																x			x			
Modular design		x			x						x		x					x					x								
Cleanliness																			x	x			x		x			x			
Attractive and functional public gathering spaces			x							x	x																				
Direct connection to shops, amenities and points of interest			x						x	x	x	x	x		x	x	x	x	x	x		x			x		x	x			

A:(CoMoUK, 2019), B:(Schelling, 2021), C:(Studio, 2016), D: Mobility hubs (Shared-Use Mobility Center, 2019), E:(Aono, 2019), F: (Pfertner, 2017), G: (Miramontes, 2018), H: (Silva & Uhlmann, 2021), I: (Coenegrachts et al., 2021), J: (Cui, 2021), K: (Metrolinx, 2011), L: (Monzon-de-Caceres & Ciommo, 2016), M: (Schemel et al., 2020), N : (Mouw, 2020), O: (Frank et al., 2021), P: (Petrović et al., 2019), Q: (Anderson et al., 2017), R: (Blad, 2021), S: (Wright & Hook, 2007), T: (Chidambara, 2019), U: (Miller, 2004), V: (Nag et al., 2019), W: (Nielsen et al., 2005), X: (Preston, 2012), Y: (Indrakesuma, 2018), Z: (Luo et al., 2021), AA: (Hasan & Al-Khafaji, 2021), AB: (Conticelli et al., 2021), AC: (Tavassoli & Tamannaei, 2020), AD: (Bolger et al., 1992), AE: (Mather, 1983)

In summary, physical integration ladder comprises the following levels:

- Level 0: No integration.
  - One shared transport mode, not at walking distance to public transport, no integration between the modes.
  - No inclusive design criteria are considered.
- Level 1: Acceptable walking distance.
  - At least two shared transport modes in acceptable walking distance to public transport.
  - At least one service (e.g., shop, parcel locker, kiosk) in acceptable walking distance.
  - The minimum legal inclusive design requirements are considered, allowing for example people with disabilities to easily access the hub
- Level 2: Wayfinding and universal design
  - At least two shared transport modes in acceptable walking distance to public transport with wayfinding and information of using the service.
  - At least one service (e.g., parcel locker, kiosk) in acceptable walking distance.
  - Universal design principles are considered.
- Level 3: Visibility and branding
  - At least two shared transport modes visible from a public transport stop.
  - An attractive design of the mobility hub, branding and aesthetically pleasing scheme.
  - At least one service (e.g., shop, parcel locker, kiosk) + information of using the service and potential conflicts (e.g., barriers between the modes that require to cross the road or walk extensively to use different modes).
  - Universal design principles are considered.
- Level 4: Conflict free and place making
  - At least two shared transport modes visible from a public transport stop with no conflicts and information of using the services.
  - At least two services;
  - Placemaking and attractive space design
  - Universal design principles are considered.

2.4.3 Digital integration

Digital integration describes the effort of integrating information on one digital platform and making it possible for different information platforms to access information using a standard format. Through digital integration, users can easily access information provided by multiple providers in one place. Examples are travel planners that let users not only identify services offered by different providers or platforms but also plan, book and pay for services of the different providers in a single application.

The Mobility as a Service (MaaS) promise is to deliver digital integration of mobility options - planning, booking and payment using a single app or platform. MaaS is thus relevant for mobility hubs: it makes it easier to use different transport modes and to improve access to the services of different providers offered at the hub. The most important aspect of MaaS is that it relies on a digital platform (mobile app or web page) at which travellers can access different aspects such as trip planning, payment, and real-time information. Users may also access other services such as weather information, synchronization with their personal calendars, travel history reports, etc. (Jittrapirom et al., 2017).

Contextualizing MaaS in terms of its topological functions, characteristics and attributes is an important step towards ensuring a sustainable mobility ecosystem while accommodating the global tendency of digitization (Amaral et al., 2021). Because mobility networks include the transport modes (e.g. private car, transit, taxis, ride-sharing services), the supporting infrastructure (e.g., rail, roads) and governance-related aspects (e.g., pricing, policies), MaaS implementations could lead to indirect, hard-to-predict impacts (Muller et al., 2021). For instance, implementing MaaS could lead to a reduction in number of vehicles, but increase the vehicle miles travelled, worsening overall congestion. It is, therefore, imperative to consider these externalities when assessing MaaS and specifically smart mobility hubs.

Sochor et al. (2018) developed a topological framework to characterise MaaS in levels varying from 0 to 4, as indicative of different levels of digital integration. The proposed topology of MaaS includes:

- Level 0: no integration; single separate services
- Level 1: Integration of information. This includes multimodal travel planners and price information.

- Level 2: Integration of booking and payment. This level offers an extension to travel planners and offer single planning, booking and payment options. It offers easier access to services for end users – such as a mobility marketplace or a one-stop shop where the user can find, book, and pay with the same app.
- Level 3: This level represents integration of the service offer, including contracts and responsibilities. Level 3 service is bundled, possibly subscription-based. The MaaS operator creates value for suppliers and users. The MaaS operator (of which there may be more than one competing with each other) typically works more closely with preferred suppliers, often one per mode, in order to not only attempt to run a profitable business, but also to create value for (and attract) the suppliers and, with that, better deals for its customers.
- Level 4: Integration of societal goals; policies and incentives. Incentives are implemented in the MaaS service (or implemented in individual services, as a Level 4 approach could be integrated at any level), reflected by how well local, regional, and/or national policies and goals are integrated into the service.

We adapted and expanded the MaaS topology from Sochor et al. to include digital accessibility and universal design principles. Designing digitally accessible mobility services at mobility hubs it important for the uptake of app-driven mobility services and making the services accessible for different user groups. As noted in Section 2.4.1, digital mobility solutions assume that an interaction takes place between the user and a digital interface (smartphone, screen, computer, electronic display). While these services are becoming increasingly widespread, certain socio-economic (income, place of residence, education, ability to use technology), demographic (age, gender), and functional barriers (limited sight, hearing, movement or cognitive capabilities) may prevent people from using digital interfaces and services in general (Lucas et al., 2016.) As digital technologies are progressively becoming indispensable to navigate the world of transport services, low levels of digital engagement may create a new layer of transport disadvantage, possibly on top of existing ones (Durand et al., 2021a). Horjus (2021) examined the potential use of shared mobility at a public transport hub in the Hague and showed that the intention to use shared transport is higher for people with higher levels of digital skills, prior shared transport experience, who are younger, highly educated and those who used multiple means of transport during their trip.

Universal design principle 1 (Equitable use) and Principle 2 (Flexibility in use) relates to mobility hub design which is useful and marketable to people with diverse abilities, and provides choices in methods of use. This implies that also that less digitally skilled persons are provided with other options to plan, book and pay for mobility offerings at a hub. Durand et al. (2021b) describe solutions to improve digital accessibility of public transport services, including access for all solutions which are potentially also suited for mobility offerings at mobility hubs, including analog alternatives to plan, pay and book trips (e.g., information kiosks with assistance), low-tech instruments such as helpdesk support, help buttons on ticket machines and the development of specific travel aids or apps for specific user groups such as people with disabilities. In the Netherlands, there are for example dedicated apps for public transport users offing door to door guidance and assistance (helpdesk support) to people with mental disabilities or disorders and elderly people (GoOV). Other low-tech alternatives used in some ride sharing and demand responsive services involve the option of care givers to book trips for family members. To the authors' knowledge, no studies have been done to examine how universal design principles can reduce digital inequities by lowering barriers towards the use of digital mobility services available at mobility hubs.

Universal design principles 3 (Simple and Intuitive Use) and 4 (Perceptible information) relate to the design of apps and other digital platforms to plan, book and pay for mobility offerings at hubs, the platforms should be easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration levels and communicates necessary information effectively to the user.

We propose the following typology describing five levels of digital integration of mobility services provided at mobility hubs:

- Level 0: No integration of information.
    - Separate services from mobility providers use different platforms.
    - No inclusive design criteria are considered.
- Level 1: Integration of information.
    - There is decision support for finding the best trip, on a trip-by-trip basis, offered by multimodal travel planners and assistants and/or digital information displays at the hub
    - Minimum universal design requirements such as simple and intuitive app design
- Level 2: Integration of booking and payment.
    - Focus on single trips and could be a natural extension to a travel planner, adding public transport ticketing, taxi, or other transport services where possible. The added value of Level 2 for the end user is easier access to services.
    - Universal design principles are considered, including simple and intuitive app design and low-tech or analog booking alternatives.

- Level 3: Integration of the service offer, including contracts and responsibilities.
    - Service is bundled, possibly subscription-based.
    - Universal design principles are considered, such as simple and intuitive app design and low-tech or analog trip booking alternatives.
- Level 4: Integration of societal goals.
    - Incentives are implemented in the MaaS or individual services, reflected by how well local, regional, and/or national policies and goals are integrated into the service.
    - The public authorities on a city, regional or national level can influence the societal and ecological impacts of mobility services, i.e. influencing users' behaviour by setting conditions for the operators (and individual transport service providers) so that they will create incentives for desired behaviour, such as reduced private car ownership and use, a more accessible, liveable city, etc.
    - Universal design principles are considered, including simple and intuitive app design and low-tech or analog booking alternatives.

2.4.4 Democratic (participatory) integration

The transformation towards a more sustainable society evokes fundamental changes in different areas. The lifestyle of people, their everyday knowledge, and their basic routines transform or will transform dramatically. Since ‘the people’ are sovereign, it is one of the constitutional rights in democratic societies that ‘the demos’ is “having part in something” (Carter 2005, p. 182) – here, the governance of their country, city, or neighborhood. Participation in a traditional and most fundamental democratic sense is expressed in free, direct, and representative elections or the political engagement of citizens in established organizations of policy-making such as parties or charity organizations (Kohout 2002). Participation may also lead to service provision relevant to society (Kersting 2008) or the stabilization of capitalist structures in post-democratic approaches (Brown 2012; Badiou 2012; Zizek 2012).

In post-globalized societies where actors like NGOs, cooperations, and international organizations support or oppose the state in policy-making, what is most commonly addressed in the term ‘governance’; scholars and practitioners have developed different approaches to capture such decentralized forms of participation. Such approaches include Collaborative Governance (Ansell and Gash, 2007; Emerson et al., 2012), Democratic Innovation (Smith, 2009) or Radical Democracy (Cohen and Fung, 2004; Fung and Wright, 2003), Co-creation (Ansell and Torfing, 2021; Torfing et al., 2019) or design thinking (Boylston, 2019). What distinguishes public participation and co-creation depends on the definition that is applied. At the core of public participation is the involvement of the public (Arnstein, 1969). Co-creation has been defined as an innovation approach that goes from problem identification to implementing a solution. Within a co-creation process, co-design is the step at which solutions are designed (De Koning et al., 2016). Pappers et al. (2020) argue that public participation and co-creation share an emphasis on the involvement of the public, but that co-creation focuses on creativity and innovation.

Among these approaches, Participatory Governance explicitly emphasizes participatory elements in the implementation of decisions (Walk, 2008; Heinelt, 2010). Scholars of Participatory Governance mention four central characteristics of Participatory Governance: appropriate representation of stakeholder interests, deliberative engagement of stakeholders, integration of different knowledge, and social learning (Kern, 2008). Participation in Participatory Governance may occur at different levels (local, regional, national, supranational), in different forms and venues (including the internet) and constitutes a dynamic relationship between participation givers and takers.

Literature on Participatory Governance applied in the sector of mobility planning, or multimodality is rare. In the context of environmental policies in general, Participatory Governance is expected to contribute to an improved quality of decisions by incorporating local knowledge and opening the political discourse for environmental concerns. Also, stakeholder involvement is expected to increase acceptance, improve compliance and the implementation of measures (Newig and Fritsch, 2009). When it comes to mobility planning documents, the European Commission for instance, explicitly recognizes the importance of stakeholder participation (Rupprecht Consult, 2019). There are different ways to conceptualize participation under the head of Participatory Governance. Newig (2011) distinguishes three variables: First, the form and direction of information flows (from simple information to face-to-face exchanges), second, the amount of influence on the decision-making process, and third, the circle of involved people. A classic of the participation literature is Arnstein’s participation ladder, with eight steps reaching from manipulation of citizens to citizen control (Arnstein 1969). (Schweizer-Ries et al., 2011) presented a table that agrees with Arnstein’s ladder in the point power share but highlights the role of participation givers and takers. This approach highlights the rights and duties of both takers and givers and allows for a more differentiated evaluation of what is going on in a process (Figure 2-3).

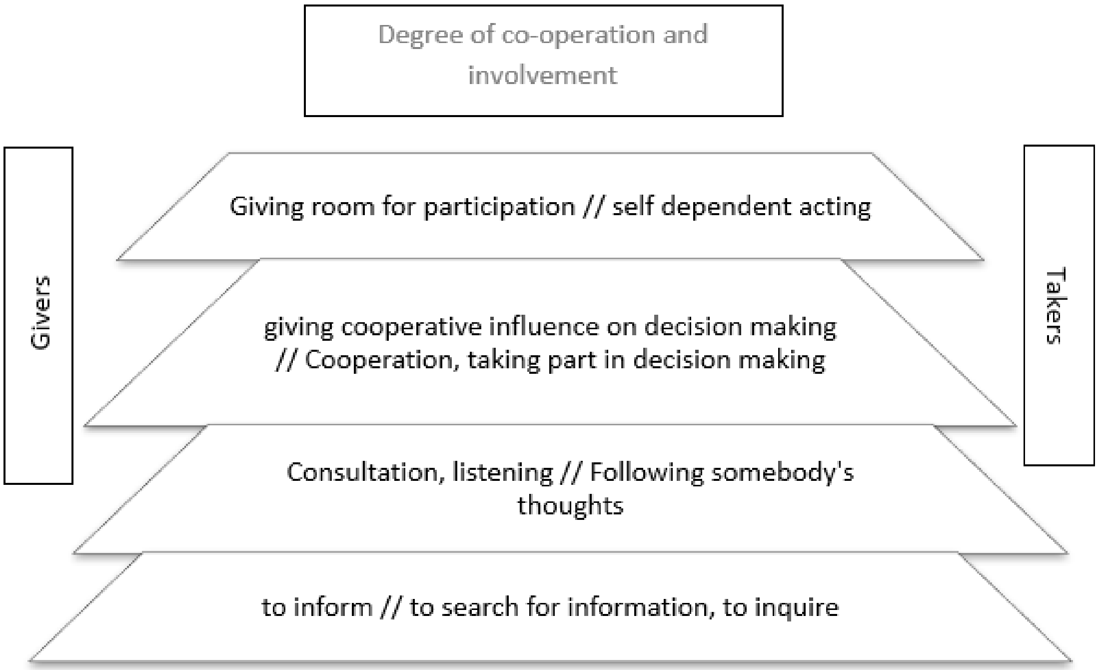


Figure 2-3 Participation ladder with rights and duties of participation takers and givers
Source: based on Schweizer-Ries (2011), own translation

Most conceptualizations of participation share a positive understanding of participation and recur on a ‘the more, the better’ logic. An a priori positive evaluation of participation has been criticized because participatory chances are not distributed equally in society, and participation takers are frequently the ‘usual suspects’ (Fuchs and Graf 2015; Graf and Fuchs 2015). Selle (2011) established the critical term ‘particitainment’ to characterize forms of participation that rather serve the official staging of participation while behind the curtains, everything remains the same. In general, critical observers think that the potential for and benefit of participation might be overestimated. They point to a lack of transparency, the increasing complexity of decision-making processes, and institutional overload, as well as the existence of powerful and diverse veto-players, including resourceful minority interests, as inhibitors of a balance of power in participation (Kuhn and Heinrichs 2011).

Although participatory governance has been criticized, policy makers, administrations as well as civil society and third sector organizations plea for an encompassing integration of citizens in urban mobility transitions to enhance the acceptance of transformation processes. However, the motivations for a far-reaching integration are diverse. While some emphasize the empowerment of the demos for reasons of democratic legitimacy (Dryzek, 2000), others highlight the meaning of market acceptance, especially when it comes to implementing new technologies (Wüstenhagen et al., 2007). As we understand it in SmartHubs project, Participatory Governance is not either or, but a continuum between those two poles. Participation in SmartHubs is located on a middle ground of more formative and more administrative approaches to better access empirical phenomena (Graf et al., 2018). Since we think that participation might contribute to the empowerment of the demos, we also share an understanding of participation as making decisions, policies, designs, and products potentially better than without the partaking of users, consumers, or citizens. We reflect on this normative setting which accompanies our understanding of participation and are open to carefully track negative developments.

In the context of the criteria Kern (2008) has launched for participatory governance and based on the Schweizer-Ries (2011) approach for participation, and principles of universal design, we propose the following typology to categorize the democratic integration of participation processes:

- Level 0: No involvement.
  - No involvement of stakeholders in the process.
  - No inclusive design criteria are considered.
- Level 1: Appropriate representation of stakeholder interests.

    - Participation takers got asked in consultation processes, stakeholder dialogs, or similar formats.
    - Participation takers have recognized the information provided and have shown responsivity.
    - The usage of service also belongs to this level.
    - No to limited attention to include vulnerable users explicitly as participation takers
- Level 2: Deliberative engagement of stakeholders.
    - Participation takers including vulnerable users argumentatively engage in decision-making. Different positions are exchanged and have been heard in a participation process.
    - Participation takers including vulnerable users actively took part in a format offered.
    - Participation givers make an invitation for participation and listen to the articulation of stakeholder interests.
- Level 3: Integration of different knowledge.
    - Participation takers including vulnerable users actively argue or deny with a policy, product, or process. Ideas, wishes, worries or conceptions of participation takers have been integrated into the participation process. They have been developed further collaboratively with participation givers and contributed to an outcome of the process.
    - Participation givers create room for decision making, and participation takers are willing to make informed decisions.
- Level 4: Social learning.
    - Participation takers including vulnerable users and givers have networked and integrated into the community.
    - Participation has been made permanent or is meant to become permanent.
    - Participation processes have taken on a life of their own and become independent from external moderation.

2.4.5 A multidimensional mobility hub typology - the SmartHubs integration ladder

Figure 2-2 visualises the full the SmartHubs integration ladder based on the physical, digital and democratic integration dimensions, and Table 2.5 presents the integration ladder with an explanation of each level.

	Physical integration	Digital integration	Democratic integration
4	Conflict free and place making	Integration of societal goals and policies, and consideration of universal design principles	Social learning
3	Visibility and branding	Integration of service offers and consideration of universal design principles	Integration of different knowledge
2	Wayfinding and consideration of universal design principles	Integration of booking and payment and consideration of universal design principles	Deliberative engagement of stakeholders, including (vulnerable) user groups
1	Acceptable walking distance to shared and public transport, minimum inclusive design standards	Digital integration of information	Appropriate representation of stakeholder interests, no or limited attention for vulnerable user groups
0	No physical integration	No digital integration	No stakeholder involvement and consideration of (vulnerable) user needs

Figure 2-4: The SmartHubs integration ladder

Table 2-12 The SmartHubs integration ladder

	Physical integration	Digital integration	Democratic integration
Level 4	**Conflict free and place making** At least two shared transport modes visible from a public transport stop with no conflicts and information of using the services and at least two services**.** Universal design principles are considered	**Integration of societal goals, policies and incentives** Local, regional, and/or national policies and goals are integrated into the service. Universal design principles are considered, including simple and intuitive app design and low-tech or analog booking alternatives	**Social learning** Participation takers and givers, including vulnerable users, have networked and integrated into the community, participation becomes permanent and independent
Level 3	**Visibility and branding** At least two shared transport modes visible from a public transport stop and at least one service (e.g., shop, parcel locker, kiosk), information about the service and potential conflicts, attractive design of the mobility hub, branding and aesthetically pleasing scheme. Universal design principles are considered.	**Integration of service offers** Shared and public transport services at the hub are bundled, possibly subscription-based. Universal design principles are considered, including simple and intuitive app design and low-tech or analog booking alternatives	**Integration of different knowledge** Participation takers, including vulnerable users, argue or deny positions, their input is integrated into the participation process, participation givers create a room for decision making
Level 2	**Wayfinding and universal design** At least two shared transport modes in acceptable walking distance to public transport with wayfinding and information of using the service and at least one service (e.g., parcel locker, kiosk) in acceptable walking distance. Universal design principles are considered	**Integration of booking and payment and universal design** Easy access to services for end users – such as a mobility marketplace or a one-stop shop where the user can find, book, and pay with the same app. Universal design principles are considered, including simple and intuitive app design and low-tech or analog booking alternatives.	**Deliberative engagement of stakeholders** Participation takers, including vulnerable users, argumentatively engage in decision-making, exchange of positions, active participation, participation givers invite participation and listen to stakeholder interests, including those of vulnerable user groups.
Level 1	**Acceptable walking distance to shared and public transport** At least two shared transport modes in acceptable walking distance to public transport and at least one service (e.g., shop, parcel locker, kiosk) in acceptable walking distance. Minimum legal inclusive design requirements are considered	**Integration of information** Multimodal travel planners can be used to plan mobility offerings at hubs. Minimum inclusive design requirements are considered such as simple and intuitive app design.	**Appropriate representation of stakeholder interests** Participation takers got asked into a consultation process, Information are recognized. No or limited attention to involve *vulnerable user groups.*
Level 0	**No physical integration.** One shared transport mode, not at walking distance to public transport, no integration between the modes. No universal design criteria are considered	**No digital integration** of shared and public transport mode options offered at the hub. There are separate services and platforms for each mode. No universal design criteria are required	**No involvement** or consideration of stakeholder interests and user needs.

The levels of integration help to distinguish mobility hubs from *smart* mobility hubs. A mobility hub according to the definition in section 2.2 is a physical location where different shared transport options are offered at permanent, dedicated and well-visible locations and public or collective transport is available at walking distance. A *mobility hub* should offers a minimum level of integration has at least level 1 on physical integration, digital and/or democratic integration. We assume that any mobility hub should comply with a minimum of accessibility and inclusion requirements as outlined in section 2.4.5, there is decision support offered by multimodal travel planners and assistants and/or digital information displays at the hub, and have an appropriate representation of stakeholder interest and consideration of the needs of vulnerable users.

We define a *Smart Mobility Hub as* a mobility hub which offers advanced levels of physical, digital and democratic integration (i.e. minimum level 2 on physical, digital and democratic integration). The higher up the physical, digital and democratic ladders, the "smarter" the mobility hub becomes. The hypothesis is that the "smarter" the mobility hub, the more user value is created, higher usage and user satisfaction levels are achieved and increased societal impacts can be expected (in terms of reduced car use and ownership levels, accessibility impacts, impact transport emissions, etc.). In other words, smart mobility hubs with high levels of integration are more likely to become a game changer game-changer towards inclusive sustainable urban mobility and accessibility. The SmartHubs research project will examine whether this hypothesis holds for existing, planned or future mobility hubs in the SmartHubs living labs.

		Physical integration	Digital integration	Democratic integration
Smart Mobility Hub	4	Conflict free and place making	Integration of societal goals and policies, and consideration of universal design principles	Social learning
	3	Visibility and branding	Integration of service offers and consideration of universal design principles	Integration of different knowledge
	2	Wayfinding and consideration of universal design principles	Integration of booking and payment and consideration of universal design principles	Deliberative engagement of stakeholders, including (vulnerable) user groups
Mobility hub	1	Acceptable walking distance to shared and public transport, minimum inclusive design standards	Digital integration of information	Appropriate representation of stakeholder interests, no or limited attention for vulnerable user groups
Single mobility services	0	No physical integration	No digital integration	No stakeholder involvement and consideration of (vulnerable) user needs

Figure 2-5: Integration level of Mobility Hubs and Smart Mobility Hubs

2.5 Applying the SmartHubs typology - examples

The SmartHubs integration ladder can be applied easily to examples of mobility hubs as described in the academic literature and planning practice. This chapter describes two examples to illustrate the SmartHubs multidimensional hub typology: neighbourhood hubs in Amsterdam and Wien.mobil Station Simmeringer Platz in Vienna.

Electric neighbourhood hubs in Amsterdam

The cities of Amsterdam, Nijmegen, Arnhem, Dreux, Leuven, Kempten en Manchester are developing mobility hubs as part of the Interreg project eHubs. The municipality of Amsterdam plans to facilitate 15 to 20 neighbourhood hubs ("Buurthub") developed by commercial shared e-mobility providers. eHUBS can vary in size (minimalistic, light, medium, large), type of location, and type of. Some eHUBs are planned to offer different shared modes from (in total 10) different providers using different apps/platforms offering e-bikes, e-cargo bikes, electric cars, Light Electric Vehicles and electric mopeds. Some companies offer multiple shared modes hubs in a single app/platform allowing planning, booking and paying of a combination of shared modes (bike, cargo bike and car). At the time of writing this report

(December 2021), the first hubs for shared and electric mobility deployed in Amsterdam have opened in the neighbourhood Buiksloterham (City District of Noord) and the neighbourhood Frans Hals (City District of Zuid) and these 2 hubs have 8 cars, 5 electric cargo-bikes and 16 electric bikes on offer for use by the residents (eHubs, 2021b). The levels of integration can be categorised as follows:

- Physical integration is at level 1: on-street locations that bring together e-bikes, e-cargo bikes, e-scooters and/or e-cars, offering users a wide range of options to experiment and use in various situations.
- Digital integration is at level 1 : Public transport is not integrated in the hub apps.
- Democratic integration is at level 1: the deployment of eHUBS in Amsterdam follows a participatory planning, allowing citizens of the neighbourhoods to decide together with the municipality what the BuurtHub will look like and what the mobility offer will be. Residents and employees living or working in the area are asked to fill in a survey and state preferences for the locations of a hub and mobility service offerings. There is, to the authors' knowledge, no specific attention for vulnerable user groups in the planning approach, e.g., elderly people, people with limited digital skills.

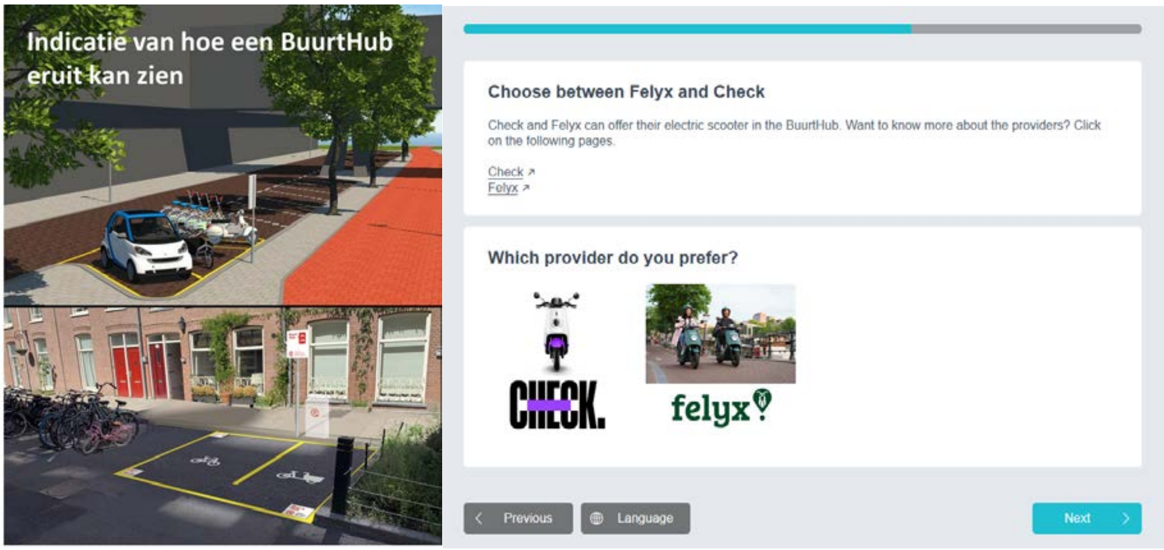


Figure 2-4 Screenshots of a survey as part of citizen participation in the ehub location Amsterdam Science Park. September 13, 2021 (source: campus.uva.nl)

Wien.mobil Station Simmeringer Platz, Vienna

The WienMobil station Simmeringer Platz is operated by Wiener Lienen, the public transport operator running most of the public transit network in the city of Vienna.

- Physical integration is at level 4: Different transport options and transport facilities (e- bike sharing and a cargo bike, bike boxes to park your own bikes, car sharing, E-charging station) are offered together in one clearly visible area at walking distance from the Wien Lienen tram stop Simmeringer Platz.
- Digital integration is at level 3. Shared transport and public transport planning and ticketing through the Wiener Lienen app, a Maas Platform. The is also and an information terminal with a touch screen.
- Democratic integration is at level 1: there have been information events where the operator directly got in contact with potential users, ideation process in mobile-participation format (SIMmobil). There is no specific attention for vulnerable user groups in the planning approach, e.g., elderly people, people with limited digital skills.

Figure 2-5 WienMobil station Simmeringer Platz (photo: Lukas Knott, TU Wien MOVE)

2.6 Users and impacts of mobility hubs

This subchapter focuses on the groups which are or could be the main users of mobility hubs. To date, there is an absence of systematic research on the profile of mobility hubs users. However, since mobility hubs constitute a combination of individual sharing systems e.g. bike sharing, car sharing, looking at the users of these systems could provide insight into the current and potential users of mobility hubs. Furthermore, MaaS applications and pilots can add information on the users of integrated multimodal mobility systems. Apart from the users, the impacts of mobility hubs are also investigated in this chapter, considering both early findings on the influence of existing hubs as well as potential impacts of future applications.

2.6.1 Users of mobility hubs

In most mobility hubs guides, a commonly appointed phrase is that 'hubs should be designed to be accessible to all users. No special mention of specific user groups is found in the majority of the relevant literature sources. To those that specific target groups are mentioned, there is still a tendency to address the majority of the population. For example, in Aono's work (2019), commuters, visitors, as well as residents, are referred to as potential users. In the rural areas, people with reduced access to mobility options such as the elderly, adolescents, and adults who do not possess a private car could be the targeted user group (Bell, 2019). Vulnerable groups are also candidates for being the main beneficiaries of mobility hubs as hubs could offer a more convenient and safer environment for transfers between different modes (CoMoUK, 2019).

Some of the few studies which offer knowledge on mobility hub user profiles have been conducted in Germany. Miramontes (2018) and Miramontes et al. (2019) examined mobility hubs in three different German cities: Munich (Münchner, Freitheit), Würzburg and Offenburg. Findings of the Munich case study suggest that most mobility hub users are 'highly educated, young males with access to multiple mobility options' (Mirramontes, 2018).

The sociodemographic characteristics of the population have been indicated by multiple research efforts as decisive factors of MaaS adaptation. Focusing on demographic characteristics, the age of individuals is expected to affect the usage of MaaS mobility offers. Although it is not clear which exact age group is most willing and ready to use MaaS, younger people are more frequently mentioned (Alonso-González, 2020, Jittrapirom et al., 2018, Zijlstra et al., 2020). Gender biases appear strong in the usage of sharing systems, including bike-sharing (Hull Grasso et al., 2020) and e-scooter sharing (Laa and Leth, 2020). For car-sharing, the gender gap is evident via the different aspects which are mentioned as the most significant factors for car-sharing usage between males and females (Karbaumer, 2018). Regarding, the combination of modes, Böcker et al. (2020) examined bike sharing use in conjunction with public transport and concluded that bike-sharing – both as a stand-alone system and in conjunction with public transport – is less accessible to, suited to, and used by women and older age groups. In a recent overview of multiple existing e-mobility sharing services, including car, (cargo-)bike, and scooter sharing, the role of sociodemographic characteristics is also highlighted, by showing that users are mostly male, middle-aged people with relatively high income and education (Liao and Correia, 2020).

Apart from individual characteristics, travel habits preceding the introduction of single sharing systems or MaaS could also impact the usage of the newly-introduced systems. Public transport users have been mentioned as early adapters of MaaS (Zijlstra et al., 2020). In terms of e-mobility services, public transport users, together with bike users are those who more often take upon the sharing services (Liao and Correia, 2020). However, not all public transport users tend to be equally positive towards shifting to more flexible mobility offers such as those offered at mobility hubs. Alonso-Gonzalez (2019) emphasizes that in conjunction with the income of the current public transport users, it is possible that the total set of offers in the context of MaaS, might not be affordable to all current public transport users. Apart from the level of public transport usage, the frequency of travelling by car influences the potential usage of MaaS. Travelling by car on an infrequent basis is a more positive indicator towards adapting MaaS in comparison to never using the car as the dominant mode of transport (Tsouros et al., 2021).

Focusing on the travel purpose usage patterns, evidence from the Munich-based mobility stations suggests that the available mobility alternatives at the mobility hub are used for various trips purposes, including both compulsory and non-mandatory trips (Miramontes et al., 2017). In the context of MaaS, compulsory trips and, in specific, commuting and business trips, could constitute the majority of trips conducted by MaaS at the early stage after the introduction of the service whereas more travel purposes could become popular gradually (Jittrapirom et al., 2020). Focusing on the individual modes/systems that can constitute a mobility hub, past research suggests that the usage of sharing systems can vary per mode of transport and system characteristics. For example, in terms of micromobility station-based systems e.g. (e-) bikes are exploited mainly for commuting and habitual trips whereas dockless sharing systems e.g. e-scooters are mostly preferred for serving recreational trips (Reck et al., 2021). However, the power of mobility hubs at providing a physical and potentially a digital space as well for a combination of micromobility systems with public transport, could assist in expanding the usage patterns of both docked and dockless systems micromobility systems.

As mentioned above, and also revealed by the variety of the main user groups of the different sharing systems that could be part of mobility hubs, hubs try to address the majority of the public. This characteristic imposes uncertainty in the success of mobility stations due to often differentiating and even conflicting requirements of different users groups. For instance, Bell (2019) mentions the need to cater to the needs of multiple subgroups groups and especially for people with reduced physical, mental, or cognitive capabilities at all aspects of a hub, including the provided information e.g. font size, colours, etc. Apart from taking into account the current target group needs, the design of mobility hubs should consider the ever-changing needs of their users (LADOT, 2017). Similarly, mobility hubs should be capable of facilitating changes in the mobility offers available in the market, especially those that provide more sustainable ways of travelling e.g. electric vehicles (Aono, 2019). Thus, both the materiality of the physical infrastructure and the space dedicated for the mobility stations should be selected in such a way that the adaptability and the modularity of the hubs to future changes are guaranteed.

2.6.2 Mobility and societal goals and impacts of mobility hubs

Mobility hubs have been referred to as a strategy towards supporting active and sustainable mobility (Aono, 2019). Looking at mobility hubs as such a strategy Aono (2019) specifies multiple relevant goals. More specifically, a mobility hub serves the following aspects: a) Provides efficient and seamless integration of sustainable transportation options, b) Focuses on improving user experience of different transportation options, c) Ensures safety and security for all travellers, d) Creates a sense of place through effective and meaningful placemaking strategies, e) Allows for flexibility to embrace technological innovations and foster resiliency, f) Addresses equity by considering accessibility to and availability of transportation options in different neighborhoods, and g) Creates opportunities to form effective partnerships.

The abovementioned objectives provide the umbrella for multiple goals of the mobility hubs: The efficient and seamless integration of sustainable transportation options aims at reducing the environmental footprint of the transportation networks by providing access to sustainable modes of transports and consequently reducing the usage of private cars (Aono, 2019). Though, individual mobility hubs or networks of hubs can serve more explicit purposes. In the Metro Vancouver case, the target goals have been defined as the transition of half trips to trips made by active modes and public transport and the reduction of the total distance travelled by one-third (Aono, 2019). In the Russian context, the development of mobility hubs aims at increasing the efficiency of the transport system and passenger traffic (Shaimardanova and Prokofiev, 2021). Frank et al. (2021) mention that achieving higher accessibility to workplaces and essential points of interest is the main objective of the introduction of mobility hubs in rural areas. The support of the access and egress parts of multimodal transit-based trips can also be the driving force for the establishment of mobility hubs (LADOT, 2017).

Focusing on the level that mobility hubs can reach their goals, there is limited research on the impacts of existing mobility hubs. A study on three mobility hub networks in Germany showed, via user surveys, that after the introduction of the hubs networks, people became more aware of the sharing transport systems (Miramontes et al., 2019). With respect to modal shift, findings support that after the introduction of mobility stations, users indicate that their levels of car-sharing and public transport uses increased (Miramontes et al., 2017, Miramontes et al., 2019).

In terms of the fields of mobility hubs impacts, the literature review suggests that the consequences of sharing systems and MaaS applications can be examined by categorizing them into societal, economic, and environmental impacts (Storme et al., 2021, Vaddadi et al., 2020, Karlsson et al., 2017). As mobility hubs aim at an overall reduction of the environmental footprint of the mobility sector, via transition to more environmentally friendly and sustainable modes of transport, the evaluation of their success and impact on the environment could be based on a holistic approach, such as the Life Cycle Assessment (LCA) (Zheng et al., 2019, Hollingsworth et al., 2019). Especially due to the involvement of e-vehicles such as e-scooters, e-cars, and e-bikes, the consideration of the disposal cost of their batteries and other equipment, LCA could be relevant for the evaluation of hubs' footprint (Liao and Correia, 2020). Another possible distinction of the impacts of hubs could follow past work on the impacts of MaaS pilots, in which the impacts are examined at three different levels: individual level, business/organization level, and societal level (Karlsson et al., 2017, Eckhadrt et al. 2020).

Looking at sharing mobility and MaaS evaluation efforts, one indicator which is commonly selected to measure their impact is the reduction in the car ownership rate (e.g. Karbaumer, 2018, Liao and Correia, 2020, Storme et al., 2021). Regarding private car ownership and the sharing modes involved in mobility hubs, micro-mobility is by itself a strong competitive to cars for short trips. However, for longer trips, micromobility offers are less efficient in terms of travel time and physical activity requirement and are, therefore, not that attractive. Nevertheless, in case micromobility offers are combined with transit as access or egress modes, then they have the potential of becoming an attractive alternative to the private car (Liao and Correia, 2020). The potential of mobility hubs to reduce private car usage via offering a better environment for the combination of multiple modes is supported by the evaluation of MaaS pilots too. Nevertheless, more indicators can offer insight into the impacts of mobility hubs. For example, qualitative impact assessment of MaaS pilots in Gothenburg (Sweden) and Vienna (Austria) suggests the usage of multiple indicators, including among others change in: total number of trips made by the service, modal shift, and attitudes towards public transport. On the business level more metrics such as data sharing, and required organizational changes are considered relevant (Karlsson et al., 2017).

As already mentioned, in terms of equity in the transportation systems, mobility hubs could provoke significant enhancement in the mobility of underserved and commonly excluded population groups. Multiple design choices such as the location of the hubs, the pricing policy, and the services provided can determine the accessibility of the hub to the entire population. As past research has already highlighted, it is essential to avoid practices which favour those who have already access to transport or technology (Flemming, 2018). Therefore, to support the role of mobility hubs as game changer, policymakers should encourage the diffusion of the technological advancements and of the new services to the entire society.

The features of the hubs determine the fields of influence of the mobility hubs. For example, in case both passenger and freight services are integrated into mobility hubs, then, as indicated by research on MaaS effects, their impact could be noticeable to more sectors, such as e-commerce and food delivery (Le Pira et al., 2021). Moreover, the characteristics of hubs are also decisive for the attractiveness and the acceptability of the whole population, including users and non-users, of the hub. The addition of temporary or permanent retail uses within or around the area of a mobility hub, could assist in boosting the local economy and encouraging social gatherings (LADOT, 2017).

The population that a mobility hub serves is also related to its catchment area. Past research supports that the area of influence of transit hubs differs based on the available access modes. Access by bikes can increase the catchment area in comparison to walking (Flamm and Rivasplata, 2014). Ton et al. (2015) further support this argument by specifying that the existence of bicycle parking at a transit station can expand the access distance by around 234 meters. Apart from the characteristics of the hub itself, the transport network characteristics in the surrounding area can also affect its catchment area. Focusing on access by bike, the distance that people are willing to cycle to reach a transit station is reduced at dense urban networks (Hochwair, 2015) and in areas with a higher number of intersections on main roads (Guo and He, 2015). The integrated use of bike sharing and the metro is also dependent on the land use distribution around the metro station. Open spaces, such as parks and squares, positively affect the use of the bike sharing-metro combination during peak periods (Guo and He, 2015).

Societal values can also influence the success rate of mobility hubs. Mobility hubs are a newly introduced mobility offer that involves modes that are not privately owned but are shared. Depending on the local context, it is possible that society associates owning a vehicle with higher societal status and connects sharing and human-powered vehicles with a lower societal status (Pojani et al., 2018, Chun et al., 2019). Thus, it might be discouraging for part of the population to change from their car-centric travel behaviour to the shared mobility alternatives that are part of a mobility hub. However, as suggested by MaaS efforts (Karlsson et al., 2017), mobility hubs, might be able to induce improvement in the attitude of the society towards sharing and public transport mobility services.

The uptake and success of mobility hubs also depends on prices (of single tickets and subscriptions) of available transport modes. Several studies on Mobility-as-a-service platforms have shown that users are sensitive to prices of available transport mode options and potential users are highly sensitive to the monthly price they are asked to pay for a monthly subscription (e.g., see Caiata et al., 2020). Furthermore, Farahmand et al. (2021) have shown that in addition to mobility package price also parking prices is an influential factor in the commuter mode choices. Costs of shared mobility options as well as costs of deposits can be an important barriers for the use of the services among low-income and other vulnerable population groups. Some shared mobility providers have started offering reduced prices for low income groups. A shared mobility provider operating in the city of Utrecht in the Netherlands for example, offers residents with low-income a 75% reduction on the trip cost of shared bicycle and shared mopeds.

2.7 Conclusions on definitions, categorisation and typologies

The concept of "mobility hub" builds upon earlier concepts used in the academic literature and planning practice focussing on physical transfers in the passenger transport domain (e.g. park and ride facilities, multi-modal transfer points) and freight logistics domain (e.g., urban and regional distribution centers). The main value added of the mobility hub concept is that it can help to provide an integrated planning approach, involving integrating between policy instruments involving different modes, infrastructure provision, management and pricing, transport and land use measures and other policy areas.

There is a large variety in different operationalizations of mobility hub all fitting under concept of mobility hub. A common element in the definitions of mobility hubs is the presence of shared mobility services, e.g., shared bikes, shared scooters, and shared cars. Most definitions focus on the mobility and transfer components of hubs and include the presence of multiple modes and transfer between modes as requirements for mobility hubs. From these definitions we can derive the following definition of a mobility hub (minimal requirements): a *mobility hub is a physical location where different shared transport options are offered at permanent, dedicated and well-visible locations and public or collective transport is available at walking distance.*

The literature distinguish different integration aspects which influences the use and societal impact of mobility hubs. Firstly, the core idea of behind mobility hub concept is physical integration - the physical connection of multiple mobility modes including shared mobility, offering a physical location for users to switch between modes. Secondly, the mobility hub concept also relates to digital integration as a hub involves app-based forms of mobility. Digital integration describing how well information from various mobility offerings are integrated into a single digital platform. Thirdly, the literature identifies the need for mobility innovations to be inclusive and cater for the needs of a wide variety of different users. There is a rich literature on user and stakeholder participation processes in mobility planning and there are well established principles for inclusive design. Based on this literature, a multidimensional topological approach for mobility hubs has been developed, i.e. the SmartHubs integration ladder, based on three dimensions: the physical, digital and democratic integration dimensions. Each dimension has 5 levels. Furthermore, universal design principles are embedded in the SmartHubs physical, digital and democratic integration ladders as a common threshold to enhance broader usability, accessibility. Universal design, digital and democratic (participation) integration are typically missing in mobility hub concepts and definitions in the literature and planning practice.

The integration ladder enables the comparison of different hubs with different services, understanding potential effects, and aiding the integration of societal goals into mobility hub developments. The levels of the integration ladders help distinguish Smart Hubs from the pool of mobility hubs**.** We define a *Smart Mobility Hub* as a mobility hub which offers advanced levels of physical, digital and democratic integration (i.e. minimum level 2 on physical, digital and democratic integration). The higher up the physical, digital and democratic ladders, the "smarter" the mobility hub becomes. The hypothesis is that the "smarter" the mobility hub, the more user value is created, higher usage and user satisfaction levels are achieved and increased societal impacts can be expected (in terms of reduced car use and ownership levels, accessibility impacts, impact transport emissions, etc.). In other words, smart mobility hubs with high levels of integration are more likely to become a game changer game-changer towards inclusive sustainable urban mobility and accessibility.

3. DEVELOPMENT OF THE SMARTHUBS OPEN DATA PLATFORM

3.1 Introduction

The multidimensional mobility hub typology developed in Chapter 2 to classify existing mobility hubs in the SmartHubs living labs and elsewhere in Europe is made accessible in an interactive open data platform (ODP) which allows an easy "expert crowd" mapping of the operational/planned mobility hubs.

This ODP is a web-based system that makes a collection of datasets on mobility hubs (among other features) available for users and allows the visualisation of its components. The most important purpose of the ODP is to get a single point of access and overviews of the datasets to the consortium members, which have been and will be collected under common rules.

The ODP uses the open source data management software "Media Wiki" (see https://de.wikipedia.org/wiki/MediaWiki) and the software extension "semantic media wiki" (see https://de.wikipedia.org/wiki/Semantic_MediaWiki) to structure the data input based on the data model in Fig. 3.2. The basis of this technical framework is to make it possible to easily export and reuse the collected data in other applications / software. The Open Data Platform is currently under development. The platform has been made available to the researchers of the SmartHubs project and includes at the moment of writing this report (27.01.2022) 68 Hub descriptions, 10 of which are Case Studies in the SmartHubs Project).

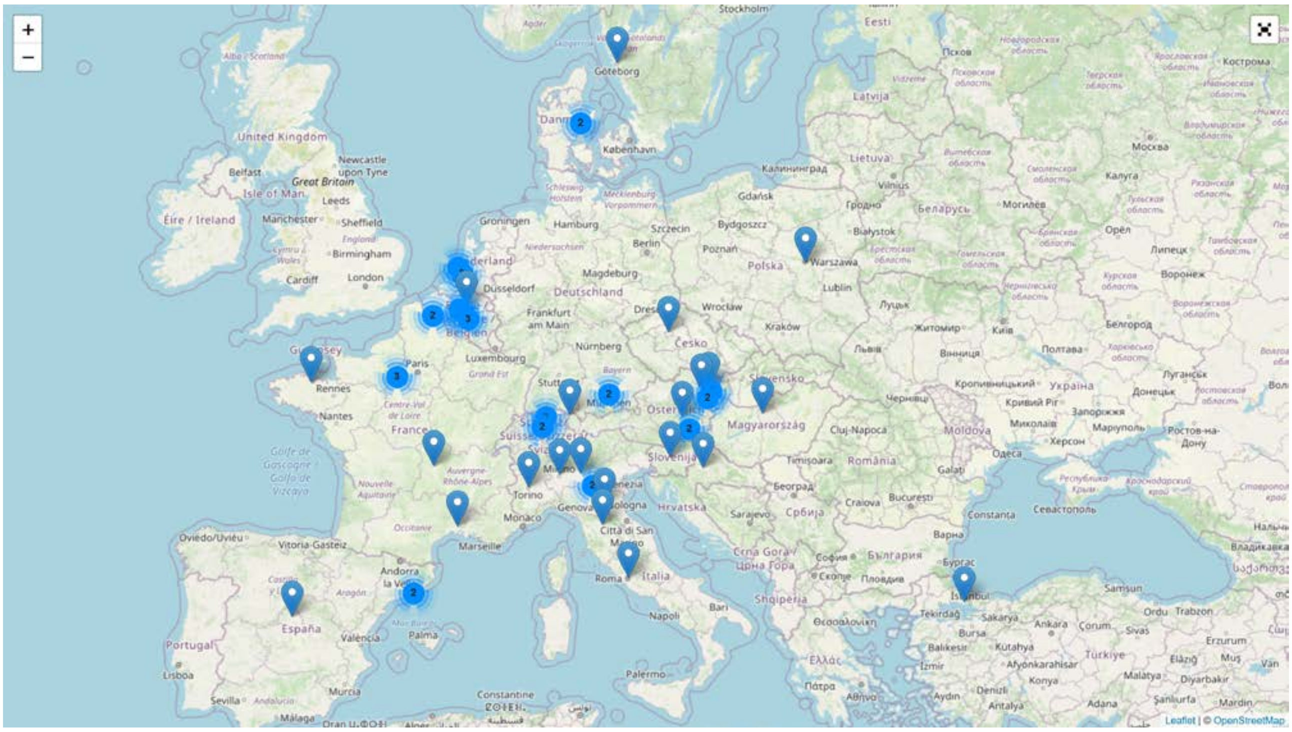


Figure 3-1 Distribution of 68 mobility hubs included in the SmartHubs Open Data platform across Europe (per 27 January 2022) Source: https://data.smartmobilityhubs.eu/wiki/Hubs

The platform serves as:

- an internal research tool to structure data around the Case Studies in the 5 SmartHubs Living Labs
- an open platform to directly open up knowledge generated in the SmartHubs project to the public
- an open platform to allow every interested person to showcase and analyse Mobility Hub examples

The remaining sections of this chapter provide a brief description of the structure, usage and data visualisations on the ODP.

3.2 Open Data Platform Workflow

The following diagram (Figure 3-2) shows the workflow of the SmartHubs case study locations and other mobility hubs (called learning cases) implementation into the ODP. For definitions please refer to section 3.3. At the time of writing (27-01-2022), there are 10 mobility hub descriptions as part of the SmartHubs case studies (CS) and 58 mobility hub “learning cases” (LC) have been added to the ODP. Modules from more SmartHubs Work Packages (WPs) and the adaption of the visualizations are also planned as a next step. In the next phase of the ODP development (planned for mid 2022), the ODP will open up editing to the broad public in order to enrich the ODP with further examples of mobility hubs.

In parallel to adding content into the ODP, also the structure and modules in the data model are further developed. Other WPs of the SmartHubs project will be able to structure parts of their data directly in the ODP (for example in preparation for Governance-issues).

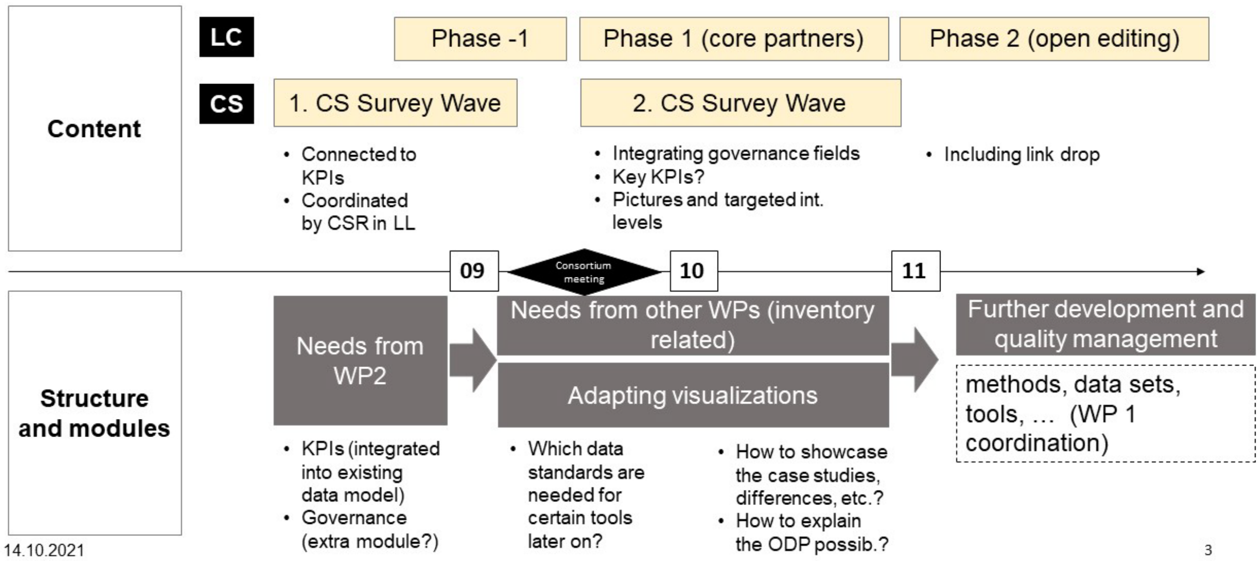
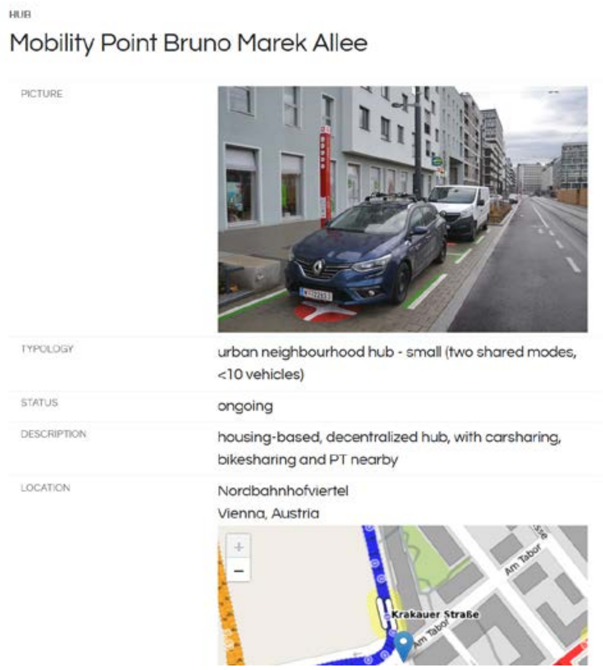


Figure 3-2 Workflow of ODP

3.3 Open Data Platform terms and model

In the ODP, a distinction is made **between an internal (with login) and external view**. While normal users see all hubs, for the SmartHubs consortium there is a clear distinction between learning cases (collection of well-equipped mobility hubs across Europe) and case studies (single selected hubs in living labs with defined location and more detailed information on the ODP). Figure 3.3 shows examples for each:

<table>
<tr><th>Case study</th><th>Learning case</th></tr>
<tr><td>


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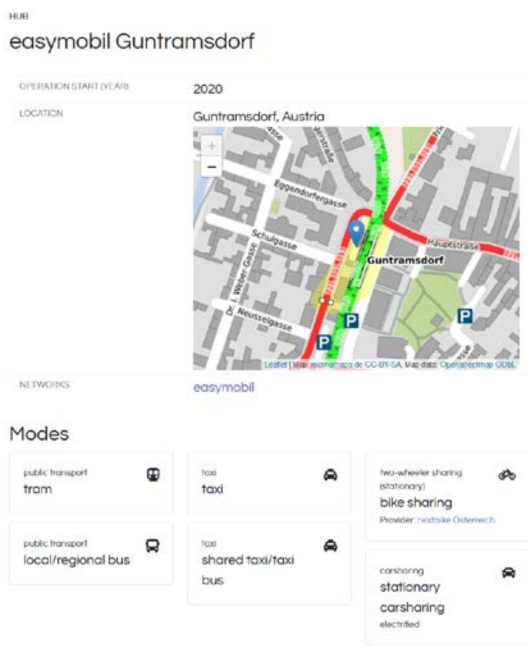

</td></tr>
</table>

Figure 3-3 Example of visualisation of a CS and a LC

For the moment the depth of detail to fill in by editors varies within the CS (more information) and LC (reduced information, focusing on the location and available modes).

The model of the Open Data Platform shows its modular backend and how it connects different sites and features. To understand the data model better, a couple of definitions are provided in table 3.1 and figure 3.4 shows the relation between attributes.

Table 3-1 Open data platform terms and definitions

Roles	Definition
CSE = Case Study Editors	defined persons (one per LL) working directly in the ODP
LLL = Living Lab Leaders	coordinates whole living lab ecosystem, bundles communication to implementation partners
LCE = Learning case editors	In the moment only active registration through ODP-Admin, in the future LCEs will be able to self-register themselves.
Terms	**Definition**
First survey	The „First Survey“ represents a first collection of Mobility Hubs, which was created by all Living Lab partners
Second survey	The “Second Survey” focusses on new input needed from CSEs due to changes in the data model.
CS = Case Studies	single selected hubs in living labs with defined location (or at least defined area of small locations test)
Hubs = A collection of registered Hubs across Europe	Mobility Hubs are dedicated locations where people can choose from different transport options. Minimum requirements: • at least 2 modes. Of these at least one individual shared mobility mode. The other can be a collective shared mobility mode = public transport) • at a permanent, dedicated, well-defined physical location (either with physical boundary or a geo-fenced digital boundary)
Networks	A collection of registered mobility-hub networks
Mobility-related services	A collection of mobility-related services, which are located in the area of the mobility Hub. This includes services for bikes (e.g. bike service station) as well as services for cars, such as the availability of parking spaces.
Additional Services	A collection of additional services, which are located in the area of the mobility Hub. These are, for example, the availability of WiFi, the presence of an info point or the possibility of making small purchases nearby
LC – Learning case	A mobility hub which is not part of the case studies in the SmartHubs project.

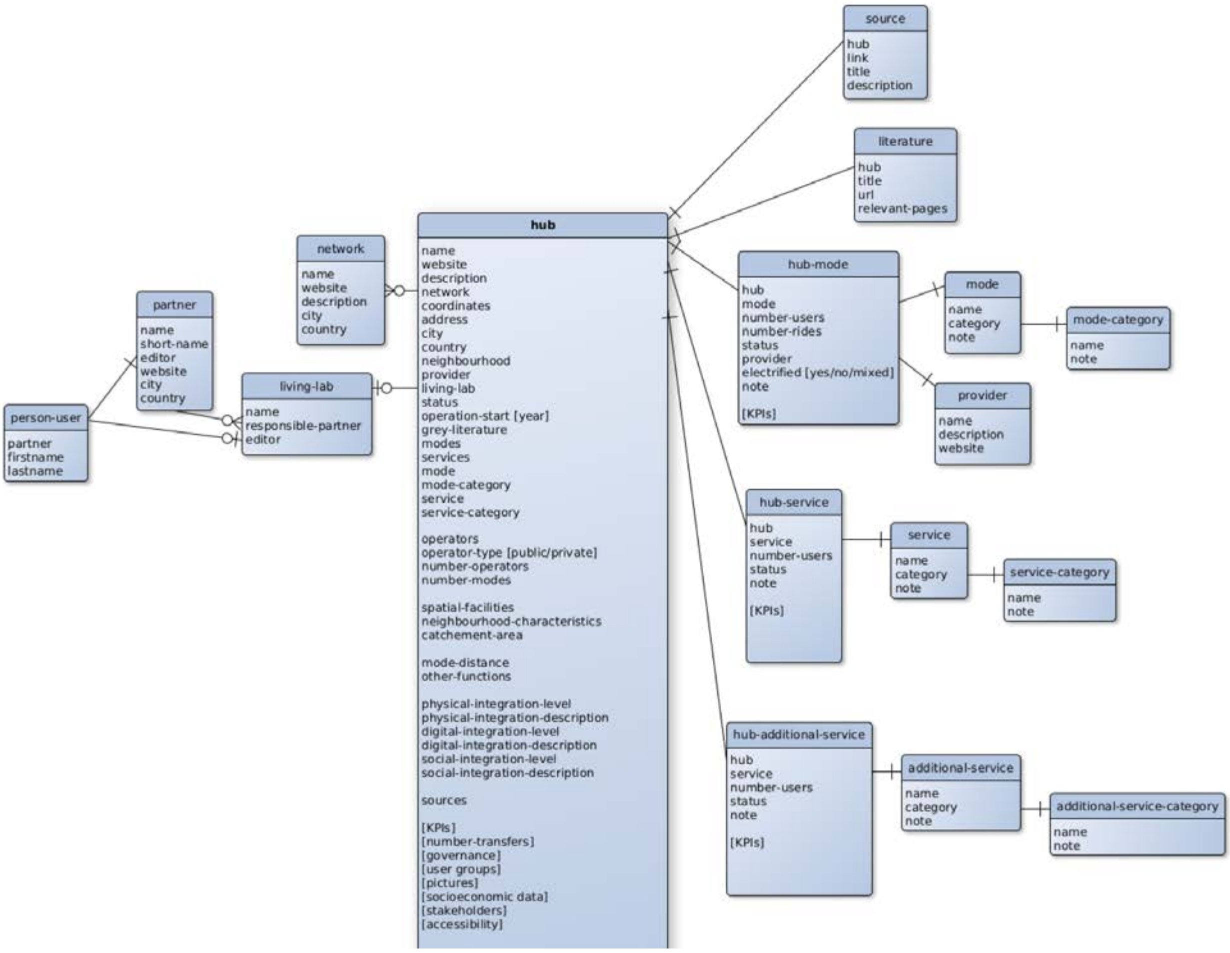

Figure 3-4: ODP data model

3.4 Handbook of the Open Data Platform

As central document for users (internal and external) to orient in the ODP a handbook was collected and will be further developed based on changes in the ODP, following mayor version are available:

- Handbook Version 2 (09.10.2021)
- Handbook Version 5 (10.11.2021)

3.5 Types of visualizations

The ODP has different options to visualize the case studies and its features. Examples are tables, diagrams and network visualisations, see Figures 3-4 to 3-6.

Case Studies - Modes

CASE STUDIES: Overview · Integration Levels · Modes · Mobility-related Services · Additional Services · Maps · Providers · Actors

HUB	#							FREE TEXT
Anderlecht hub	8	• stationary carsharing	• metro • tram	• ride-hailing	• taxi	• bike sharing • step/kick scooter sharing	• bike sharing	
Beylikdüzü Hub	4		• Metrobus • local/regional bus		• taxi	• step/kick scooter sharing		Uber, Private Shuttles
Haagse Markt	6	• free floating carsharing • stationary carsharing	• local/regional bus • tram			• moped/motorcycle sharing	• bike sharing	
Leyenburg Hub	6	• free floating carsharing • stationary carsharing	• local/regional bus • tram			• moped/motorcycle sharing	• bike sharing	automated shuttle (provided by HTM)
Mobility Point Bruno Marek Allee	5	• stationary carsharing	• local/regional bus • tram				• bike sharing • cargo bike sharing	
Mobilitätstation Pillichsdorf	2	• stationary carsharing	• local/regional bus					
Schiedam Hub	8	• stationary carsharing	• local/regional bus • local/regional			• moped/motorcycle sharing	• bike sharing	

Figure 3-1 Case Studies Table

- Maps of the case study location with different predefined zoom-levels:

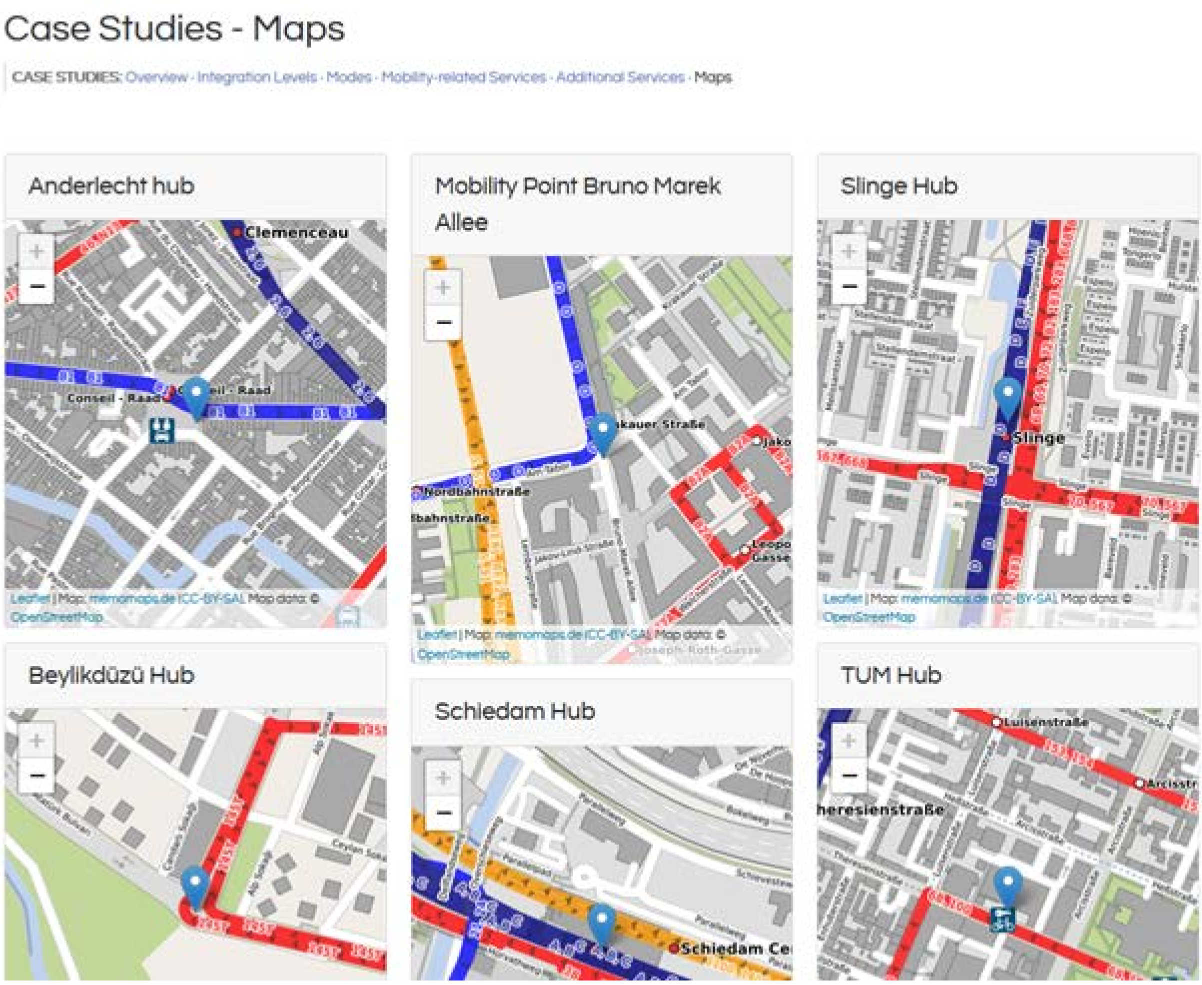

Figure 3-2 map-view of hub locations

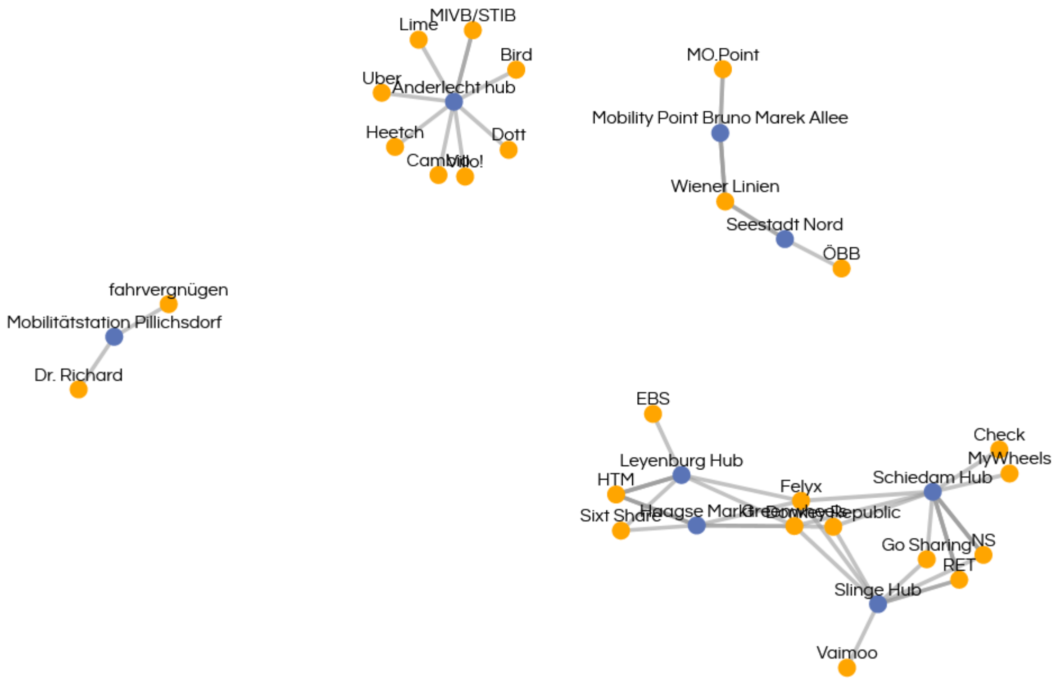

Figure 3-3 providers active in case studies (Examples of Vienna, Belgium

3.7 Quality assurance

When the data is included into the OPD responsible partner (MOVE) will perform some basic quality inspection. This includes check for dataset completeness, basic correctness of data inserted in different data fields (not content related but data-type related). Also MOVE will administrate new registered users and check their activities to avoid unwanted activities on the ODP.

3.8 Further steps and outlook

As sketched in the introduction it will be possible for everyone interested in the topic of Mobility Hubs to contribute to the ODP in the future. It is planned (mid 2022) to open up ODP for the general public. This would make it possible for interested experts to also map their mobility hub on the same level of detail in the ODP as the SmartHubs Case Study Hubs.

In a long term perspective there is already discussion in the core team of the project on how to ensure the existence of the ODP also after the project lifetime - for example through hosting on university servers, etc, but decision is pending

In the moment also the “Level or type” of openness of the data is not specified - a prefered Creative Commons license would be “Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0)” (see https://creativecommons.org/licenses/by-nc-sa/4.0/).

In the future it can be considered to invite, include, and provide rights to external partners (EU-institutions and transnational projects) to contribute to further development of the data model, export functionalities and visualizations.

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ANNEX 1: OVERVIEW OF ENGLISH, DUTCH AND GERMAN LANGUAGE DEFINITIONS OF MOBILITY HUBS

English language definitions	
Amoroso et al. (2012)	An intermodal hub can be defined as a place where transportation networks are organized to facilitate intermodality between different modes. Intermodal hubs should intrinsically have an urban dimension and be globally designed as “plug flows”, being interfaces between transport networks and territory, being an element to create “urbanity”. Intermodal hubs focus technical, social, urban, transport, service aspects and they play a multi-modal, multi-service, multioperator role.
Anderson et al. (2017)	Mobility hubs are agglomerations of transportation modes that concentrate emerging shared mobility services in well-defined locations, delivering several benefits to users.
Coenegrachts et al. (2021)	The shared mobility hub clusters different new and conventional mobility services at a physical location.
CoMoUK (2019)	A mobility hub is a recognisable place with an offer of different and connected transport modes supplemented with enhanced facilities and information features to both attract and benefit the traveller. A mobility hub is designed and is spatially organised in an optimal way so as to facilitate access to and transport between modes, including human-powered and shared modes, as well as provide extra transport-related and digital services.
eHUBS (2021)	eHUBS are on-street locations that bring together e-bikes, e-cargo bikes, e-scooters and/or e-cars, offering users a wide range of options to experiment and use in various situations. eHUBS can vary in size (minimalistic, light, medium, large), type of location, and type of offer. They can be small and located in residential areas, with just one or two parking spots, or bigger and positioned close to stations and major public transport interchanges.
Garde et al. (2014)	mobility stations at strategically relevant traffic nodes – incbetween different modes of transport including the availability of environmental-friendly forms of mobility including at least two forms of public transport. A basic requirement of mobility stations is the connection
Los Angeles Department of City Planning (LADOT) (2017)	Mobility Hubs provide a focal point in the transportation network that seamlessly integrates different modes of transportation, multi-modal supportive infrastructure, and place–making strategies to create activity centers that maximize first–mile last mile connectivity.
Metrolinx (2011)	Mobility hubs consist of major transit stations and the surrounding area. They serve a critical function in the regional transportation system as the origin, destination, or transfer point for a significant portion of trips. They are places of connectivity where different modes of transportation – from walking to riding transit – come together seamlessly and where there is an intensive concentration of working, living, shopping and/or playing.
Miramontes (2018)	transport nodes where different mobility options, especially public transport and shared mobility services are spatially concentrated and virtually integrated through information and marketing
Miramontes et al. (2017)	A multimodal mobility hub connecting public transport (PT) and new shared mobility services.
Navrátilová et al. (2021)	Mobility Hubs are transit stations that lie on the backbone of public transport, connecting regional headquarters with regional centers (district or regional city, but also, for example, municipalities with extended powers). A variety of mobility solutions is offered at mobility hubs to cover the first as well as the last mile. They minimise the time needed for the transfer while removing physical barriers to change the means of transport. Mobility Hubs also serve to distribute information on public transport arrivals and to calculate travel times, including the necessary transfers to move from individual to public transport and vice versa. They often offer new types of sustainable mobility - bicycle rentals, electric scooters, charging stations for electric cars, as well as information on parking, etc.
Pitsiava-Latinopoulou &	The main objective of a passenger intermodal terminal is the integrated and efficient transfer of passengers between various routes and different modes of transport

Iordanopoulos (2012)	
Schemel et al. (2020)	In the current transport system, mobility hubs are commonly seen as physical places that connect a variety of transport modes. A mobility hub can be anything from a bus stop and a bike sharing station to an inner-city main train station. Mobility hubs need to enable the physical co-location of modes. A functioning mobility hub needs to provide a variety of modal options and act as an interchange between these modes. It needs to effectively integrate in existing, planned and future transport systems, and cater to various and changing user needs. Mobility hubs are the places where different transport modes and services meet, so that people and goods have access to mobility solutions and a seamless journey. In the context of this report and the developed mobility hubs framework, a mobility hub becomes a driver for sustainable mobility behaviour and transforms from a place of transition to a destination within a city's fabric. A mobility hub is as much defined by its provision of a variety of environmentally-friendly transport modes, as by its ability to actively influence user behaviour towards adopting these alternative transport options.
van Gils (2019)	An eHUB is a physical cluster of different transport modalities. It is a transport hub based at a local level. Different zero-emission (electric as well as non-electric) and shared transport modes are made available. EHUBs can be linked together in a network, as well as connected to the existing public transport network. This combination creates transport hubs and enhances connectivity.
Dutch language mobility hub definitions	
Crow (2021)	Een mobiliteitshub is een knooppunt in een multimodaal mobiliteitsnetwerk. Op dit knooppunt komen verschillende vervoerswijzen en hun infrastructuur, groottes en schaalniveaus samen. Een hub fungeert als Een mobiliteitshub is een knooppunt in een multimodaal mobiliteitsnetwerk. Op dit knooppunt komen verschillende vervoerswijzen en hun infrastructuur, groottes en schaalniveaus samen. Een hub fungeert als begin-, eind- of overstappunt in de reis. Daarbij is een onderscheid te maken tussen vervoerstromen van personen en vervoerstromen van goederen (logistiek en stadsdistributie), die kunnen overlappen
DELVA Landscape Architects / Urbanism et al. (2019)	Een collectief parkeergebouw waarvan bewoners, werknemers en bezoekers gebruik maken, bij voorkeur gecombineerd met andere collectieve diensten, zoals energieopwekking/opslag of wateropvang. De hubs zijn zo gepositioneerd dat iedereen er een op loopafstand tot z'n beschikking heeft.
Gemeente Utrecht (2021)	Een deelhub is een centrale plek waar deelauto's en andere vervoermiddelen, zoals elektrische scooters en fietsen beschikbaar zijn.
Goudappel et al. (2021)	Een hub is in onze ogen een OV-knooppunt en/of een geclusterde, ruimte-efficiënte parkeeroplossing voor meerdere doelgroepen (openbaar, dubbelgebruik) die een naadloze overstap van het ene naar het andere vervoermiddel mogelijk maakt. Mobiliteitshubs vormen daarmee een essentiële schakel in het systeem van gedeelde mobiliteit. Elke reiziger kan elke keer opnieuw zijn of haar reis samenstellen, afgestemd op zijn of haar behoeften van dat moment; ruimtelijk komt dit samen op mobiliteitshubs. Naast dat de hub dient als overstap van de auto of fiets naar het OV, is het ook een plek waar functies kunnen worden toegevoegd (horeca, pakketmuur) of gebruikers kunnen verblijven (flexwerkplekken, overlegruimtes).
KiM (Witte et al., 2021)	Het KiM gebruikt een brede definitie van hubs als fysieke schakels tussen vervoersmodaliteiten die naast hun mobiliteitsfunctie ook als concentratiepunt voor ruimtelijke ontwikkeling kunnen dienen. Hubs bestaan, in de praktijk of in conceptvorm, op verschillende schaalniveaus, van een buurtvoorziening tot een (inter)nationale mainport. Hubs verschillen ook in de vervoersdiensten die er aangeboden worden. Dit kan een multimodale overstap zijn maar ook toegang tot deelmobiliteit en lichte elektrische vrachtvoertuigen (LEVV). Daarnaast verschillen ze in de mate waarin ook niet-mobiliteitsgerelateerde diensten aangeboden worden Mobiliteithubs zijn schakels in het mobiliteitssysteem die de overstap tussen vervoermodaliteiten zo prettig en efficiënt mogelijk maken. Ze kunnen ook een wisselwerking hebben met nabijgelegen voorzieningen, van een lokale bibliotheek als wachtruimte voor de bus tot een grootschalig cluster van kantoorruimte en retail rond de luchthaven

Mobiliteitsalliantie, (2020)	Hubs bieden een plek waar vraag- en aanbod van vervoersmodaliteiten op elkaar aansluiten. Verbeterd comfort en efficiency staan hierbij centraal, voor zowel personen- als goederenmobiliteit. de “hub” vormt het fysieke overstap(slag)punt van de ene op de andere modaliteit. Op een hub komen digitale (informatie) stromen bij elkaar om de seamless reis van mensen en/of goederen mogelijk te maken
Natuur & Milieu(2020)	Een mobiliteitshub is een hoogwaardige fysieke locatie die een gevarieerd aanbod van duurzame en actieve vervoersmiddelen combineert met aangename verblijfsmogelijkheid. Reizigers hebben keuzemogelijkheden en kunnen eenvoudig overstappen op een ander vervoersmiddel. De hub is meer dan een verzameling of knooppunt van vervoersmiddelen. Een mobiliteitshub is een aantrekkelijke en herkenbare omgeving, die comfortabel en veilig is. Het is er aangenaam voor reizigers om te verblijven en over te stappen; het is er ook aangenaam voor omwonenden en anderen. Hubs zijn schakels in een netwerk van mobiliteit en zorgen ervoor dat vervoersmiddelen makkelijker gebruikt kunnen worden. Een hub is op loopafstand van een halte van het openbaar vervoer. De maximale afstand tot een hoogwaardige openbaar vervoervoorziening is 1 kilometer en de maximale afstand tot een openbaar vervoer halte is 500 meter. Dit biedt de reiziger vrijheid en flexibiliteit.
reisviahub.nl, (2021)	Een hub is een plek waar je kunt overstappen van het ene naar het andere vervoermiddel. En waar je op een prettige manier even kunt wachten. Extra voorzieningen maken de hub tot een aangename plek.
German language mobility hub definitions	
Fallast & Huber (2015)	An den multimodalen Knoten wird ein möglichst breites Spektrum des Mobilitätsa ngebotes der Stadt räumlich konzentriert zur Verfügung gestellt. An diesen multi modalen Knoten soll sowohl der leichte Zugang zu den verschiedenen Verkehrsmitteln ermöglicht werden, als auch das Umsteigen zwischen den verschiedenen Verkehrsmitteln erleichtert werden. Multimodale Knoten sind auch2019 bevorzugte Standorte für Radverleih-Angebote.
IGES Institut (2021)	Mobilitätsstationen sind i.d.R. durch ihre räumlich enge Verknüpfung verschiedener Verkehrs- und Mobilitätsangebote geprägt und tragen dadurch wesentlich zur Förderung der Inter- und Multimodalität bei. Dabei kommen den öffentlichen Verkehrsmitteln und geteilten Mobilitätsangeboten (u.a. Carsharing und Bikesharing) zentrale Rollen zu.
Jansen et al. (2015)	Eine Mobilstation ist eine Kombination aus Mobilitätszentralen und Umsteigepunkten, die effizient verschieden Verkehrsmittel miteinander verknüpft und an großen Stationen Beratungen in Servicegebäuden anbietet. Grundvoraussetzung jeder Mobilstation ist, dass es mindestens einen ÖPNV Anschluss gibt und der Umweltverbund (Fuß- und Radverkehr) Vorrang vor dem motorisierten Individualverkehr hat. Darüber hinaus bieten Mobilstationen unterschiedliche Formen des Sharings an. Es gibt Bike- und Carsharing Angebote, sowie oftmals eine Autovermietung. Eine Mobilstation zeichnet sich dadurch aus, dass sie durch moderne Kommunikations- und Informationsdienste Funktionen, wie die Planung der kürzesten und effizientesten Route bereithält. Die Mobilstation ist der bauliche Ausdruck einer modernen Mobilität und bieten jedem die Möglichkeit sich effizient und umweltbewusst in einem bestimmten Radius fortzubewegen.
Rehme et al. (2018)	Verknüpfungs- oder Knotenpunkt in den Wegeketten, an dem unterschiedliche Mobilitätsdienstleistungen bereitgestellt werden. . Transit-/Umstiegestationen mit den sich angrenzenden fußläufig erreichbaren Bereichen (ca. 800 Meter Radius). Verknüpfung von Mobilitätsketten.
Rube et al. (2020)	Mobilitätspunkte sind öffentliche, räumlich und gestalterisch verknüpfte Infrastrukturanlagen, an denen mindestens ein geteiltes Verkehrsmittelangebot bereitgestellt wird. Sie können sowohl als intermodale

	Verknüpfungspunkte als auch als Zugangspunkt zu multimodalen Mobilitätsdienstleistungen dienen.
Zientek et al. (2018)	Eine Mobilitätsstation ist ein Ort der eine Räumlichkeit, an dem unterschiedliche Mobilitätsangebote und Services miteinander verknüpft werden und ein einfacher Zugang zu diesen gewährt wird. Durch die Bündelung und Vernetzung mehrerer Mobilitätsangebote wird Multimodalität und Intermodalität gefördert und eine Mobilitätsgarantie (auch ohne privaten Pkw) geschaffen.
Zukunftsnetz Mobilität NRW (2017)	multimodale Verknüpfungspunkte verstanden, an denen mindestens zwei Verkehrsmittel verknüpft werden. Dabei ist die Verknüpfung so gestaltet, dass ein örtlicher Wechsel zwischen den Verkehrsmitteln durch räumliche Konzentration der Angebote und bestenfalls durch entsprechende Gestaltungsmaßnahmen mit einem Wiederkennungswert für den Nutzer ermöglicht wird. Die Mobilitätsangebote sind dabei nutzerfreundlich gestaltet.