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What the HUB? Towards a typology of mobility hubs

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Abstract

Mobility hubs are increasingly mentioned in urban planning and transportation policies as a potential solution to societal challenges such as urban accessibility and affordable public transport. Despite its frequent referencing, an overall academic conceptualisation in the form of a typology is still lacking. This study contributes to this gap in the literature by identifying six types of mobility hubs by the method of grounded theory. Data for this study were gathered by conducting 16 expert interviews, one panel discussion, a text analysis of 33 publications, and a literature study. The results of this paper are threefold. First, an analysis of the use of the concept showed that mobility hubs are seen as a 'catch-all' concept that covers many conventional passenger transport hubs. Nevertheless, mobility hubs are shown to be different from conventional passenger transport hubs by their broader scope, denser transport network, focus on facilities and services, and their role in spatial development. Second, the development of a typology resulted in six distinct types of mobility hubs. These types are determined by their level of quantity and complexity of both services and facilities, and transport modes. These determinants are expected to be mutually reinforcing, with the exception of two types of hubs. Finally, five future challenges are identified. The results of this exploratory study should be interpreted as a reflection of the potential types of mobility hubs. The results can be used for an initial differentiation of mobility hubs before additional research into the local surroundings is conducted.

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1. Introduction

Over the last years, urban regions have shown a trend of increasing population levels and decreasing levels of available space (UN-Habitat, 2020). The combination of activities in urban areas such as working, living, and recreation are putting the liveability and accessibility of the area under pressure (UN-Habitat, 2020). The mobility patterns that go together with these activities play a substantial role in this pressure by influencing transport infrastructure and the level of emissions (Mraihi et al., 2015; van Wee & Handy, 2016). The use of mobility hubs is internationally suggested by researchers and governments as a potential solution (Anderson et al., 2017; Bell, 2019; Tran & Draeger, 2021; Ministerie van Infrastructuur en Waterstaat, 2019; SANDAG, 2021).

The concept of mobility hubs is getting increasingly more attention in publications of (local) governments, consultants, project developers, and passenger transport companies (Provincie Zeeland, 2021; Royal HaskoningDHV, n.d.; AM, 2020; NS, 2021). However, the many different uses of the concept often contradict each other and present a variety of focus points. Presently, little is known about the concept of mobility hubs. This research contributes to this gap in knowledge by developing a conceptual framework in the form of a typology of mobility hubs. Consequently, this study aimed to answer the following research question: 'What are the different types of mobility hubs?'. In addition to a conceptual framework, this research aimed to create a coherent body of knowledge of the concept of mobility hubs. This has been approached by analysing its context and by presenting its future challenges. More specifically, the aim of this study was threefold:

1) To investigate in which context the concept of mobility hubs is empirically used.
2) To conceptualize mobility hubs in the form of a typology, that is, to propose the key properties, empirical regularities, and interrelations.
3) To contribute to the forthcoming implementation of mobility hubs by proposing its future challenges, which stand for tasks that are difficult to accomplish, but necessary for mobility hubs to function.

Recently, some researchers touched upon the topic, for example with research on the user needs at mobility hubs (Bell, 2019; Tran & Draeger, 2021). However, a clear conceptual framework in the form of a typology of mobility hubs has not yet been academically researched. This paper contributes to this gap of literature by providing the first mobility hubs typology based on grounded theory and thereby capturing this movement in academic literature.

Research on mobility hub types is socially relevant for multiple reasons. One of the main reasons is that mobility hubs can contribute to the liveability and climate objectives of regions (Anderson et al., 2017; Tran & Draeger, 2021). Furthermore, mobility hubs can enhance economic productivity and efficiency by allowing each part of the trip to be completed in the most cost-efficient way (Anderson et al., 2017; Monzón et al., 2016). In this context, especially the development of a typology of mobility hubs is socially relevant, since typologies support policy makers in discussing the benefits and needs of a concept. This makes typologies a suitable instrument for policy making (Peek, 2006).

This paper is structured as follows. Firstly, more information is given about the definition and the scope of mobility hubs studied in this paper. Secondly, an explanation is given of the data and the academic methods of grounded theory and typology development. The data and methods section is followed by an analysis of the context in which the concept is used. After the identification of the context, the typology is developed. Types were developed by identifying the properties and dimensions, analysing empirical regularities, and investigating interrelationships. The typology is followed by the identification of future challenges of mobility hubs. Finally, a conclusion is drawn, points for discussion are given, and suggestions for future research are made.

2. Definition and scope

Before analysing the mobility hub concept, this chapter explains the definition of mobility hubs that will be used throughout this paper and the scope of this study.

2.1. Definition

In this study, the definition of mobility hubs formulated by the Netherlands Institute for Transport Policy Analysis (KiM, 2021) is used:

“A mobility hub is a physical link between multiple transport modes, which, in addition to its mobility function, can serve as a concentration point for spatial development.”

This broad definition of mobility hubs is used as there is currently no generally accepted definition in the existing literature. Most definitions tend to focus on mobility and spatial development (Monzón et al., 2016; Anderson et al., 2017), which are both covered by this definition. Important in the above definition is that it includes multiple transport modes such as private vehicles and public transport modes. It is also noteworthy that the mobility hubs facilitate multimodality by their physical link in passenger transport, which can be facilitated at different levels of scale. In this context, multimodality stands for distinct journeys travelled with different kinds of modes or combinations of transport modes (Groth & Kuhnimhof, 2021).

The definition of passenger transport hubs has many similarities with the definition of mobility hubs, but also some dissimilarities. The following definition is used for passenger transportation hubs:

“A passenger transportation hub is a place that provides a passenger with a seamless journey in a joint travel chain with distinct modes of transportation.’’

(Storme et al., 2021).

Both hubs are concentration points where multimodality is offered. However, mobility hubs differ from passenger transportation hubs by their broader focus area (see Fig. 1). In contrast to passenger transport hubs, which focus especially on the interconnection between the different collective transportation systems, mobility hubs also focus on spatial development and accessibility to and from collective and non-collective transport systems (Storme et al., 2021). For example, mobility hubs differ by providing a more mazed transport system (Storme et al., 2021). Hence, one can say that mobility hubs partly consist of conventional passenger transport hubs, but not the other way around (see Fig. 1). Besides the distinct definitions in the literature, there are empirical differences between passenger transport hubs and mobility hubs which are thoroughly explained in Chapter 5.

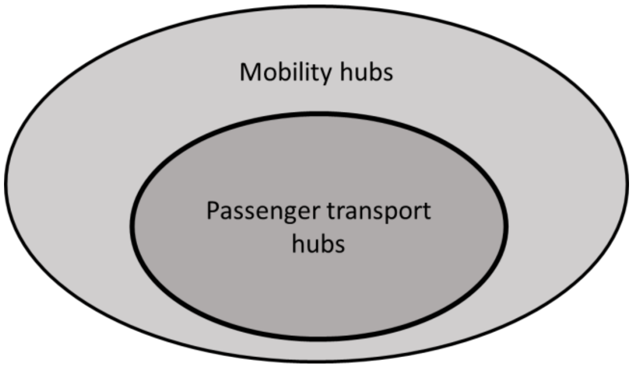


Fig. 1. Visualisation of the relation between passenger transport hubs and mobility hubs.

2.2. Scope

In this study, the scope of mobility hubs is mainly set by the aforementioned definition of mobility hubs and by the additional considerations outlined in this section. These additional considerations relate to the mobility hub's target group, scale, and the number of transport modes offered. The defined scope in scale and number of transport modes that is used in this study is visualised in Figure 2.

Only the mobility hubs that mainly focus on passenger travel are included in this study. As a consequence, hubs that focus on cargo are outside the scope and will not be considered. Examples are distribution hubs and logistics hubs such as distribution centres and ports.

The second additional consideration is made based on the scale. The mobility hubs studied in this paper mainly focus on a local, regional, interregional, or national scale. Hence, mobility hubs such as airports that are characterised by operating on an international scale, are not incorporated. However, mobility hubs such as central railway stations that have destinations abroad are incorporated, as their focus is mainly on a national scale instead of an international scale.

Finally, only mobility hubs that offer an interchange between at least two different public or shared modes of transport available at the mobility hub are included. This additional consideration is derived from the definition of mobility hubs of Storme et al. (2021). An example of a mobility hub within this scope is a metro station that also offers transport modes like shared mopeds or bicycles. An example of a potential mobility hub outside this scope is a hub where only one transport mode is offered such as a local bus at a bus stop or a shared bicycle at the corner of a street.

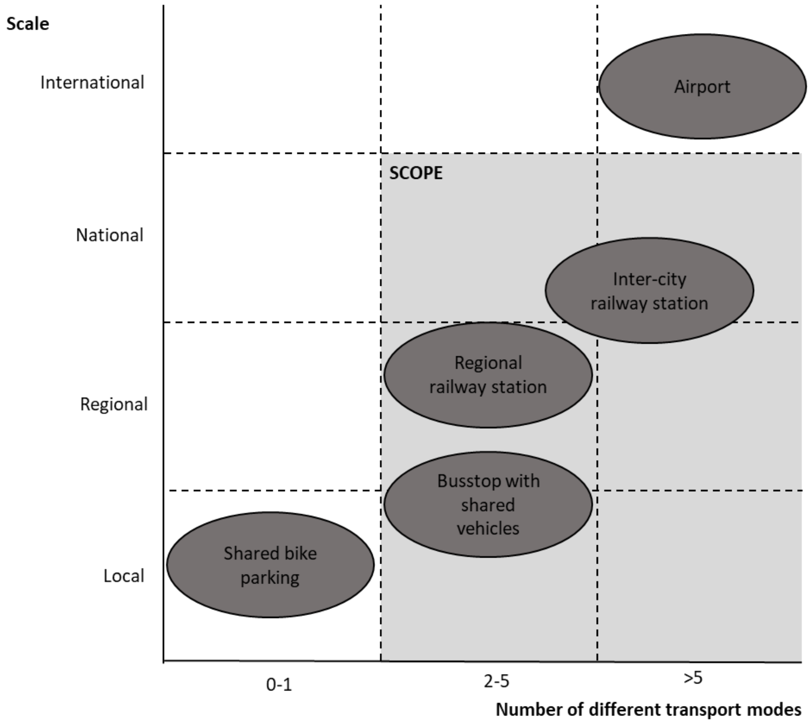


Fig. 2. Research scope.

3. Data and methods

This study is based on one main method and five different ways of data gathering. The first part of this chapter consists of describing the various data usages and their sources. The data used in this research were gathered by five different methods, as incorporating various data sources fits best with the exploratory nature of grounded theory (Denk et al., 2012).

The second part of this section elaborates on the methodology of this study. The main method used is grounded theory (Glaser, 1992). This method was applied to gather the data for the development of a typology. The distinct steps of typology development structured the data and contributed to a consistent process of theory building.

3.1. Data

Five ways of data gathering were used in this study. Firstly, literature on the typologies of other transport hubs was analysed. Secondly, text analysis was conducted on several textual sources published by different organisations involved in the development of mobility hubs. Thirdly, expert interviews were taken. Fourthly, a panel discussion was conducted. Finally, the data gathered were examined with academic literature. All different data were combined into a typology.

The literature study consisted of literature on transport hub typologies and contextual literature on multimodality and the integration of land use and public transportation. This literature is further explained and motivated in the literature study of this research. The combination of text analysis, expert interviews, and the panel discussion formed the empirical study and is described further below. The data sources of the literature study and the empirical study are visualised in Figure 3.

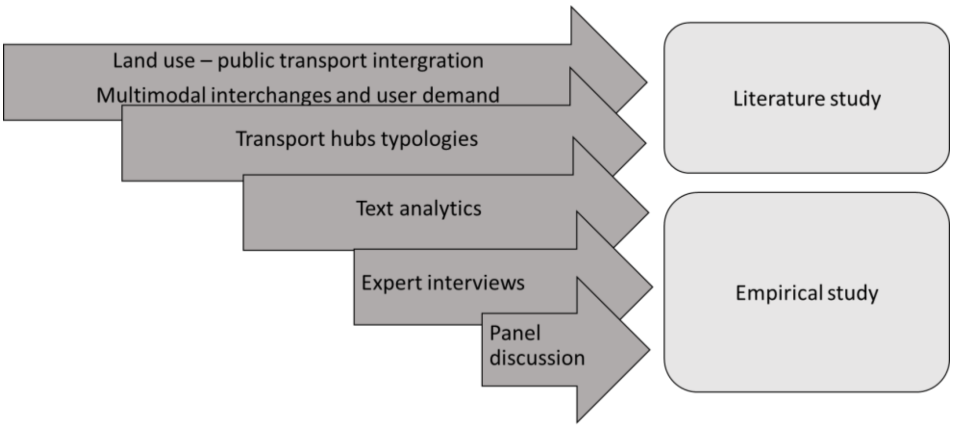


Fig. 3. Data sources.

3.1.1. *Expert interviews and panel discussion*

Semi-structured interviews were conducted to provide a greater understanding of an experts' perspectives and experiences. This way of interviewing creates in-depth data and is commonly used in grounded theory, as it structures theory development while giving space for discoveries (Bluff, 2005).

The experts interviewed can be classified into four different professional stakeholder groups, namely consultants, governmental institutions, mobility providers, and property developers. In total, 16 experts from 13 different organisations were interviewed (see Appendix A). Experts were selected by their professional involvement in projects or policy making related to mobility hubs. The four classified professional stakeholder groups are according to researchers the most important parties identified in the development of mobility hubs in the Netherlands (CROWa, 2021; KiM, 2021).

Attention was given to the geographical diversity of the expert group. Therefore, various experts that operate nationally, regionally, and locally have been interviewed, within and outside the Randstad of the Netherlands. All interviews were conducted via teleconferencing, and most of them were recorded. The interviews were coded in the analytical software programme ATLAS.ti.

From this group of interviewed experts, seven experts have participated in conducting a panel discussion (see Appendix A). In this panel discussion, insights into the future challenges were further discussed and investigated. Furthermore, the outcomes of this study were reflected and validated. The panel discussion was conducted via teleconferencing.

3.1.2. *Text analysis*

Text analysis was conducted on various publications in order to get insight into the context in which the mobility hub is described. This method enables researchers to exploit more unstructured data and thereby tap into unreached knowledge. The method is previously used in transport literature (Kinra et al., 2020; Schmalz et al., 2021; Serna & Gasparovic, 2018) and has contributed to decision making in transport policy (Kinra et al., 2020).

For the text analysis, 33 publications were selected. Various publications were analysed such as case study reports, policy papers, white papers, and articles. All publications are described in Appendix B. Publications were selected from all four groups of professional stakeholders and additional publications of knowledge institutions were included. Differentiation between the publications was made in two different ways. First, publications that have mobility hubs as their main topic were differentiated from publications that describe mobility hubs as a part of their content. Second, publications were clustered by source.

Text analysis was conducted by investigating word frequency, colocations of words, and comparison of sources. Mainly the technique of automatic coding was used. After automatic coding, the codes were individually checked to ensure the coding was consistent and that all word forms such as adjectives or plural forms and synonyms of a code were included. For instance, the code of ‘social goal’, should have included similar words like ‘social objective’ and ‘target’, and should have excluded words like ‘target group’.

3.2. Methods

The main research method to develop a typology of mobility hubs in this paper was grounded theory. Both typology development and grounded theory have guidelines for theory building, which are further explained in this section.

3.2.1. Grounded theory

In this study, the basic methodology used to gather data is based on the principle of grounded theory. Grounded theory is an inductive research methodology that is used to construct theories. This research methodology is particularly well-known in social sciences but is also frequently used in transport literature (Denk et al., 2012; Lumsdon & McGrath, 2011; Mingardo et al., 2015). This inductive research method was best suited for this study due to the exploratory state of mobility hubs and due to the capacity of this method to generate a theory from perceived patterns (Denk et al., 2012).

The method of grounded theory was first developed by Glaser and Strauss (1967). Over the years, Glaser and Strauss developed different perspectives on grounded theory (Strauss 1978; Strauss and Corbin, 1990; Glaser 1992). In this study, the work of Glaser (1992), also known as the Glaserian or orthodox grounded theory approach (Lumsdon & McGrath, 2011), was used. The Glaserian approach was chosen for different reasons, but mainly because it allowed for the central category of the phenomenon of mobility hubs to develop during the study. To be able to use the Glaserian Grounded Theory method, this study has included all procedures, including coding, constant comparison, theoretical sampling, memoing, category building, property development, densification, core category identification, delimitation, saturation, sorting, and communication of the research results.

3.2.2. Typology analysis

Grounded theory was used as the main research method to investigate data for the typology. In academic literature, a typology analysis is generally used as a strategy to analyse descriptive qualitative or quantitative data and to develop types within a phenomenon. Contrary to traditional linear or interaction theories, typology theories have the advantage of offering non-monotonic functions in the relationship between independent and dependent variables (Doty & Glick, 1994). Especially the ability to dive into complex structures makes typology development useful (Praharaj & Han, 2019). In this study, the typology was developed to understand and simplify complex processes of non-monotonic functions in the concept of mobility hubs. Furthermore, the typology was developed to provide a framework that allows the identification of similarities and differences among the mobility hubs. Hence, it provided a greater understanding of the process that led to variation among groups of mobility hubs.

Although typologies are most frequently used in human sciences (Given, 2012), the method has shown to be useful also in other disciplines such as in urban and transport sciences. Examples of typologies in transport literature are typologies of travel behaviour (Oostendorp et al., 2019) and typologies of transport hubs like airports (Mashhoodi & van Timmeren, 2020). Typologies are also used in urban economic literature, for instance, in the context of the economic performances of cities (Praharaj & Han, 2019). The typologies of transport hubs are described more thoroughly in the literature study of this research.

The terms typology, classification scheme, and taxonomy have been interchangeably used in the existing literature (Given, 2012; Hambrick, 1983; Scott, 1981). However, taxonomy and classification schemes are different from typologies. The main difference is to be found in the results. Whereas the outcome of classification systems and taxonomy are related to hierarchically nested decision rules, the outcome of typology refers to a theory of conceptually derived interrelated sets of ideal types. The difference in results also indicates differences in implementation. Whereas classification is used for the construction of a mutually exclusive and comprehensive set of organisational forms, typologies are used to predict the variance of a specified dependent variable (Doty & Glick, 1994).

3.2.3. Type construction by grounded theory

The qualitative approach of a typology by grounded theory required four stages of analysis. First, relevant dimensions to analyse were developed. Second, cases were grouped and empirical regularities were analysed. Thirdly, meaningful relations were analysed, and types were constructed. These first three stages were a continuous process. The final stage concluded this continuous process by finalizing stage three and by characterising the constructed types. The various stages are visualised in Figure 4.

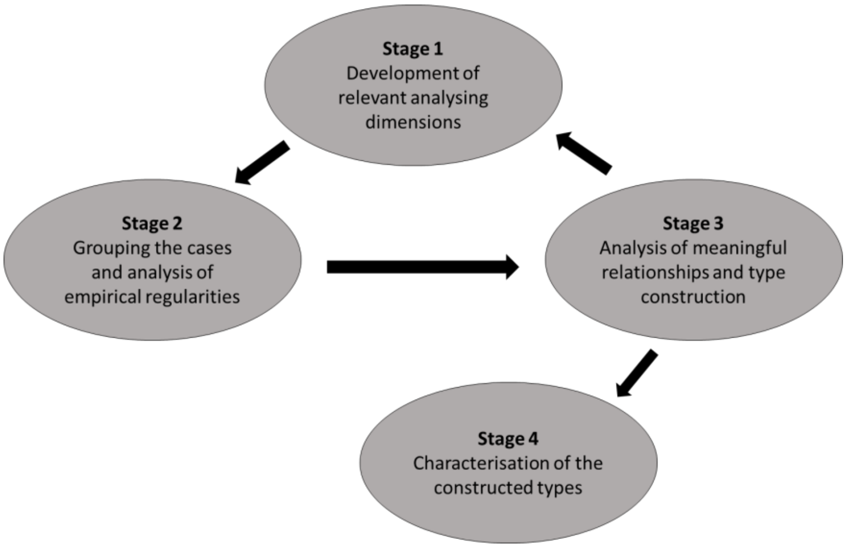


Fig. 4. Model of empirically grounded type construction. Adapted source: Kluge (2000).

3.2.4. Theory building

Building a theory is especially important for the use of a typology, as it distinguishes typologies from classification. To meet the definition of a theory, theories must satisfy three primary criteria. First, the constructs must be identified. The properties of the constructs were defined in this study by identifying ideal types. Second, the relation among these constructs needs to be specified. In this study, this criterion was met, since the typology hypothesizes the relationships between the similarity of an actual form of a mobility hub to an ideal type and the accompanying variables. In this context, the greater the similarity to an ideal type is, the higher the effectiveness of the relationship is. Third, the relations must be falsifiable, which implies that the predictions associated with a typology must be testable and subject to disconfirmation. In this study, the option for falsification has been incorporated by creating a formula that measures the deviation between a real mobility hub and an ideal type.

This formula for measuring deviation can both be used in predicting the dependent variable and in measuring the fit (Doty & Glick, 1994). The deviation can be assessed by a form of the weighted Euclidean distance formula, which is presented in equation 1. The formula is not further applied in this study, since the conceptualisation was investigated rather than the application or deviation.

$$D_{im} = \sqrt{(X_i - X_m)\, W\, (X_i - X_m)'} \qquad (1.0)$$

Where:

D_{im} = distance between ideal type *i* and mobility hub *m*

X_i = a 1 x *j* vector that represents the value of ideal type *i* on attribute *j*

X_m = a 1 x *j* vector that represents the value of mobility hub *m* on attribute *j*

W = *j x j* diagonal weighting matrix that presents the theoretical importance of attribute *j* to ideal type *i*

4. Literature

The literature section of this research is built upon three parts. The first part consists of literature on land use and public transport integration, which can be seen as the building blocks of mobility hubs. The second part consists of literature on multimodal interchanges and multimodal user demand. This literature gives insight into potential mobility hub structures and their preconditions. Finally, literature on transport hubs typologies is described to identify determining properties in other typologies. The analysis of various transport hub typologies in different sectors shows the many potential frames for a mobility hub typology.

4.1. Land use and public transport integration

The integration of land use and public transport can be seen as the foundation of mobility hubs (Monzón et al., 2016). In contrast to the limited literature on the concept of mobility hubs, there is already a body of knowledge in the academic literature on its foundation principles (Bertolini, 2005; Kamruzzaman et al., 2014; Nigro et al., 2019). The models which are most used in the integration of land use and public transport are transit-oriented development models and node-place models.

4.1.1. Transit-oriented development

Since 1990, land use and public transport integration has been most prominently approached by transit-oriented development (TOD) models (Calthorpe, 1993; Nigro et al., 2019). TOD stands for the development of urban areas around transit nodes and is characterised by high urban density and high-capacity public transport such as rail transport hubs (Cervero, 1998; Curtis et al., 2009; Nigro et al., 2019).

Over the past few years, theoretical TOD principles have been applied in urban development plans and programmes in several cities and metropolitan regions. The application of the TOD approach has shown some existing barriers that prevented the realisation of the TOD principles. Some examples of barriers are implementation costs and conflicts in policy objectives (Nigro et al., 2019).

One of the tools created to structure discussions and to identify and overcome these barriers has been the classification of transport nodes. Classifications have helped to create questions about the required level of urban density, the required level of transport services and facilities, and the usefulness of mixed uses. Furthermore, classifications have helped to decrease complexity and increase comparability, which paved the way for the formulation of comprehensive policies (Kamruzzaman et al., 2014).

4.1.2. The node-place model

One of the main methods used in academic literature for measuring the characteristics of a transport node is Bertolini's node-place model (Bertolini, 1999). In this model, the interdependencies between a node and a place are the most important drivers of dynamics in development. In urban development programmes, the balance between a node and a place is usually one of the key policy objectives (Nigro et al., 2019).

The 'node' aspect in the node-place model stands for the transport services which are offered such as train frequency and the number of destinations served. The transport services impact the accessibility, which in turn impacts the attractiveness of the area. The 'place' aspect in the node-place model stands for the volume of the potential users of an area and the degree of a functional mix of the area. The volume of the potential users consists of the number of workers, visitors, and residents of an area. The potential demand for transport services is derived from these two decisive factors (Bertolini, 2005; Nigro et al., 2019).

Most earlier studies related to the node-place model focused merely on dense urban development and high-capacity transport nodes. More recent studies have expanded the analysis by including more variables in order to produce more robust results. The measurement of the node is extended by considering different modes of transport such as bikes and cars (Nigro et al., 2019). The measurement of the place is also extended by considering urban patterns within the catchment area or by considering the designs of the built environment (Vale et al., 2018; Caset et al., 2018). The inclusion of these variables has shown that contextual factors play a substantial role in the results of the node-place model for land use and transport integration (Lyu et al., 2016).

4.2. Multimodal interchanges and user demand

Next to research on the foundations of mobility hubs, research on existing multimodal interchanges and their user demand can give insight into the use of mobility hubs. Previously, research on multimodal interchanges mainly focused on the optimisation between the interchange and its mobility demand. Nowadays, more integrated and behavioural aspects for their use gain academic interest. Some examples of these aspects are the geographical location and the usability of all interchange locations of the journey (Bell, 2019).

Bell (2019) and Gebhardt et al. (2016) show that the geographical location is related to the transport modes offered. Whereas urban mobility is strongly characterised by the use of active mobility in combination with public transport, mobility in the rural area is characterised by a relatively less strong public transport system and higher importance of motorized individual transport. Furthermore, the level of intermodality is higher in densely populated urban areas as compared to rural areas, due to fewer public transport options being available.

Preconditions for hubs that provide an interchange are by Bell (2019) differentiated in basic demands and additional demands. Basic demands mostly refer to the infrastructural design and the services and facilities at the location that secure safety, barrier-free interchanges, and comfortable usage. In facilities, these requirements are expressed in the need for waiting shelters, lighting, (digital) travel information, and barrier-free access points. Meeting these basic demands should decrease displacement resistance. Additional demands mostly refer to extra information on route choices or tourist information, restaurants, and entertainment. Bell (2019) indicates that interchange locations that act as a simple access point to multimodal transport can only be transformed into hotspots for social and leisure activities when both demands are met.

4.3. Transport hubs typologies

Finally, the typologies of other transport hubs in literature could give insight into relevant properties for empirical grouping and might explain interrelationships. Typologies of transport hubs are mainly found in network studies and studies on public transport hubs, airports, and logistics hubs.

Hubs in the transport network have originally been characterised by their level of scale. The definition of scale is defined as the highest spatial scale level a transport network can offer at the hub (Peek, 2006). Differentiation is made between an international, national, interregional, regional, metropolitan, and local scale (Peek, 2006). Airports and seaports show empirical regularities in scale by their geographical location. For example, hubs that have the geographical quality of centrality within a city are characterised by a higher scale (Fleming & Hayuth, 1994). Over the years, characteristics of transport hubs other than their location in the transport networks have gained academic interest (Peek, 2006).

Typologies of public transport hubs are mostly seen in railway station typologies. Railway station typologies show that, in contrast to a more transportation perspective on the scale, also the transport modes and the relative location in the city environment play a crucial role in the development potential of a hub (Peek, 2006; Liu et al., 2021; Zemp et al., 2011). A classification of Zemp et al. (2011) in railway stations shows that context is a determining factor. Examples of contextual factors are the distance to or from the railway station, supporting transfers between modes of transport, the commercial use of real estate in the facility, the provision of public space, and the relative attractiveness of private transport in travel time or uncertainty. The research of Liu et al. (2021) supports the importance of the surrounding environment of a hub by constructing a typology of urban railway stations based on land use and built environments.

Airport typologies contribute to this literature by showing yet other determining properties. Next to the aviation network connectivity and the geographical location (Wong et al., 2019; Mashhoodi & van Timmeren, 2020; Rodríguez-Déniz et al., 2013), also the regional economy (Wong et al., 2019), the availability of other airports in the region (Wong et al., 2019), and the differentiation between cargo and (international) passengers (Wong et al., 2019; Kazda et al., 2020) play a role in the developed types. For instance, airport types can be distinguished in super-hubs, regional hubs, and local hubs (Wong et al., 2019).

Finally, the logistics hubs typologies propose the integration of relatively the most properties into one typology. A Dutch distribution centre typology developed by Onstein et al. (2021) includes functional attributes and client sector characteristics next to the geographical and contextual characteristics, and identifies eight types of distribution centres. Their analysis has shown that the context in which relatively bigger distribution centres operate are more heterogeneous than the context of smaller ones. The research also indicates that the products shipped to a logistics hub influence the facilities needed at the location. Examples of logistics hub types are city hubs and bulk facilities (Onstein et al., 2021).

The literature review on transport hubs shows that properties such as scale, transport mode, location, and context are crucial for empirical grouping and explaining interrelationships (Von Ferber et al., 2009; Mashhoodi & van Timmeren, 2020; Kazda et al., 2020). Furthermore, it shows that researchers mainly use properties that are relatively more quantitative, rather than qualitative, in the development of a typology. In this context, properties such as transport modes and scale tend to be more useful for typology development, rather than more observational characteristics like functions and goals (Peek, 2006; Kazda et al., 2020).

5. Analysis of concept use

The empirical analysis started with analysing the use of the concept, before the different properties and its dimensions were analysed. The use of the concept was analysed in four parts. Firstly, a macro text analysis was conducted to get insight into the most frequently mentioned words in the publications on mobility hubs. Secondly, a micro analysis was conducted that described which words were most frequently colocated with the word 'hub' in a sentence. A differentiation was made between publications that have mobility hubs as their main topic of interest and those that have not, and between the sources of the publications (see Appendix B). Thirdly, the difference in definitions used for the concept of mobility hubs was analysed. Finally, the contemporary character and the proposed added value of the concept of mobility hubs were analysed.

5.1. Macro text analysis

In the macro text analysis, the publications were analysed on the sources, year of publication, and the main topic of the publication. Publications that mention mobility hubs were identified for all four professional stakeholder groups in this research. The publications had in common that they were all published in the last four years. Differences between the publications of the four professional stakeholder groups were mainly to be found in the main topic of the publication, the type of publication, and the number of publications.

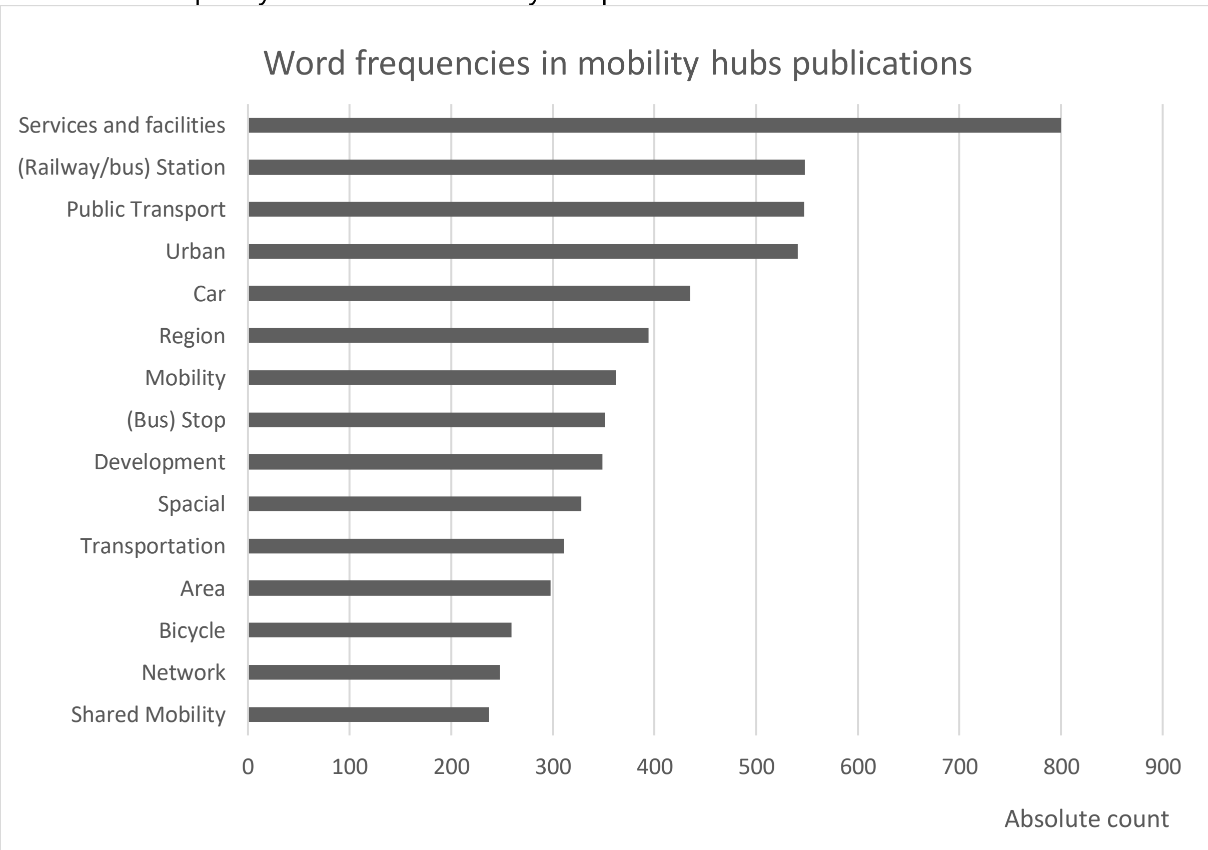
In contrast to governmental institutions and consultants, mobility providers and project developers had fewer publications available that specifically focused on mobility hubs. Instead, mobility providers and project developers tended to focus relatively more on topics such as spatial development, station development or shared mobility, and mentioned mobility hubs as a means to reach their goals (see Appendix B).

Another difference was found in the type of publications. Governmental institutions were found to publish mainly policy reports, while project developers publish mainly articles and white papers. Consultants had the highest variety of publications. They worked on case study reports, white papers, as well as policy papers for governmental institutions. Mobility providers were found to publish mainly policy reports and white papers.

A final difference in the macro text analysis was found in the number of publications. Governmental institutions and consultants were found to have relatively more publicly accessible publications, compared to project developers and mobility providers. This difference was also reflected in the data analysis by the incorporation of relatively fewer publications of project developers and mobility providers. Furthermore, the four publications of mobility hub providers and the five publications of project developers were mainly characterised by articles, which resulted in relatively fewer sentences to analyse compared to the extensive policy papers of governmental institutions.

The most frequently used words in publications that have mobility hubs as their main topic can give an indication of the context in which the concept is used. The fifteen most used words are described in Table 1. Based on word frequency, three groups were identified. The first group was the group with the most used words, which are words that are counted over 600 times in all the considered publications together. These words are related to ‘services’ or ‘facilities’. The second group was the group with an absolute word count between 400 and 600 times. These are words such as ‘station’, ‘public transport’, ‘urban’, and ‘car’. The third and final group consist of words that are counted less than 400 times, for example, words like ‘region’, ‘network’, and ‘transportation’.

Table 1
Fifteen most frequently used words in mobility hub publications.



5.2. Micro text analysis

The differences in focus points between the professional stakeholder groups were derived by a micro text analysis of the publications. In the micro text analysis, all the sentences with the word ‘hub’ were investigated. Thereby, also publications that do not have a mobility hub as the main topic were included (see Appendix B). The results are presented in Table 2 and further explained below. The analysed words in the micro analysis were selected based on the main topics identified in the macro text analysis. It is also noteworthy that shared mobility and transport modes were differentiated in the analysis, as their usages differ between the professional stakeholder groups. The results of the micro analysis are supported with quotes from the publications.

Table 2
Frequency of colocation with the word 'hub', per sentence and differentiated by publication source.

Words	Consultants (N=10)		Governmental institutions (N=11)		Mobility providers (N=4)		Project developers (N=5)	
	Absolute	Column-relative	Absolute	Column-relative	Absolute	Column-relative	Absolute	Column-relative
Accessibility	34	2,58%	61	3,98%	1	2,04%	0	0,00%
Area	95	7,21%	142	9,26%	3	6,12%	2	8,00%
Digital	6	0,46%	31	2,02%	1	2,04%	1	4,00%
Function	100	7,59%	177	11,55%	2	4,08%	0	0,00%
Goal	33	2,51%	96	6,26%	3	6,12%	0	0,00%
Governance	48	3,64%	44	2,87%	3	6,12%	0	0,00%
Liveability	11	0,83%	28	1,83%	2	4,08%	0	0,00%
Network	144	10,93%	88	5,74%	0	0,00%	1	4,00%
Services and facilities	259	19,67%	188	12,26%	0	0,00%	2	8,00%
Shared mobility	112	8,50%	72	4,70%	3	6,12%	7	28,00%
Social	65	4,94%	25	1,63%	1	2,04%	0	0,00%
Spatial	41	3,11%	96	6,26%	1	2,04%	2	8,00%
Transport modes	296	22,47%	333	21,72%	9	18,37%	6	24,00%
Users	31	2,35%	139	9,07%	20	40,82%	3	12,00%
Visibility and findability	42	3,19%	13	0,85%	0	0,00%	1	4,00%
Totals	1317	100,00%	1533	100,00%	49	100,00%	25	100,00%

Transport modes such as trains, cars, and bicycles are shown to be used most frequently in combination with the word 'hub' in a sentence. In contrast, words related to the digital environment, liveability, social aspects, visibility, and findability are shown to be used the least in combination with the word 'hub' in a sentence.

The ten consultants' publications showed that the word 'hub', besides its colocation with transport modes, is also relatively often colocated in sentences with words related to services and facilities, networks, and shared mobility. The following quote from a publication of two consultancy firms is an example of this emphasis:

"Furthermore, at the hub, there are facilities such as parcel boxes and meeting locations and there is sufficient shared mobility available for the last mile."

(APPM & Goudappel, 2021).

The eleven publications of governmental institutions showed that governmental institutions relatively often describe mobility hubs in the same sentences with transport modes, services, and facilities as well, but focus compared to other professional stakeholder groups more on the function and the surrounding area. An example of this is shown by a quote out of the publication of a governmental institute:

"Hubs can evolve into larger hubs with more facilities: what starts as a neighbourhood hub can grow in specific locations into a hub with more connections, a larger service area and more facilities, while at the same time maintaining the neighbourhood function." (Rijkswaterstaat, 2020).

The four publications of mobility providers indicated that, compared to the other professional stakeholders, mobility providers tend to focus relatively more on the travellers and their travel behaviour. This is shown by the frequent combination of the word 'hub' with words related to transport modes and their users. The following quote shows the focus of mobility providers on travellers and travel behaviour:

"Hubs enable travellers to travel easily and flexibly, using various (clean) forms of transport that suit their specific purpose." (Hely, ParkBee & Bouwinvest, 2020).

The five publications of project developers analysed indicated that project developers tend to describe mobility hubs relatively often in a context together with spatial development, parking spaces in the public space, and shared mobility. The following quote from a publication of a project developer shows the emphasis on the parking spaces:

"When a hub is realised in a neighbourhood, fewer parking spaces are needed in the public space." (AM, 2020).

5.3. A variety of definitions

The empirical study indicated that the definition of mobility hubs differs between the professional stakeholder groups. Neither a group of professional stakeholders, nor a group of publications consistently used the same definition for a mobility hub. For example, the formulated definitions were distinct in scale, amount of non-mobility functions and transport modes offered, and the level of clustering.

Especially mobility providers and consultants who work in the field of public transport were found to mention the connection of mobility hubs with public transport as an essential property. Furthermore, most governmental institutions have mentioned public accessibility as a key component of the definition.

5.4. Added value of the modern concept

The empirical study showed that the concept of mobility hubs has only recently been introduced in the Netherlands. As mentioned before, text analysis showed that views on mobility hubs have first been published around four years ago. The interviewed experts acknowledged the contemporary character by stating that none of them had heard of the concept earlier than around four years ago.

Furthermore, almost all experts described mobility hubs as a 'hyped' concept or a 'catch-all' concept. The catch-all concept refers to the perception that the term mobility hubs can be applied to most conventional passenger transport hubs. When almost every conventional passenger transport hub could be a mobility hub, the added value of this new concept becomes more diffuse. The most mentioned example is that of a central railway station. The link between mobility hubs and conventional passenger transport hubs is also seen in the text analysis, as 'bus stops' and 'railway stations' are some of the most frequently used words in publications on mobility hubs.

The high level of similarity between conventional passenger transport hubs and mobility hubs led some experts to state that the concept is 'hyped'. However, differences have mainly been explained by two perspectives. From the mobility perspective, mobility hubs differ from conventional passenger transport hubs by including a broader scope of transport hubs and by providing a denser transport network. From the non-mobility perspective, mobility hubs provide additional functions by their facilities and services and role in spatial development in the area. This is also indicated by the frequent use of the words 'services' or 'facilities', 'spatial', 'development', and 'area' identified in the text analysis (see Table 2), and by the colocation of the words 'spatial' and 'development' within a sentence. The latter is counted 49 times in the text analysis on mobility hub publications.

Although most components of the concept are not completely new, the interviewed experts indicated that the use of this modern and more integrated concept could facilitate governance. From their perspective, years of collaboration between mobility providers, project developers, and governmental institutions could have led to patterns and tunnel visions. Most of the experts thought that introducing a new concept could help to bring the parties on the same page, redirect their common goals, and thereby develop comprehensive policy.

6. Property and dimension analysis

The property and dimension analysis embodied the first step in the construction of a typology and is outlined below. In this analysis, all the properties and dimensions of mobility hubs were identified. The difference between a property and a dimension is the ability to scale the corresponding characteristic. Whereas a property stands for a characteristic that is not directly scaled, a dimension stands for one or multiple properties that can be scaled. An example of the first one is the design of a mobility hub, and an example of the latter is the quality of the facilities. The properties and dimensions analysis contributed to the indication of the empirical regularities and relationships between the research elements in the succeeding steps of typology construction. Furthermore, the properties identified will characterise the constructed types in the final step of typology development (Kluge, 2000).

6.1. Property analysis

In both the literature analysis and in the empirical analysis, multiple properties were identified. Although the literature on the properties of (passenger) transport hubs was not completely applicable to mobility hubs, most of them corresponded to the properties identified in the empirical analysis. In the empirical analysis, the importance of locational, spatial, network, and accessibility properties were emphasized. The properties identified are presented in Table 3.

Properties that overlapped have been combined into one aggregated property. The most important properties for the typology are described in more detail in the dimension analysis.

Table 3
Property analysis on mobility hubs.

Property	Example	Literature
Accessibility	Public access	Elshater & Ibraheem (2014), Monzón et al. (2016), Rodríguez-Déniz et al. (2013)
Efficiency & productivity	Profit	Rodríguez-Déniz et al. (2013), Martynova & Valeeva (2015), Ellis & Calantone (1994)
Facilities & services	Public toilet	Elshater & Ibraheem (2014), Martynova & Valeeva (2015), Van Hagen & de Bruyn (2002), Ellis & Calantone (1994)
Findability & Visibility	Signing	Elshater & Ibraheem (2014)
Function	Providing the last and first mile	Elshater & Ibraheem (2014)
Geographical location	City centre	Von Ferber et al. (2009), Mashhoodi & van Timmeren (2020), Kazda et al. (2020), Van Hagen & de Bruyn (2002)
Social goals	Social accessibility	Peek (2006), Yatskiv & Budilovich (2017)
Governance	Public-private partnerships	Kazda et al. (2020), Elshater & Ibraheem (2014), Martynova & Valeeva (2015)
Transport modes	Train	Van Hagen & de Bruyn (2002), Kazda et al. (2020)
Network	Rail network	Elshater & Ibraheem (2014), Rodríguez-Déniz et al. (2013), Mashhoodi & van Timmeren (2020), Martynova & Valeeva (2015), Van Hagen & de Bruyn (2002)
Scale	Regional scale	Rodríguez-Déniz et al. (2013), Kazda et al. (2020)
Spatial environment	Retail competition	Mashhoodi & van Timmeren (2020), Elshater & Ibraheem (2014), Van Hagen & de Bruyn (2002), Ellis & Calantone (1994)
Technology	Mobility as a Service application	Martynova & Valeeva (2015)
Transport infrastructure	Runway length	Rodríguez-Déniz et al. (2013), Kazda et al. (2020)
Travel behaviour	Displacement resistance	Elshater & Ibraheem (2014)
Users	Commuters	Rodríguez-Déniz et al. (2013), Kazda et al. (2020), Van Hagen & de Bruyn (2002)

6.2. Dimension analysis

Inspired by the work of Monzón et al. (2016), the different properties have been organised into two main dimensions. The first dimension is the function and logistics dimension. This dimension includes structural properties like scale and modes of transport. The second dimension is the local constraints dimension, which includes contextual properties like geographical location and governance.

6.2.1 Function and logistics dimension

The five properties that were most mentioned in the function and logistics dimension are the properties of transport modes, services and facilities, scales, functions, and social goals.

The property that was mentioned first in most interviews is the property of transport modes. The types of transport modes can be differentiated between public transport such as trains and busses, shared vehicles like electric bikes and cars, and private vehicles such as cars.

The second property most mentioned is the property of services and facilities. Services and facilities consist of both mobility related and non-mobility related services and facilities such as parking facilities, visitor services, and waiting facilities. The basic services and facilities offered at mobility hubs are related to the infrastructural features. These basic services and facilities should provide a safe, barrier-free, and comfortable use of the mobility hub. Examples are waiting shelters and barrier-free access points (Bell, 2019).

Another main property described within the function and logistics dimension is the aspect of scale. Scale was described by the four professional stakeholder groups in many ways, but mainly covers the catchment or service area of a mobility hub (Goudappel & APPM, 2020). Although the scale was one of the most mentioned properties of grouping during the experts' interviews, no expert mentioned exact numbers to quantitatively differentiate between the scales. Instead, most of the experts differentiated in scale by levels of reach such as the neighbourhood level, district level, city level, regional level, national level, and international level. The lowest scale would be the neighbourhood level, and the highest scale would be the international level.

Finally, the last two main properties mentioned are the properties of functions and social goals. The function and the social goal of a mobility hub are related to each other, but can be differentiated at the conceptual level, since functions support social goals. Some examples of functions are reducing resistance to multimodal transfers and facilitating alternative first and last mile solutions. Examples of social goals are strengthening accessibility and improving the quality of the living environment. These findings are in line with the different functions and social goals of mobility hubs identified by the Netherlands Institute for Transport Policy Analysis (KiM, 2021).

6.2.2 Local constraints dimension

In addition to properties in the function and logistics dimension, there are also properties related to the local constraints dimension. The five most mentioned aspects were the aspects of geographical locations, digital locations, users, governance, and the surrounding environment of a mobility hub.

From the local constraints dimension, the property of the geographical location was during the interviews usually firstly mentioned. Geographical locations can be differentiated in two steps. The first step is the differentiation between urban areas and rural areas. The second step consists of differentiation within the urban area between the city centre, city districts, the edge of the city, and the metropolitan area (Monzón et al., 2016). This geographical location is an important property, since it defines limits to the growth of a mobility hub and the volume of its users (Monzón et al., 2016).

Next to a geographical location, the digital location was also frequently mentioned as a property. The location of the mobility hub is usually digitally visualised in online route planning, which is one of the determinants of smoothing multimodal travelling (Bell, 2019).

The surrounding environment of a mobility hub is another property of the mobility hub that was often mentioned besides the geographical location and the digital location. This property was mentioned because it influences the attractiveness and use of a mobility hub (Monzón et al., 2016). For instance, the availability of public services or retail in the surrounding environment can attract visitors.

Another property is the user group of the mobility hub. Within the category of passenger transport, user groups of mobility hubs can be distinguished between residents, visitors, and commuters (Monzón et al., 2016). The user group is an important property, since it determines the demanded functions and services at a mobility hub (Bell, 2019; Monzón et al., 2016).

A final property mentioned regarding the local constraints dimension is the governance of the mobility hub. Several parties are involved in the various distinct phases of the development of a mobility hub. From parties that are responsible for the quality of the public space and the public transport system, to businesses involved in project development, providing transport modes, and (digital) infrastructure. Among other things, the parties involved in the governance of a mobility hub develop the business case and determine its design (Monzón et al., 2016).

7. Analysis of empirical regularities

The second stage of typology development consisted of grouping the cases on defined properties and their dimensions, which allowed the identified groups to be analysed on empirical regularities. The properties that were identified as most suitable for empirical grouping are the main mode of transport, location, scale, services, and facilities. The empirical grouping is visualised in Table 4.

Table 4
Empirical regularities between the main mode of transport, services, facilities, location, and scale.

Main mode of transport	Services and facilities	Location	Scale
Inter-city train	Ticket service, tourist information, service point retail, lockers, elevator, vending machine, ticket service, covered waiting area, travel information, bicycle, and car parking	Urban area, rail network	(Inter)national
Metro	Elevator, vending machine, ticket service, waiting shelters, travel information, and bicycle parking	Urban area, metro network	Regional
Tram	Waiting shelters and travel information	Urban area, tram network	Regional
Regional trains	Ticket service, waiting shelters, travel information, and parking space for car and bicycle	Rural area, rail network	Regional
High-frequency busses	Waiting shelters and travel information	Rural area, street network	Regional
Busses	Waiting shelters and travel information	Rural area, street network	Local
(shared) Cars, (shared) bicycles, and (shared) mopeds	Parking spaces and electrical loading facilities	Neighbourhood, street network	Local

7.1. Main mode of transport

The main mode of transport is one of the key properties to investigate empirical regularities on, which is shown by its prominent role in railway station typologies and airport typologies (Peek, 2006; Kazda et al., 2020). The main mode of transport can indicate the services and facilities offered, the location and the reach and thereby the scale of a mobility hub. For example, a hub with an inter-city train as the main mode of transport usually provides more services and facilities and operates at a bigger scale than a mobility hub which has shared bicycles as the main mode of transport. Furthermore, the types of transport modes also indicate the location of a mobility hub in the transport network, such as a street network for busses or a rail network for regional trains.

7.2. Services and facilities

Services and facilities are the second property that was commonly mentioned by the interviewed experts for empirical grouping. Most mobility hubs have some basic services and facilities as described in the property section, that create a hub function. However, the level of quantity and complexity of the services and facilities could deviate between the mobility hubs.

When the mobility hub has a larger scale, the location is visited by relatively more users. With more users, offering additional services like retail is more viable. In turn, services and facilities show empirical regularities with the main mode of transport, since the main mode of transport determines the scale. The importance of the number of users for the viability of services and facilities is also shown in the level of services and facilities per geographical location of a mobility hub. Mobility hubs at locations that are more urbanised such as village centres or city centres generally offer relatively more services and facilities than mobility hubs at village edges.

Differentiation between mobility hub types based on services and facilities is previously made by governmental institutions in the Netherlands as the Province of Zeeland and the region of West-Brabant (Provincie Zeeland, 2021; APPM & Goudappel, 2021).

7.3. Location

Location is another commonly used property for empirical grouping, which is confirmed by typologies of railway stations, airports, and seaports (Peek, 2006; Mashhoodi & van Timmeren, 2020). The location of a mobility hub can both be defined by its location in the transport network and by its geographical location. The location in the transport network mainly shows empirical grouping on the mode of transportation. For instance, regional trains are in need of a rail network. The geographical location was relatively more often mentioned by experts in empirical grouping with properties such as scale, services, and facilities instead of transport modes.

7.4. Scale

Scale is the final main property identified for empirical grouping, which is measured by the catchment area of the mobility hub. Scale is commonly used in the empirical grouping of transport hubs, since it is usually correlated with the surface size of a hub (Onstein et al., 2021). In other typologies, this definition of scale is sometimes described by the (market) service area (Onstein et al., 2021; Von Ferber et al., 2009). The scale is an important property for empirical grouping, as there are substantial differences between the market service areas that hubs serve (Onstein et al., 2021). Furthermore, it determines its local, regional, or national accessibility (Peek, 2006).

Another important regularity with the property of scale is found with the property of location. Literature shows that hubs that have higher connectivity with other hubs in the network are usually located in higher centrality locations which provide more functions (Von Ferber et al., 2009). The latter is shown by mobility hubs in city centres that have one of the highest scales and provide various functions (KiM, 2021).

8. Analysis of interrelationships

The empirical and literature studies showed that mobility hubs have different forms and properties, in which some of the properties of mobility hubs are interrelated. In this section, the most important interrelationships are described. First, the main structure of the interrelationships is described to reorder some of the properties. The main structure is built upon three parts: the context, structure, and purpose of a mobility hub. The three parts describe different properties and are individually outlined after a description of the main structure is given.

8.1. Main structure of interrelationships

The conceptual frameworks of KiM (2021) for mobility hubs and the one of Zemp et al. (2011) for railway stations are combined to create the main structure of interrelationships. The structure identifies the interrelations between most of the properties which are mentioned in the property analysis. The main structure of interrelationships is visualised in Figure 5.

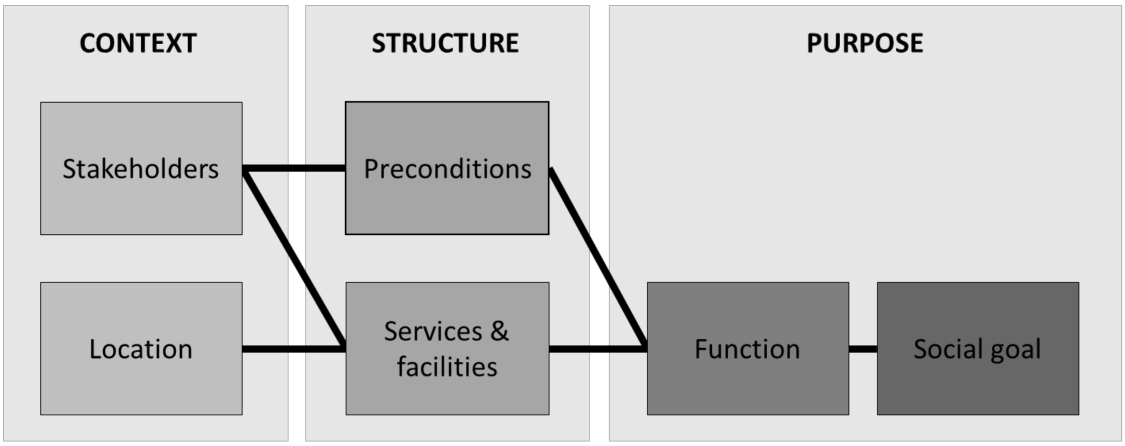


Fig. 5. The main structure of interrelationships for mobility hub properties. Based on the conceptual frameworks of KiM (2021) and Zemp et al. (2011).

All the interrelationships show that the mobility hub does not function in a vacuum. The stakeholders and the location set the context and determine the demanded functions of the mobility hub. The demanded functions define the structure of the mobility hub, which consists of the services, facilities, and preconditions. The right combinations of services, facilities, and preconditions ensure that the mobility hubs offer the demanded or intended functions. The function and the social goal together form the purpose of a mobility hub. In the purpose of the mobility hub, the intended functions contribute to the intended social goals. In conclusion, only when the context and structure are right, the purpose of a mobility hub can be fulfilled.

8.2. Context

The context consists of all contextual constraints that are permanently relevant for the system. These contextual constraints are the stakeholders and the location. The properties of users and governance come together in the stakeholders, and the properties of geographical location, network, and the surrounding environment come together in the location.

As specified in Figure 5, context influences the structure of mobility hubs in three ways. First, the context defines which functions are demanded at a mobility hub. For example, stakeholders like the users of the mobility hub could demand shared vehicles, and other stakeholders like governments could demand electrification of transport by loading facilities. Second, stakeholders have an influence on setting the right preconditions. The stakeholders develop the hub and can thereby take into account the preconditions such as public accessibility and clear signing for wayfinding. Third, the location determines the potential for services and facilities at the mobility hub. The viability of, for instance, grocery stores at a mobility hub is dependent on the distance to other grocery stores in the surrounding area. Furthermore, the location determines the potential for the use of different transport modes by its location in the traffic network.

8.3. Structure

The structure of a mobility hub consists of the physical mobility hub with all its services, facilities, and preconditions. Examples of services and facilities are service desks, parking facilities or waiting areas. The preconditions capture the before identified properties such as physical accessibility, the digital environment, visibility, and findability. In the main structure of interrelationships, the preconditions set by the stakeholders ensure that the services and facilities come about to the intended functions. For example, a digital environment like an application made by shared mobility providers is usually needed to use their vehicles and is thereby essential in the function of providing shared mobility. Furthermore, physical accessibility is a precondition for users to come to the mobility hub and make use of its facilities and services. Thereby, the structure of a mobility hub has an important role in creating the functions of a mobility hub.

8.4. Purpose

Finally, the structure of a mobility hub contributes to its purpose. The purpose of a mobility hub consists of the function and the social goal. When the facilities and services are offered under the right preconditions, the mobility hub can serve its intended function. In turn, intended functions will contribute to intended goals. Some examples of functions are facilitating shared mobility and decreasing displacement resistance. Examples of social goals are increasing accessibility and decreasing CO_2 emissions.

Empirical research has shown that mobility hubs could have multiple functions and societal goals and could operate more optimally when they are integrated (Goudappel, 2020; KiM, 2021). Furthermore, societal goals are empirically shown to be highly related to geographical locations. In which mobility hubs in rural areas frequently go together with societal goals in accessibility and inclusivity, and those in urban areas with societal goals in sustainability and liveability (KiM, 2021).

9. Empirical type construction

Based on the identified empirical regularities and interrelationships between the properties, mobility hub types were developed. The types were differentiated by facilities and services, transport modes, geographical location, and scale as visualised in Figure 6. This section explains thoroughly which framework and determining properties were used for empirical type construction and concludes with the conceptual framework in the form of a typology.

9.1. Framework

The framework is based on the work of Wijntuin (2018), who created a conceptual framework to gain insight into retail locations. His framework distinguishes dwell time, retail demand, location, and scale. The determining properties of the framework developed in this study are facilities, services, and transport modes. These determining properties are chosen based on their role in empirical grouping and ability to explain interrelationships. The properties of location and scale were added as an extra dimension.

9.1.1. Quantity and quality of services, facilities, and transport modes

The determining properties of services, facilities, and transport modes are described by their levels of quantity and complexity. The services, facilities, and transport modes are not specified in the framework, because a typology is based on ideal types rather than on a classification in aspects (Doty & Glick, 1994). The least complex transport modes are described by shared bicycles and shared mopeds, as they require the least transport infrastructure and amount of space. Whereas the most complex transport modes are described by high-frequency inter-city trains. In services and facilities, the lowest level of quantity and complexity is described by the facility of available parking spaces, and the highest level is seen when the mobility hub offers both many mobility related services and non-mobility related services such as staffed service desks, package pickup-points, tourist information facilities, and retail.

9.1.2. Geographical location and scale

The geographical locations in the framework added a third dimension to the typology. This dimension showed that different types of mobility hubs could be located in the same geographic location, but still differ based on their average level of quantity and complexity of transport modes, services, and facilities. The potential geographical locations were implemented in the typology by the brown-coloured circles in Figure 6.

The scale added a fourth dimension and is indicated by the size of the brown-coloured circles (see Fig. 6). Differentiation is made between the local scale (smallest sized circle), (inter)regional scale (medium sized circle), and the national scale (largest sized circle). The third and fourth dimensions are not determining properties in the typology, but rather contribute to the imagination.

9.2. Typology

In the constructed conceptual framework, six types of mobility hubs can be differentiated (see Fig. 6). From a smaller to a larger scale, the mobility hubs types are named as follows:

- Community hub;
- Neighbourhood hub;
- Rural hub;
- City edge hub;
- City district hub;
- City centre hub.

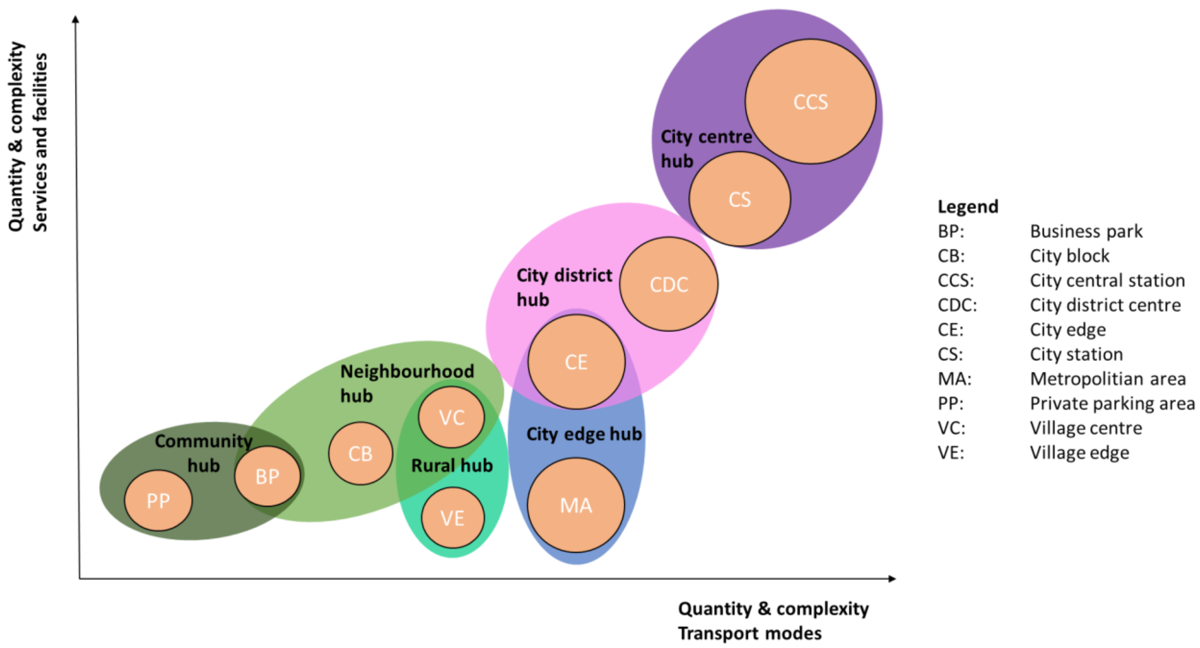


Fig. 6. Constructed types in the conceptual framework.

10. Types and characterisation

This chapter elaborates upon the six types of mobility hubs identified in the conceptual framework.

10.1. Community hub

The community hub is characterised by its accessibility to a selective social group (that is, a community). Community hubs are located in privately owned areas such as garages of apartment complexes and business parking lots. The main transport modes offered in this type of mobility hub are shared cars, bicycles, and mopeds. There are limited facilities or services available in this community hub other than parking facilities for private vehicles. The small number of services or facilities can be explained by the relatively low number of users and the privatized character of the location. Community hubs are frequently associated with project development, since offering shared mobility can decrease the need for parking spaces, which consequently can increase the density in housing. Examples of communities eligible for community hubs are the inhabitants of an apartment building who can use the community hub in their garage (see Fig. 7) or a group of workers who can make use of the community hub in their business parks.

Community hubs differ from neighbourhood hubs by their limited number of facilities and services, and the general absence of a public transport connection. In contrast to neighbourhood hubs, community hubs often do not offer local services for the neighbourhood, such as package pick-up points, since they are not located in the public space.

Fig. 7. Hely Hub OurDomain Amsterdam South East, located in Amsterdam. With electric shared cars and bikes. Exclusively available for residents of OurDomain Amsterdam South East. *Source:* https://www.thisisourdomain.nl/amsterdam-south-east-news/onze-nieuwe-smart-mobility-hely-hub, accessed in September 2021.

10.2. Neighbourhood hub

A neighbourhood hub is characterised by its location in a neighbourhood and the scale of the neighbourhood. The main transport modes offered in the neighbourhood hub are shared (electric) cars, bicycles, and mopeds. These hubs are generally developed in combination with a public transport connection like a bus line (KiM, 2021). Users typically reach the mobility hub by foot or bicycle. Neighbourhood hubs in cities can be found in cities like Nijmegen, which provides shared mobility around the university campus and in the city centre (see Fig. 8). An example of a neighbourhood hub in a village centre is the hub located in the village ‘t Veld (CROW, 2021b).

In comparison to a rural hub, neighbourhood hubs have a higher level of quantity and complexity of services and facilities, but also have a lower level of quantity and complexity of transport modes. In contrast to rural hubs, neighbourhood hubs are generally located nearby neighbourhood amenities like grocery stores and can offer local services such as package pick-up points. The lower level in quantity and complexity of transport modes of neighbourhood hubs relative to rural hubs is explained by the absence of high-frequency bus connections or regional trains.

Fig. 8. Ehub in the city centre of Nijmegen (Hertogstraat) with transport modes like electrical shared (cargo) bikes, cars, and a local bus, and services and facilities such as an electrical charging station, a restaurant, a bank, and a cinema. *Source:* https://twitter.com/gem_Nijmegen/status/1312678940272668672/photo/1, accessed in September 2021.

10.3. Rural hub

The rural mobility hub is characterised by its location in a rural area. These mobility hubs mainly focus on the accessibility of the rural area and are characterised by public transport hubs such as bus stops and small railway stations. Furthermore, rural hubs are generally characterised by the need for private vehicles to be able to reach the hub. As a result, the hubs provide many parking spaces (CROW, 2021a). An example is the railway station in Vorden, where shared mobility, regional train lines, and bus lines are combined with relatively many parking spaces for bicycles and cars. The bus line between the railway station in Vorden and the railway station in Doetinchem avoids village centres and stops only at village edges instead, to help increase its pace and frequency. The railway station in Kesteren (see Fig. 9) is another example of a rural hub. This rural hub has local bus connections with the city of Tiel and only stops at village edges.

The rural mobility hub is located in areas that are relatively less urbanised than neighbourhood hubs, city district hubs, and city edge hubs. Rural hubs generally offer less complex transport modes, services, and facilities than city edge hubs. High-frequency train and tram connections are usually not available in rural hubs, nor are there many loading facilities.

Fig. 9. Kesteren railway station, with transport modes such as regional trains, busses, and a taxi, and facilities like public toilets, bicycle lockers, and ticket machines. *Source:* https://www.gelderlander.nl/neder-betuwe/station-kesteren-niet-naar-casterhoven~a2d1c43b/, photo by William Hoogtelying, accessed in September 2021.

10.4. City district hub

The city district hub is characterised by its location within a city district and the scale of the city district. These mobility hubs mainly focus on liveability within the city district and the clustering of functions, which can enhance urban (re)development (KiM, 2021). City district hubs are usually planned for urban locations where car parking is getting restricted to guarantee accessibility for visitors and residents. In this way, the city district hubs contribute to (re)development and densification in urban areas (CROW, 2021b). Some examples of city district hubs are hubs in Amsterdam Bijlmer or Rotterdam Blaak (see Fig. 10), where multiple transport modes such as train, busses, metro’s, trams, taxis, and shared mobility come together. They also fulfil a social neighbourhood function by their small retail facilities and package pick up points.

City district hubs have a relatively higher level of services, facilities, and transport modes than neighbourhood hubs, city edge hubs, and rural hubs. Furthermore, city district hubs have an (inter)regional scale, in contrast to the local scale of rural hubs and neighbourhood hubs.

Fig. 10. Mobility hub Rotterdam Blaak. With transport modes such as (inter-city) trains, metro, local busses, and shared vehicles, and services and facilities like a public library, retail, and a covered waiting area. *Source:* https://indebuurt.nl/rotterdam/genieten-van/mysteries/wat-betekent-de-naam-blaak~82827/#&gid=1&pid=1, photo by Rotterdam Branding/Ossip van Duivenbode, accessed in September 2021.

10.5. City edge hub

The city edge hub is characterised by its (inter)regional scale and is usually developed as a Park and Ride (P+R) location. The city edge hub is sometimes called a transfer hub (Rijkswaterstaat, 2020; KiM, 2021), as it offers a transfer between cities and their outer areas. City edge hubs generally provide limited facilities and services, but do provide the essential facilities for transfers between mainly private vehicles to collective transport modes such as a shuttle bus or tram. Some examples of essential facilities are car parking facilities, carpooling facilities, and electrical loading facilities (CROW, 2021b). These hubs are usually located at the edge of a city, in front of a ring road, or in the outer metropolitan area. Example of city edge hubs are the P+R Westraven in Utrecht (see Fig. 11), the P+R Hoogkerk in Groningen, and the P+R in Nijmegen North.

City edge mobility hubs offer relatively less complex transport modes than city centre hubs or city district hubs, where most forms of public transport are intertwined. Furthermore, the city edge hub offers fewer services and facilities than a city centre hub and a city district hub.

Fig. 11. The P+R location of Westraven with transport modes such as shared bikes, local busses, and trams, and facilities like public toilets, ticket machines, electrical loading, and many parking spaces. *Source:* https://goedopweg.nl/pr/p-r-westraven, accessed in September 2021.

10.6. City centre hub

The city centre mobility hub is characterised by inner-city high-quality public transport, which is relatively easily accessible by active mobility such as walking and cycling. In addition, they are characterised by spatial development and the availability of most modes of transport such as tram, metro, regional train, inter-city train, taxis, and shared mopeds. The centrality, high accessibility, and public facilities of a city centre hub usually go hand in hand with a high interest of businesses and residents to co-locate, which drives up land prices. The rising land prices limit the available space for (car-related) parking spaces around the mobility hub (CROW, 2021a). The city centre hub has the form of a railway station, which can be both a central railway station of a relatively bigger city like Utrecht or Arnhem (see Fig. 12) and a railway station in the centre of a relatively smaller city like Haarlem or Assen.

City centre hubs have the highest scale in quality and complexity of both services and facilities, as well as in transport modes. City centre hubs are also the only type of mobility hubs that operate on a national scale.

Fig. 12. Arnhem central railway station. The station includes facilities and services such as international money exchanges, lifts, toilets, lockers, service desks, tourist information, and transport modes such as regional trains, inter-city trains, busses, taxis, and shared vehicles. *Source:* https://www.unstudio.com/en/page/12109/arnhem-central-masterplan, accessed in September 2021.

11. Future challenges

In the empirical analysis, future challenges related to the use of the concept of mobility hubs and its implementation were identified. These future challenges are:

- To discourage alternatives.
- To use the concept in terms of a means instead of a goal in itself.
- To create uniformity of design.
- To develop positive business cases.
- To balance flexibility and consistency.

The empirical study indicated that introducing the concept of mobility hubs is accompanied by a lot of positivism, as it can contribute to societal goals by stimulating desirable mobility choices. However, stimulation might not be enough to create behavioural changes in mobility choices. To create actual behavioural change, alternatives should be discouraged. Alternatives can be discouraged by increasing the motor vehicle taxes on a national level, disbanding regional bus stops and target group transportation on a regional level, and setting restrictive car parking policies on a local level. Traffic congestion, for instance on motorways, should not be solved by increasing road capacity. Instead, policy makers should focus on changing mobility patterns and stimulating the use of public transport or shared mobility. Setting these prerequisites requires a systematic change in thinking, which could be met with resistance. Discouraging alternatives might therefore be difficult to decide on politically.

Next to discouraging alternatives, a challenge lies in the use of mobility hubs as a means instead of a goal in itself. Different experts define the concept of mobility hubs as ‘hyped’ and refer to their perception in which mobility hubs are seen as a goal in itself rather than as a means. As a result, stakeholders could be distracted from their actual goal and could lose sight of other potential means. This perception could be supported by the number of grants and co-financing options made available for mobility hubs (Provincie Gelderland 2020; Provincie Zeeland, 2021). Nevertheless, other means such as creating a more bicycle or pedestrian friendly environment could do the trick for a specific goal as inner-city accessibility as well.

Another important challenge is creating uniformity in design for mobility hubs. Except for railway stations (ProRail & Bureau Spoorbouwmeester, 2019), there is currently no uniformity in the design of mobility hubs. Some examples of elements of design are architecture and signing. The latter is used to facilitate wayfinding and branding. Currently, local governments initiate or stimulate the development of mobility hubs to experiment with the concept. On the one hand, experimenting creates room for investigating market demand, exploring implementation options, and accelerating development. On the other hand, local arrangements and experiments could result in scattered mobility and non-uniformity in the use and design of mobility hubs. Non-uniformity could endanger the adaptability of the mobility hubs as it creates uncertainty for the users about how to use the hub or which modes of transport and services or facilities to expect on-site. Mobility hubs do not function in isolation, but rather in a mobility system or network. This requires uniformity and recognisability for its users and a comprehensible system (KiM, 2021), both digitally and on-site (Bell, 2019).

Another future challenge is the ability of mobility hubs to develop positive business cases. Some mobility providers in public transport currently have transport concessions with governmental institutions to build positive business cases and reliable transport, in both rural and urban areas. However, other mobility providers, for instance in shared mobility, do not have equal constructions. These mobility providers mainly offer sustainable mobility at locations where there is enough market demand to develop positive business cases. Locations where there is not enough market demand, which is generally the case in rural areas, will not be provided. This is in contrast with some services in public transport which also make financial losses in the rural area, but are publicly funded due to their public value. Hence, this future challenge relates to the need to equally value the different transport modes at mobility hubs. Tackling this challenge might go hand in hand with discouraging alternatives, since discouraging alternatives could result in more market demand for a mobility hub.

The final, main future challenge lies in balancing flexibility and consistency. From the perspective of the potential users, consistency in the availability of transport modes at a mobility hub is desired. The switch from private transport to public transport or shared micro-mobility demands a behavioural change in travel patterns. Changing travel behaviour could be costly for the traveller in terms of time, effort or money. Therefore, the user is in need of consistency in the transport modes offered. However, mobility providers favour more flexibility. The success of a mobility hub is dependent on ongoing developments in Mobility as a Service (MaaS) and on the behavioural change in travel patterns of its users. Consequently, flexibility in upscaling, downscaling or removing mobility hubs could be desired as well. Creating a balance between flexibility and consistency remains a challenge.

12. Concluding remarks

In conclusion, mobility hubs are a modern concept with many opposing views and interpretations. Although the concept itself is new, it has extensive roots in land use and public transport integration, and it is generally associated with familiar concepts such as passenger transport hubs and railway stations. The differences this study observes between mobility hubs and conventional passenger transport hubs are twofold. From the mobility perspective, mobility hubs have a broader scope and a denser transport network in comparison to conventional passenger transport hubs. From the non-mobility perspective, mobility hubs are distinct by their emphasis on services and facilities and their ability to contribute to multiple societal challenges. The different steps of typology construction showed that especially services, facilities, transport modes, location, and scale are suited for empirical grouping. Furthermore, the study showed that most interrelationships can be structured in a conceptual framework that distinguishes the mobility hubs' context, structure, and purpose. The investigated properties for empirical grouping and the main structure of interrelationships support the developed typology. This typology determines types based on the level of quality and quantity of both their transport modes, as well as their services and facilities. The mobility hub types identified are the:

- Community hub;
- Neighbourhood hub;
- Rural hub;
- City district hub;
- City edge hub;
- City centre hub.

The level of quantity and complexity of transport modes on the one hand, and that of services and facilities on the other hand, are expected to be mutually reinforcing. An exception is made for two types of hubs: the rural hub and the city edge hub. These two types offer a relatively lower level of quantity and complexity of services and facilities than would be expected based on their level of quantity and complexity of transport modes. Future challenges for the mobility hubs are discouraging alternatives, creating uniformity in design, developing positive business cases, balancing flexibility with consistency, and using the concept as a means instead of a goal in itself.

13. Discussion

This study has created a conceptual framework for mobility hubs by identifying mobility hub types. In the current mobility transition, exploratory research, as this study, is essential in understanding complex new concepts like mobility hubs. The identified types can contribute to policy making, since the results give insight into how to disentangle the use and future challenges per type of mobility hub. However, a shortcoming of a typology is that it does not incorporate the unique local contexts. The developed typology could give the impression that mobility hubs can be exclusively labelled based on this study, which is incorrect since the local surroundings are expected to highly influence its use (Bell, 2019). In addition, the mobility transition still takes place and future paths of developments in Mobility as a Service and micro-mobility are difficult to predict. It is therefore uncertain if the identified types are future-proof. Consequently, the results of this exploratory study should be interpreted as a reflection of the potential forms and contributions of mobility hubs rather than a rule. The results can be used for an initial differentiation before additional research into the local surroundings is conducted.

In addition, this study indicates distinct focus points between the professional stakeholder groups but cannot statistically validate them. Interviewing experts from four different professional stakeholder groups has given this exploratory research a broad perspective, but at the same time has the consequence of a relatively lower number of experts per group. Although text analysis mainly supported these indicated differences, this method cannot be used for statistical differentiation either, since the volume and the type of publications differ substantially. Distinguishing focus points between professional stakeholder groups is further constrained by the fact that some of the publications cannot entirely be attributed to one organisation. This is explained by co-creation. For example, the policy paper of Rijkswaterstaat (2020) is based on input from consultancy organisation VerhoevenSC. Other examples are the policy paper of APPM & Goudappel (2021) for the Province of Noord-Brabant which is written in collaboration with policy advisors of local municipalities, and the case study report of mobility provider Hely (Hely, ParkBee & Bouwinvest, 2020) which is co-authored by an organisation that is active in Real Estate investments. Therefore, a publication that is attributed to one organisation can be highly influenced by another organisation, which in turn influences the results of the text analysis.

A group that is not included in this study are the users of mobility hubs, as they are usually not involved in its development. Nevertheless, the user group does play a significant role when the mobility hub is implemented, since their use indicates a mobility hub's effectiveness to create hub functions and to contribute to societal goals. Further research could investigate the user behaviour and preferences to set the right preconditions for an effective use. An example of an identified future challenge that is highly related to user experiences and satisfaction is the challenge of creating uniformity in design (Bell, 2019; Monzón et al., 2016; Chauhan et al., 2021). A potential solution to this future challenge could be investigated by including the user group in further research**.** Suggested research is to copy the design of railway stations, for instance of retail facilities, to other mobility hubs and to investigate the user experience.

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Appendix

Appendix A: Interviewed experts

Expert name	Function	Organisation	Category	Date	Attendance panel discussion
Jarko van Nunen	Project manager & business developer hubs & leisure	Royal HaskoningDHV	Consultancy	17-05-2021	Yes
Jasper Meekes	Policy advisor mobility	Municipality of Nijmegen	Governmental institution	18-05-2021	No
Sven Mittertreiner	Policy advisor mobility	Municipality of The Hague	Governmental institution	20-05-2021	Yes
Charles Huijts	Policy advisor mobility	Municipality of The Hague	Governmental institution	20-05-21	Yes
Gerbrand van den Eeckhout	Development manager	Arriva	Mobility provider	26-05-2021	No
Lieve van der Putte	Junior project developer	AM	Project developer	28-05-2021	No
Martijn Stemerdink	Development manager	Janssen de Jong Projectontwikkeling	Project developer	30-05-2021	No
Daan Klaase	Manager planning and development	NS	Mobility provider	30-05-2021	Yes
Machiel Kleingeld	Development manager	Arriva	Mobility provider	01-07-2021	No
Christiaan Kwantes	Consultant mobility & space	Goudappel	Consultancy	01-07-2021	No
Edvard Hendriksen	Consultant sustainable mobility	Over Morgen	Consultancy	02-07-2021	No
Jan-Jelle Witte	Researcher	The Netherlands Institute for Transport Policy Analysis (KiM)	Governmental institution	06-07-2021	Yes
Kjell Knippenberg	Product owner	Hely	Mobility provider	07-07-2021	No
Steven Meerburg	Policy advisor mobility	Province of Zeeland	Governmental institution	08-07-2021	Yes
Bart Verhaeghe de Naeyer	Policy advisor sustainable civil engineering	Province of Zeeland	Governmental institution	08-07-2021	Yes
Jacco Lammers	Co-owner	GoAbout	Mobility provider	13-07-2021	No

Appendix B: Publications analysed

Publication source	Title	Year	Organisation category	Publication category	Mobility hub as main topic
Aan de Stegge Twello	Mobility hub fluorterrein Haarlem. Nieuw mobiliteitsconcept.	n.d.	Project developer	Article	Yes
AM	Deelmobiliteit: een gebiedsopgave. Sturen op Bereikbare en Aantrekkelijke gebieden	2020	Project developer	Whitepaper	No
AM	Gemeente Rijswijk, AM, Dura Vermeer, Synchroom en VolkerWessels vastgoed sluiten intentieovereenkomst locatie Pasgeld in Rijswijk	2019	Project developer	Article	No
APPM	Slimme oplossingen voor de Sluisbuurt Amsterdam	2020	Consultancy	Case Study report	No
APPM	Hub om de Hub	2020	Consultancy	Article	Yes
APPM & Goudappel	Ontwikkelplan mobiliteitshubs West-Brabant	2021	Consultancy	Policy paper	Yes
CROW	Mobiliteitshubs landelijk gebied	2021	Knowledge institution	Policy paper	Yes
CROW	Leidraad parkeren bij knooppunten en mobiliteitshubs	2021	Knowledge institution	Policy paper	No
Dura Vermeer	Doorbraak voor transformatie Haarlem Schalkwijk Midden	2020	Project developer	Article	No
Gemeente Groningen	Verkenning Mobiliteitstransitie Groningen	2019	Governmental institution	Policy paper	No
Goudappel	De mobiliteitshub: van houtkoolschets naar foto	2020	Consultancy	Whitepaper	Yes
Goudappel & APPM	Gelderse Mobiliteitshubs. Cruciale schakels in bereikbaarheid en leefbaarheid	2020	Consultancy	Policy paper	Yes
Goudappel & Rebel	Mobiliteitsconcept voor Merwede Eindrapport	2018	Consultancy	Policy paper	No
Groene Metropoolregio Arnhem Nijmegen	Mobiliteitshubs in de groene metropoolregio Arnhem Nijmegen	2021	Governmental institution	Policy paper	Yes
Hely	Aanbieden deelmobiliteit een must voor stedelijke hoogbouw	n.d.	Mobility provider	Whitepaper	No
Hely, ParkBee & Bouwinvest	Mobility as a Service: hoe realiseer je een succesvolle mobility hub?	2020	Mobility provider	Whitepaper	Yes
Janssen de Jong Projectontwikkeling	'Mobility as a Service' als voorwaarde voor binnenstedelijke gebiedsontwikkeling	2019	Project developer	Article	No
Kennisinstituut in Mobiliteit	Verkenning van het concept mobiliteitshub	2021	Governmental institution	Policy paper	Yes

Metropoolregio Amsterdam	Leidraad Gebiedsontwikkeling & Smart Mobility	2021	Governmental institution	Policy paper	No
Ministerie van Infrastructuur en Waterstaat	Schets Mobiliteit naar 2040: veilig, robuust, duurzaam	2019	Governmental institution	Policy paper	No
Ministerie van Infrastructuur en Waterstaat	Ontwikkelagenda Toekomstbeeld OV	2021	Governmental institution	Policy paper	No
Ministerie van Infrastructuur en Waterstaat	OV-knooppunten. De verbinding tussen reizen en verblijven.	2020	Governmental institution	Policy paper	No
Mobiliteitsalliantie	Startnotitie hubs	2020	Knowledge institution	Policy paper	Yes
NS	Journey to the future[1]	2019	Mobility provider	Policy paper	No
Over Morgen	Duurzame mobiliteit en gebiedsontwikkeling	n.d.	Consultancy	Whitepaper	No
ProRail	Station NXT	2019	Mobility provider	Policy paper	Yes
Provincie Gelderland	Visie voor een bereikbaar Gelderland	2020	Governmental institution	Policy paper	No
Provincie Zeeland	Richtingennotitie Slimme Mobiliteit	2020	Governmental institution	Policy paper	No
Provincie Zeeland	Concept Regionale Mobiliteitsstrategie	2021	Governmental institution	Policy paper	No
Rebel	Radicaal kiezen voor de juiste balans	2019	Consultancy	Whitepaper	No
Rijkswaterstaat	De multimodale Hub en Rijkswaterstaat	2020	Governmental institution	Policy paper	Yes
Royal HaskoningDHV	Mobiliteitshub Werpsterhoeke	n.d.	Consultancy	Case Study report	Yes
&Morgen	Mobiliteit en Gebiedsontwikkeling	n.d.	Consultancy	Whitepaper	No

[1] Translated to Dutch.