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Connecting people and places: Analysis of perceived pedestrian accessibility to railway stations by Bavarian case studies

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ABSTRACT

Walking connects different modes of transport and acts as the main feeder for public transport. Nonetheless, ensuring high-quality accessibility for pedestrians to railway stations is seldom evaluated beyond measurable factors such as walking distance and time. Although several studies found differences in calculated and perceived accessibility, little research has so far focused on the factors that are influencing perceived pedestrian accessibility and thus causing these differences. In order to contribute to the current efforts of conceptualizing perceived accessibility, this study explores the factors which determine whether or not people walk to train stations. Potential influencing factors were first derived from a literature review and clustered into six quality criteria (directness, simplicity, traffic safety, security, comfort and built environment). Then, on-site and online surveys were conducted in five Bavarian towns (Germany) to understand the importance of the identified factors and how this differs between different people and places. The results confirm that above all comfort, safety and security factors play an important role for pedestrian accessibility. In addition, significant differences were found between different age groups and city sizes.

1. Introduction

All trips begin on foot. Walking is especially important for public transport trips: walking overall serves as the main feeder for public transport and thus also for the railway system. Although the proportion of pedestrians can vary considerably, in Europe typically, more than 50% of trips to and from railway stations are made on foot (Ceder, 1998; La Paix and Geurs, 2014). Travellers that reach the railway station by car, bicycle or bus, still have to walk the last metres to the platform. In general, public transport is only attractive if the whole trip chain is competitive with other modes of transport, especially cars (Keijer and Rietveld, 2000). Thus adequate pedestrian infrastructure to and at public transport stops is crucial to foster public transport usage. Evidently, walking is a key element of railway stations and mobility hubs: it allows different transport modes and nodes to be connected, thereby enabling intermodality and promoting sustainable mobility. Apart from the feeder role it has to public transport, active mobility brings many health benefits for its users (Lin et al., 2015). Moreover, walking is for free, uses urban space efficiently, is environmentally friendly, allows for easy interaction with other people, strengthens the local economy and requires comparatively little investment (FGSV, 2014; Jou, 2011).

Pedestrian accessibility can be defined as the ease with which certain destinations can be reached by walking (Koenig, 1980; Niemeier, 1997). To firstly analyse and secondly enable the ease of reaching the stations in reality, a shift from mobility-based planning to accessibility-based planning is advisable. This shift can already be observed in quite some fields and studies (Handy, 2020; Merlin et al., 2018). The quality of pedestrian accessibility is dependent on the location of the destination, the network connectivity (Geurs and Van Wee, 2004; Kathuria et al., 2019), and the resulting trip duration. However, pedestrian accessibility is not only influenced by time-related factors. A study by Kathuria et al. (2019) shows that the public transport ridership increases with improved walkway quality. The surrounding environment of the walkway also impact the perceived pedestrian accessibility (Bivina et al., 2020; Erath et al., 2021; Gupta et al., 2022; Pueboobpaphan et al., 2022). For example, if a route leads through an unpleasant area, it might feel longer than it actually is (Bahn.Ville-Konsortium, 2010; Ralph et al., 2020). Lastly, the health and well-being of the pedestrian determine whether some routes are accessible or not (Brons et al., 2009; De Vos et al., 2013). If a person is mobility-impaired or has other limitations, some paths may be not accessible at all. Overall, it can be said that good pedestrian accessibility is essential to making walking to railway stations an attractive option.

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This highlights the usefulness of comprehensive accessibility studies in this regard.

While some factors influencing walking, such as distance, footpath width and presence of street lights can easily be measured, others such as the attractiveness of the surrounding environment are harder to evaluate. In fact, even if evaluation criteria for those factors influencing walking are found and measured, it does not necessarily mean that they are *perceived* the same by (all) pedestrians. These differences in calculated and perceived accessibility were posed in several studies and are attracting the interest of a rising number of researchers (such as Curl et al., 2015; Damurski et al., 2020; Lättman et al., 2018; Pot et al., 2021; Ryan and Pereira, 2021; Ryan et al., 2016). In contrast to calculated accessibility (using spatial data to compute accessibility indicators), perceived accessibility describes how people actually experience the potential to participate in spatially dispersed opportunities (Pot et al., 2021) and is attempted to be derived through surveys and mobility behaviour studies. While calculated pedestrian accessibility to transport stations has been discussed at length in literature and is applied in practice, little research has focused on perceived factors influencing pedestrian accessibility (Curl et al., 2015; Ryan and Pereira, 2021).

The purpose of this study is to answer the following research questions: Which factors influence the perceived pedestrian accessibility of railway stations? How does this differentiate for different people and places? Although this exploratory study focuses on perceived pedestrian accessibility to railway stations in Bavaria, the results may also be transferable to pedestrian accessibility to other destinations in other regional contexts. Therewith, this paper aims to contribute to current efforts (e.g. by Pot et al., 2021; Ryan and Pereira, 2021) of conceptualizing perceived accessibility and further advancing the shift from mobility-based to accessibility-based planning (Pot et al., 2021).

This paper is structured as follows: Chapter 2 will start with a literature review, followed by the explanation of the design of this study in Chapter 3. Chapter 4 summarises the results, which are later discussed in Chapter 5 with regard to their relevance for the research question. Finally, Chapter 6 concludes the paper and points out future needs for action – for research and practice.

2. Literature review

The following literature review explores how railway stations interact with the city (Section 2.1), how pedestrian accessibility (to railway stations) can be evaluated (Section 2.2), how measured and perceived pedestrian accessibility differ (Section 2.3), and how this is related to the concept of walkability (Section 2.4). The identified research gaps are summarized in 2.5.

2.1. Functions of railway stations

In contrast to travelling by car, bicycle or foot, public transport does not allow for spontaneous interactions with the external environment, as the routes and entry and exit points are fixed. Thus, railway stations are the portals into places and their opportunities for many people (Bertolini, 2008). In the sense of transit oriented development (Vale, 2015), a railway station has to be well-connected, not only to other nodes on the transport network, but also to its surroundings (Crockett and Hounsell, 2005) - especially for pedestrians (Brons et al., 2009), because at the latest upon entering the station, everyone becomes a pedestrian. In other words, only if network connectivity is met with station accessibility does the public transport system as a whole flourish.

However, reducing a railway station to its mobility function denies its potential as a location in its own right: they are and have to be more than nodes on a transport network (Bertolini, 1996). If designed well, the railway stations are places of service, leisure, commerce and communication (Zemp et al., 2011). While the high accessibility levels ideally given at a railway station attract offices and housing, the high volumes of passengers travelling through railway stations generate demand for retail and gastronomy. Vitalising the surroundings of railway stations in this way also augments the objective and perceived sense of security (Beckmann et al., 1999). Therefore such an intense and diverse functional use not only enhances the overall attractiveness of the location, but also contributes to the local economy around the railway station (Zemp et al., 2011). The many commercial opportunities together with the higher sense of security in turn increase the attractiveness of public transport and spawn higher demand for this mode (Tiwari, 2015). All this makes a railway station a lively place in a city that contributes to a city's character and is more than only a stop on a transit line (Bahn.Ville-Konsortium, 2010; Wulfhorst, 2003).

The importance of walking in enhancing the attractiveness of a railway station is clear: "the larger the number of people that can reach a certain station in a short amount of time, the higher the density of functions around it" (Wenner et al., 2020). The same applies the other way around. Good pedestrian accessibility of the station surroundings thereby increases the catchment area and thus the potential number of public transport passengers (Hillnhütter, 2016).

2.2. Concept of pedestrian accessibility

Accessibility was first defined as the "potential of opportunities for interaction" by Hansen (1959) and later specified by Geurs and Van Wee (2004) as the "extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)". Accessibility is characterised by land use, transportation, temporal and individual components (Geurs and Van Wee, 2004). Although there are some overlaps, the first two describe the *place*, while the last two mainly capture how *people* with individual preferences and differing temporal constraints can access destinations. In the context of time-geography (Hägerstrand, 1970), the terms *place-based accessibility* (Hu and Downs, 2019) and *person-based accessibility* (Fransen and Farber, 2019; Järv et al., 2018; Páez et al., 2012) are used to specify these to parts. Individual and temporal factors such as income, age, gender, educational level, car and time availability, as well as the time of the day and year, all influence how people perceive their access to certain destinations (e.g. railway stations) by different modes - and consequently their mobility decisions. According to Handy and Niemeier (1997), "the key is to measure accessibility in terms that matter to people in their assessment of the options available to them". For the transportation component, this means knowing what features of different modes of transport are important to people (Handy and Clifton, 2000).

Pedestrian accessibility outlines the concept for walking specifically, as the accessibility of this mode is determined differently. Pedestrian accessibility is not only influenced by objective, measurable characteristics, but also subjective, perceived characteristics, such as sense of safety or comfort (Lin et al., 2015). Comfort in this sense is defined as the persons level of ease, convenience and contentment while walking (Alfonzo, 2005). Walking attractiveness includes, but is not limited to, unobstructed and safe accessibility with good connectivity, safe crossing opportunities and well-designed footpaths that are easy to walk on (Lo, 2009; Ujang and Zakariya, 2015). There is rising certainty that pedestrian accessibility is strongly connected to perceived quality levels of the land use and transport systems (Arslan et al., 2018; Gkavra et al., 2019; Liang and Cao, 2019) and dependent on individual characteristics, capabilities, attitudes and preferences (Pot et al., 2021). Whether or not an individual chooses to walk to a destination is therefore influenced by various factors, ranging from large elements such as the type of urban form to small elements such as street furniture (Alfonzo, 2005; Arslan et al., 2018) and external conditions such as weather. Due to their slow speed and direct interaction with the environment, pedestrians are generally more aware and sensitive to their surroundings than drivers, which is highly related to the individual walking comfort (Handy et al., 2002). Therefore, a stronger focus on micro-features is needed to fully understand the interactions (Bivina et al., 2020; Clifton et al., 2007).

Pedestrian accessibility in relation to public transport stations has been investigated in recent studies, e.g. by Bivina et al. (2019), Kathuria et al. (2019), Sarker et al. (2019), Bivina et al. (2020), Rossetti et al. (2020), Gupta et al. (2022), and Pueboobpaphan et al. (2022), generating similar results as the general pedestrian accessibility studies. Sarker et al. (2019) found that especially the working population usually chooses the most direct and shortest route. In addition to route directness, micro-scale (e.g. sidewalk availability, surface quality) and meso-scale built environment factors (e.g. population density and land use diversity) were found to have an positive impact on access mode choice (Gupta et al., 2022; Kathuria et al., 2019), while the effects of micro-scale factors were more significant (Bivina et al., 2020). Especially safety and security factors were found as the most influential regarding pedestrian accessibility (Bivina et al., 2019; Gupta et al., 2022). Improving the walking environment can therewith increase the distance people are willing to walk, thus also increasing the service coverage area of stations (Pueboobpaphan et al., 2022) and consequently the ridership numbers (Kathuria et al., 2019).

Rossetti et al. (2020) proposed a method to calculate pedestrian accessibility to railway stations by creating detailed pedestrian isochrones and calculate how many inhabitants have access to the public transport system within a certain time, while Pueboobpaphan et al. (2022) found that acceptable walking distances was less for Bangkok than suggested by standard methods. This again hints at the fact that calculated and perceived accessibility may differ.

2.3. Mismatch between calculated and perceived accessibility

Calculated accessibility refers to the calculation of accessibility by the use of accessibility indicators based on spatial data. This term is e.g. used by Ryan and Pereira (2021), and Pot et al. (2021), while others use terms like *objective accessibility* (Lättman et al., 2018) or *measured accessibility* (Ryan et al., 2016). Anyhow, as all models and indicators are somehow generated by humans, they can never be fully *objective* (Haugen et al., 2012; Ryan and Pereira, 2021; Schwanen and de Jong, 2008). Also, the term *measured* can be misleading, as accessibility itself cannot be measured by a simple device, as e.g. sidewalk width. Instead, technical indicators are needed that somehow *calculate* accessibility by the use of data and certain input parameters. Therefore, the authors decided to go with the term *calculated accessibility*, as it is also recommended by Ryan and Pereira (2021), Pot et al. (2021).

When referring to how individuals perceive their ease of reaching destinations, the terms *subjective accessibility* (Damurski et al., 2020), *perceived accessibility* (Lättman et al., 2018; Pot et al., 2021; Ryan et al., 2016; van der Vlugt et al., 2019), *self-reported accessibility* (Curl et al., 2015; Ryan and Pereira, 2021) or *experienced accessibility* (Chorus and de Jong, 2011) are used. While *subjective accessibility* mainly serves as a counterpart to *objective accessibility, self-reported accessibility* refers to survey results, which is the method used in most studies to derive perceived accessibility, but the term focuses on the method rather than the outcome. Regarding *experienced* and *perceived accessibility*, the authors consider both terms as fitting but decided for *perceived accessibility*, as the majority of existing literature also used this term. Pot et al. (2021) define perceived accessibility as “the perceived potential to participate in spatially dispersed opportunities”. This definition is also used in course of this paper, with specification to railway stations.

Regardless of the terminology, several studies found a mismatch between different accessibility metrics (Curl et al., 2015; Damurski et al., 2020; Gebel et al., 2011; Lättman et al., 2018; McCormack et al., 2008; Pot et al., 2021; Ryan and Pereira, 2021; Ryan et al., 2016). While attractiveness of public transport is classified by means of travel time, quality of service, waiting times and comfort, only a few measurable factors such as travel distance and/or travel time are usually considered for walking. Although there are reasons to believe that these factors are not necessarily the most appropriate when it comes to accessibility by active modes (Páez et al., 2020): “Crucial to determining the acceptable distance in a given situation is not only the actual physical distance, but also to a great extent the experienced distance” (Gehl, 1987). In contrast to *place-based accessibility, calculated accessibility* is not excluding the individual and temporal component per definition. But as the perceived factors are not even close to being fully researched, there are only few studies (D’Orso and Migliore, 2018; Erath et al., 2017; Gaglione et al., 2021) considering walkability factors. Thus, there is a tendency to overestimate accessibility levels (Curl et al., 2015; Ryan and Pereira, 2021).

2.4. Walkability

Besides *pedestrian accessibility*, the term *walkability* is often used in literature to make a statement about how walking-friendly an area is. The Walk Score ® index, which is very often used to assess walkability, also uses gravity-based accessibility measures (Hall and Ram, 2018). While the Walk Score ® itself can be considered as an ‘objective’ measurement, especially when it comes to perceptions, more research can be found in the walkability field than in perceived pedestrian accessibility.

The American-Planning-Association (2006) defines walkability as: “A place in which residents of all ages and abilities feel that it is safe, comfortable, convenient, efficient, and welcoming to walk, not only for recreation but also for utility and transportation”. The definition and the term, which already contains the word *ability*, hints at the fact that age and personal abilities have an impact on the walkability. Although those factors are also included in the individual component of accessibility, the term *walkability* puts additional emphasis on the perception of the people walking (as stated in the definition: how people “feel”). In this context, researchers (e.g. Blecic et al., 2015; Fancello et al., 2020; Reyer et al., 2014) also refer to the capability-approach by Nussbaum (2003). According to Sen (1980), *capabilities* cover “what people are actually able to do and to be”. The individual capabilities of a person are based on internal and external factors: (1) the ability, persons internal power, detained but not necessarily exercised, to do and to be, and (2) the opportunity, presence of external conditions which make the exercise of that power possible (Blecic et al., 2015). In order that a person is capable of doing something, e.g. walking to the railway station, both the internal and external factors need to be in line. The concept of capability is tightly intertwined with the individual component of accessibility (Vecchio and Martens, 2021), in turn influencing perceived accessibility (Ryan et al., 2019).

Even though there is no standard definition for walkability (Forsyth, 2015) and not all of them include the availability of destinations, plenty the results are also useful for understanding pedestrians perceptions that may also influence perceived pedestrian accessibility.

As for this research the availability of specific destinations, namely railway stations, was of fundamental importance, the term *pedestrian accessibility* is used to describe the walking conditions to those. To emphasise the individual perceptions of the pedestrians, the word *perceived* is added.

2.5. Research gap(s)

Good pedestrian accessibility is paramount in order to encourage people walk to the railway station and increase the users of the railway offer. There is a common agreement, that perceived factors are crucial in this regard and the solely consideration of calculated measures leads to distorted results. However, in order to include the perceived factors in the analysis of accessibility, they must first be explored and fully understood – this is the stage of work that researchers in the field are currently in. To current point in time, it is neither clear which factors are the most important ones when it comes to perceived accessibility nor how this differs for different people and at different places.

3. Research framework and methodology

This research project aims to contribute to this/these research gap(s) and to explore factors influencing perceived pedestrian accessibility to one specific destination: railway stations. Five municipalities are therefore chosen as study areas (Section 3.1). First, a general set of quality criteria (Section 3.2) is derived and developed from literature and subsequently used as a hypothesis framework to evaluate the perceived accessibility. Then, surveys on the perceived pedestrian accessibility are conducted in the selected study areas (Section 3.3). The results are analyzed in order to better understand how individual people at different places perceive accessibility (Section 3.4). The following sections and Fig. 1 give more detail on each part of the methodology.

3.1. Study context

The study was conducted in Bavaria (one of the 16 German federal states). In specific, five Bavarian municipalities were selected: Aichach, Bad Neustadt a.d.Saale, Freilassing, Hilpoltstein and Landshut (see Fig. 2). The focus was on small to medium-sized cities, where the railway station usually plays a bigger role in everyday mobility than in metropolises, which usually have several public transport hubs. The municipalities were chosen as to represent different station typologies in terms of size, passenger numbers and their role in the network. In addition, the willingness of the local authorities to participate was also decisive, as the aim of the project (where this study was part of) was to identify deficits in the pedestrian accessibility of railway stations and to develop concrete measures to improve the situation together with local planners and stakeholders (Pajares et al., 2021). However, this paper focuses solely on the findings in regard to perceived accessibility.

In Bavaria, strengthening local public transport, cycling and walking is a central transport policy goal (Bayerische Staatskanzlei, 2021). The Bavarian railway infrastructure consists of around 6,500 km of track and 1066 stations (Bayerisches Staatsministerium für Wohnen, Bau und Verkehr, 2021b). But, as shown in Fig. 3, 59% of all trips in Bavaria are conducted using private motorised vehicles and only 10% of the trips are made using public transport (infas, 2018). These numbers confirm that in Bavaria public transport in general, and rail transport in particular, are currently not exploited to their full potential.

The low mode share of pedestrians and public transport users in Bavaria could be attributed to shortcomings in pedestrian accessibility, as people are less likely to use the train as the distance between home and station increases (Keijer and Rietveld, 1999). The location of railway stations in Bavaria is a product of history: many are not located in the pedestrian-oriented city centers but rather in outlying districts that are usually more car-oriented and less densely populated.

3.2. Quality criteria

In German as well as international literature, essential quality criteria for pedestrian traffic have been discussed (Alfonzo, 2005; Carr et al., 2010; Lo, 2009; Southworth, 2005). Based on the literature, six overarching quality criteria to evaluate pedestrian accessibility are defined: Directness, Simplicity, Traffic Safety, Security, Comfort, Built Environment. Each quality criterion was assigned a set of indicators. The resulting quality criteria and their corresponding indicators are listed in Fig. 4. The indicators were chosen specifically for the use case of access to railway stations.

The quality criteria, especially comfort and security are significantly influenced by individual perception. Since these cannot be derived directly, the quality criteria are assessed using proxy indicators (e.g. footpath width, lighting). One indicator can have an influence on several quality criteria. For example, the footpath width influences both comfort and traffic safety. The indicators were assigned to the quality criterion for which they are deemed most relevant. The following subsections outline the interplay of the chosen quality criteria and their (proxy) indicators.

3.2.1. Directness

The directness is primarily dependent on the actual length of the route to the railway station, as opposed to the aerial line distance. To provide direct routes to the population, a high local connectivity (ratio of links and nodes) is needed. Major obstacles in terms of directness, besides badly connected neighborhoods, are linear barriers such as fences, railway tracks or busy roads that can only be crossed at certain points. The actual length of the route affects how attractive a route is perceived (Handy and Clifton, 2001; Lo, 2009; Saelens et al., 2003). A comfortable walking distance for the majority of people is around 10 minutes (Calthorpe, 1993), which also seams to be valid for trips to train stations (Daniels and Mulley, 2013; O'Sullivan and Morrall, 1996).

3.2.2. Simplicity

The simplicity of a route depends, among other things, on the number of roads to be crossed. For pedestrian crossings with traffic lights, the waiting time and the duration of the green phase are deciding factors. In addition, a distinction must be made between automatic light signal systems and light signal systems with manual signal request devices. In addition, means of orientation to and from the railway station are important in terms of simplicity, and especially necessary for people who are not familiar with the area. This can be provided by consistent signposting, which also help to counteract overestimation of walking distances (Ralph et al., 2020). Furthermore, lines of sight towards characteristic buildings in the city can significantly improve orientation in public spaces.

3.2.3. Traffic safety

The traffic safety as perceived by pedestrians is determined by the characteristics of the footpath and by the presence of other road users on or near the footpaths. The availability of sidewalks and the spatial buffer between sidewalk and road are therefore important (Kweon et al., 2021). Not only driving cars affect the traffic safety of pedestrians, cyclists on the pavement can also lead to dangerous situations (Mesimäki and Luoma, 2021). In addition, parked cars on the street (or even on the walkway) obstruct the visibility of pedestrians (Oxley et al., 1997).

3.2.4. Security

How protected pedestrians feel from incidents by other humans and crime depends on the liveliness and social control of an area (Arslan et al., 2018; Saelens et al., 2003). Low visibility of sidewalks, e.g. in underpasses (Hillnhütter, 2016) or in areas with dense vegetation (Golan et al., 2019; Lin et al., 2015; Wimbardana et al., 2018) or low lighting levels (Saelens et al., 2003; Wimbardana et al., 2018), leads to decreased perceived security, while a lively environment ("eyes on the street" concept) can increase it (Gehl, 2013; Jacobs, 1961). In addition, cleanliness and appearance of the path and the surrounding environment have an impact hereon (Golan et al., 2019; Saelens et al., 2003).

3.2.5. Comfort

How comfortable it is to walk on a specific path depends on infrastructural criteria, such as footpath width (Alfonzo, 2005), surface (Wimbardana et al., 2018) and guidance (Saelens et al., 2003). Sufficient footpath width is important to ensure comfortable overtaking or crossing of pedestrians. If a footpath leads along a road, footpath width is perceived differently depending on the permitted speed on the road. At high speeds and with high traffic volumes, a spatial separation of road and footpath is therefore vital, also to reduce the noise levels for the pedestrians. If the footpath surface is uneven or contains many potholes, walking on it requires additional attention and may reduce the accessibility for some users. Freedom from barriers is not only of particular importance to people with limited mobility, but also for people with prams or heavy suitcases, for example, to comfortable travel

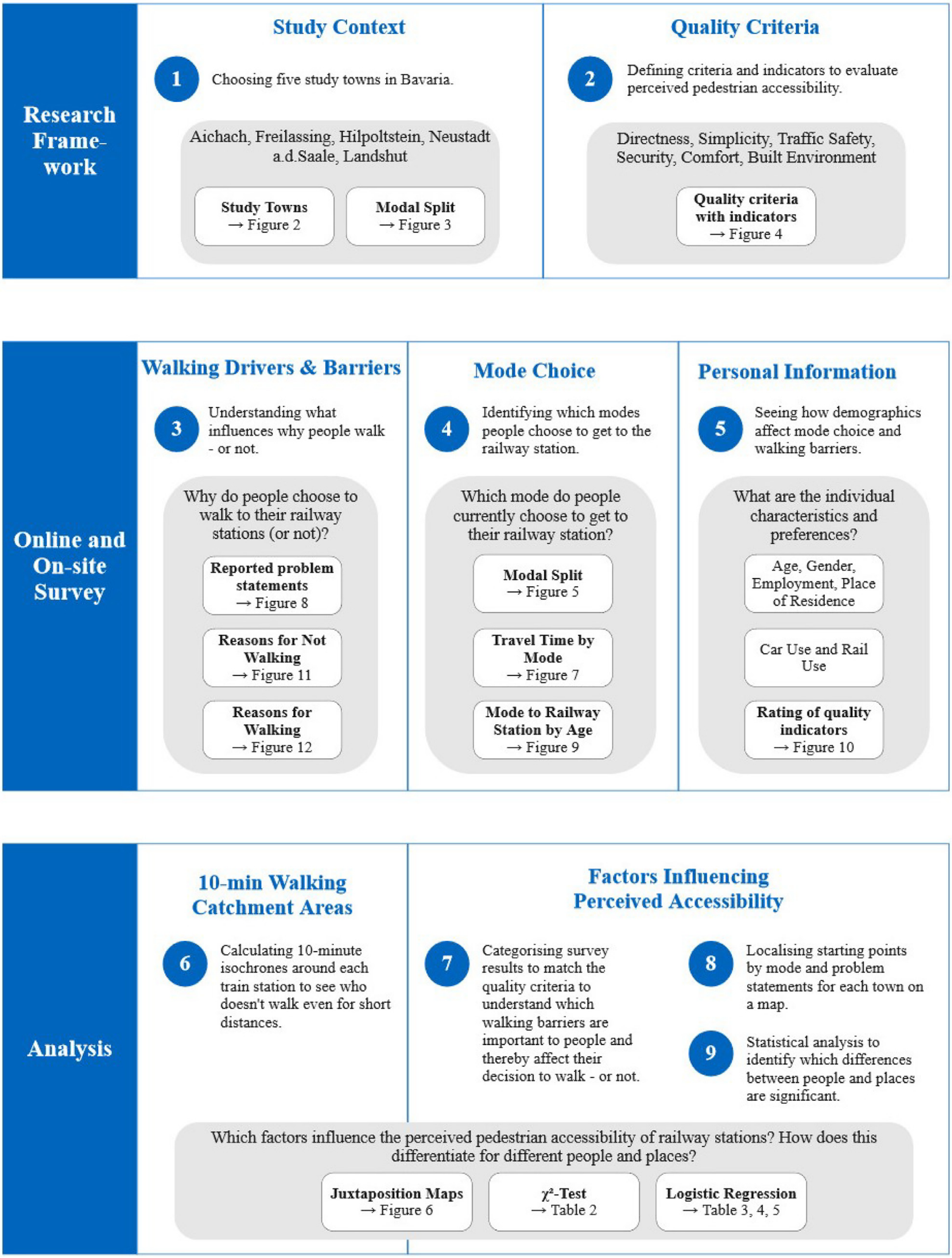


Fig. 1. Methodological steps.

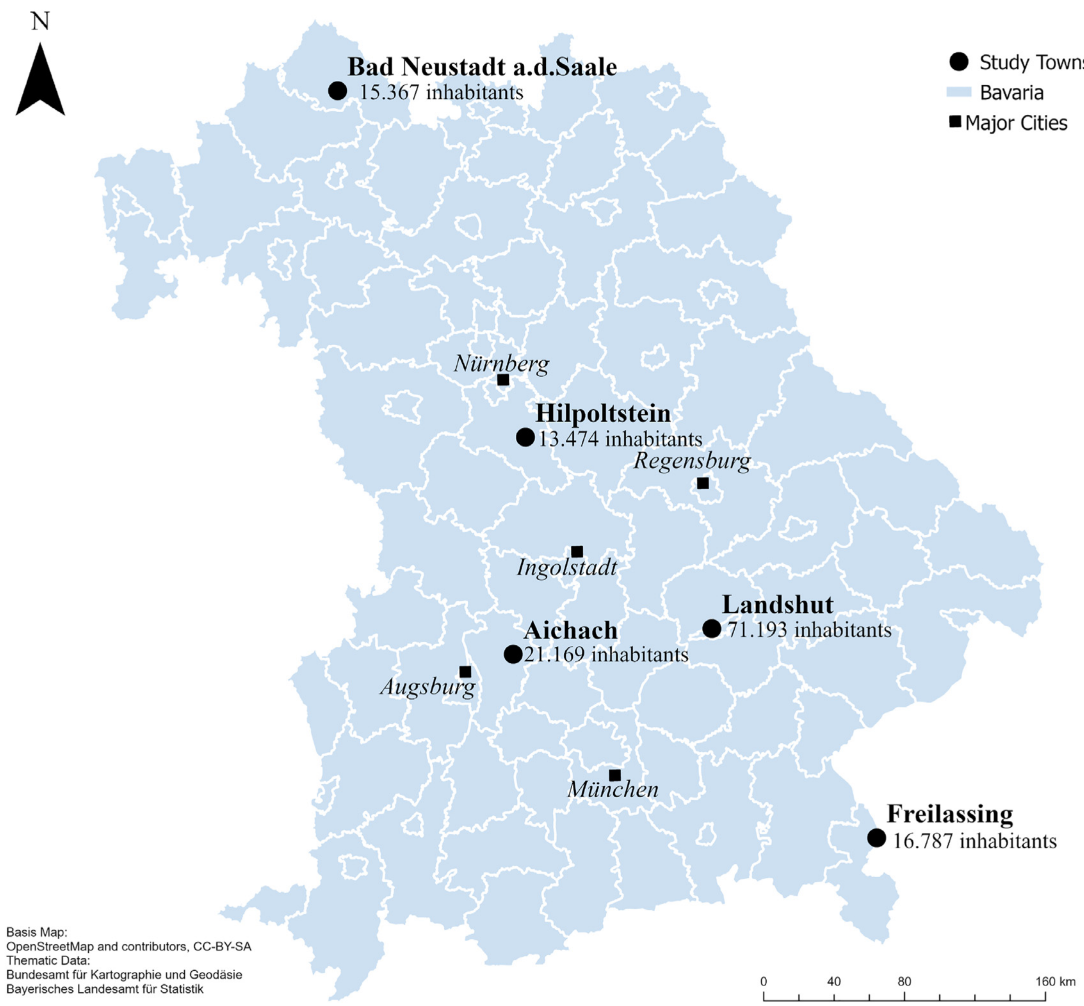


Fig. 2. Selected municipalities in Bavaria.

on footpaths (Zakaria and Ujang, 2015). In addition, walking comfort is influenced by the inclination (Handy and Clifton, 2001) and by the presence of weather protection (e.g. arcades, trees) (Arslan et al., 2018; Pilipenko et al., 2018; Whyte, 1980).

3.2.6. Built environment

How attractive a footpath and consequently walking in-general is perceived by pedestrians, is largely influenced by the built environment in which the footpath is located (Pushkarev and Zupan, 1971; Southworth, 2005). For example, a path through a busy city centre with many shops and people is more entertaining than a path through a deserted industrial area or a boring underpass (Hillnhütter, 2016). Additionally, city centres provide numerous points of interest (POI) to visit and run errands along the way (Lin et al., 2015; Saelens et al., 2003). But not only buildings and people, also natural elements such as street trees and green spaces provide visual and auditory stimuli and have an positive impact on the attractiveness of an area (Golan et al., 2019; Lin et al., 2015).

3.3. Survey

The locals' knowledge about existing weak points in the footpath network is invaluable. Experiences and feelings while walking can not be assimilated other than asking people frequenting those paths on a regular basis. The perceptions of local rail users were gathered using on-site and online surveys. The surveys were conducted in all five municipalities in autumn 2017. The on-site surveys were conducted directly at the railways stations. Five interviewers spend two days on each of the station and surveyed as many persons as possible within this time. The on-site survey was deliberately kept short due to the often limited time available at the railway station. A purposive sampling approach was used. In order to participate, survey candidates had to be frequent rail users (at least once a month) and non-transfer passengers (the stations surveyed had to be the starting or ending point of the train journey). These criteria were asked right at the beginning of the survey. However, occasional customers and transfer passengers were also given the opportunity to name problem areas that came to their attention. The online survey was published on the project's own website and was advertised by the municipal officials. The following questions were asked in both surveys (on-site and online):

General: As perceived accessibility is difficult to grasp, mode choice and specific survey questions are used as proxy to assess perceived accessibility. First, general information about the survey participants and their travel behaviour was recorded:

- Personal information: Age, gender, employment, place of residence
- Car use: Driver's license, car availability
- Rail use: frequency, destinations, purpose (e.g. work, education, shopping)

Non-Walkers: Then, participants were asked which mode of transport they used to reach the railway station. If respondents stated that they did not walk to the railway station, they were asked:

- Why did you not walk to the railway station?

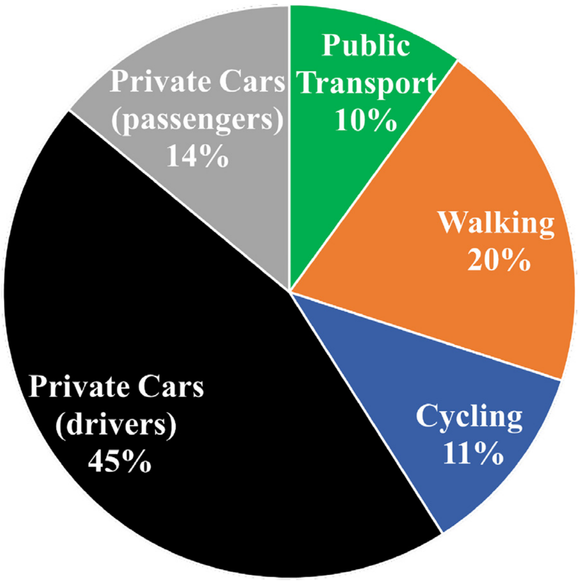


Fig. 3. Modal Split in Bavaria (infas, 2018).

- Why did you choose the other mode of transport?
- Have you ever walked to the railway station?

Walkers: If respondents stated that they walk to the railway station, they were asked:

- Why did you walk to the railway station?
- What would be the maximum distance you are willing to walk to the railway station?
- What and where are weak points on the way to the railway station and at the railway station itself?

In the online survey, problem areas could directly be pinpoint in a web-based tool. In addition, the participants were asked to rate how important different quality indicators for pedestrian accessibility are to them.

3.4. Analysis

For each city, the location-based survey results (starting points, mode of transport to the railway station, reported problem statements) were visualised in a map (see Chapter 4). The reported problem statements were matched with the quality criteria and their respective indicators that were found in the literature (see Chapter 3.2; e.g. the statement “There is no barrier-free access to platform 7.” was matched with *Comfort -> Freedom of barriers*). The reported problem statements were visualized by the use of a colour schema (Built Environment: blue, Comfort: yellow, Security: pink, Directness: orange, Simplicity: green, Traffic Safety: red). This colour scheme is used throughout the paper to make it easier to read the graphics and understand the connections. In addition, as proposed by Rossetti et al. (2020), travel-time isochrones (contour-based accessibility measure) were calculated for the five assessed train stations, using 10 minutes walking time and a walking speed of 5 km/h, and thus representing the average time that people are willing to walk to places. For the walking path network, OpenStreetMap data was used (OpenStreetMap-Contributors, 2021). The calculated isochrones were intersected with population data from the Census household survey (Statistische Ämter des Bundes und der Länder, 2011). Therewith, it was assessed if there is a connection between mode choice, walking distance to the railway station and reported problem areas.

If participants started their trip roughly within the 10 minutes walking distance from the railway station and chose a motorised mode, their survey answers were analysed in more detail to understand why. The mode choice differences between walking and cycling were not assessed, as these two active modes usually complement each other, depending on the total trip (chain) length and personal preferences. The answers to the non-location-based survey questions were summarised in diagrams.

In addition, chi-squared-tests and a logistic regression model were used to explore the differences in mode choice and the reasons therefore between places (cities) and people (gender and age). The software Epi Info 7 (Nieves and Jones, 2009) was used therefore. Chi-squared-tests were conducted (see Table 2) to test the association between the potential predictors (age group, gender, city) and the dependent variables (modes). Furthermore, a logistic regression model was built for mode choice, reasons to walk and reasons not to walk. Age groups (<18 - children ; 18 to <30 - junior adults ; 30 to <60 - senior adults ; >60 - elderly), gender (female ; male) and municipalities (>20.000 inhabitants - medium ; <20.000 inhabitants - small) were used as other variables (see Tables 3–5). Children as vulnerable groups were selected as a comparison group for the age groups. The input data were filtered according to the gender and age groups mentioned above.

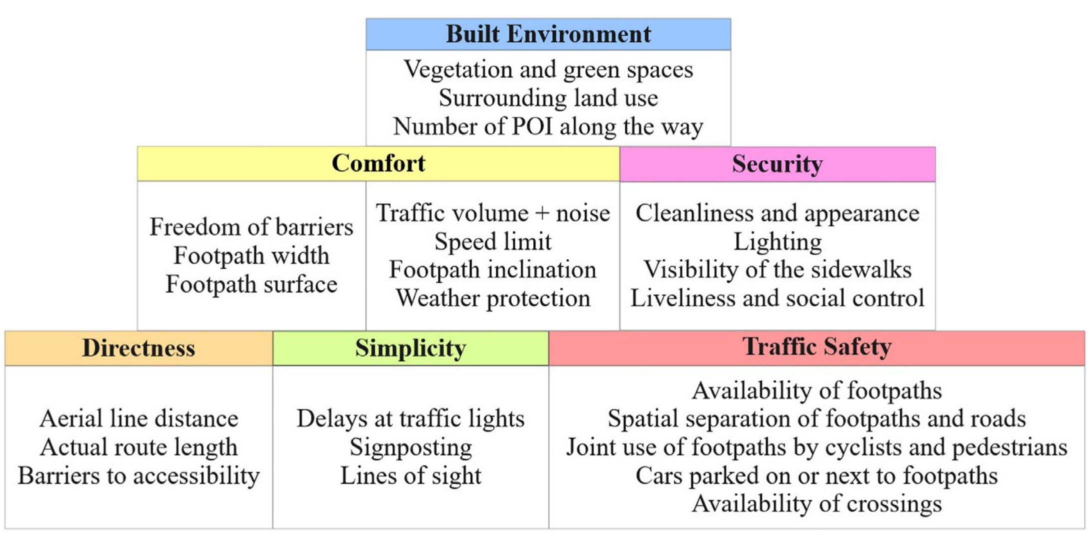


Fig. 4. Six quality criteria for pedestrian accessibility, with their respective indicators.

Table 1
Number of survey participants and descriptive statistics.

Municipality	Inhabitants	# of participants		
		on-site	online	sum
Aichach	21,169	121	15	136
Bad Neustadt a.d. Saale	15,367	85	41	126
Freilassing	16,878	115	118	223
Hilpoltstein	13,474	89	8	97
Landshut	71,193	127	35	162
Sum	**137,990**	**537**	**217**	**754**

Age Groups	Bavaria (Census 2011)	% of participants		
		on-site	online	sum
<18 (children)	17%	38%	2%	24%
18 to <30 (junior adults)	15%	27%	18%	29%
30 to <60 (senior adults)	49%	27%	57%	34%
>60 (elderly)	19%	8%	23%	10%

Gender	Bavaria (Census 2011)	% of participants		
		on-site	online	sum
Male	49%	49%	59%	54%
Female	51%	51%	41%	46%

4. Results

A total of 754 valid questionnaires was gathered (537 on-site and 217 online; see Table 1). According to the calculation method proposed by Kadam and Bhalerao (2010), 384 or more surveys are needed to represent Bavaria and to have a confidence level of 95% that the real value is within ±5% of the surveyed value – under the precondition that the sample is randomized. However, the cities used different advertisement methods, which leads to an unequal distribution of online survey participants per city. To understand how randomized the survey sample is, the distribution of the participants' age groups and genders is compared to the last Bavarian census (Statistische Ämter des Bundes und der Länder, 2011). It reveals that the younger half of survey participants (<30 years) is somewhat over represented in comparison to the census, while the older half of participants (>30 years) is somewhat underrepresented. The reason for this could be that the share of public transport users is also higher among younger people than among older people (Nobis & Kuhnimhof, 2018). In addition, a higher proportion of men participated in the online survey. Since the aim of the study is not to make generalised statements for the whole of Bavaria, but rather to explore how certain people perceive the pedestrian accessibility of railway stations, the sample size achieved is considered sufficient for this purpose, even if not all social groups are equally well represented.

In the following, the results are aggregated from the responses in the on-site and online surveys. The focus lies on the survey questions concerning walking to and from the station.[1] First, the statistical analyses are presented in Tables 2–5, then the results are described by the help of figures.

In four of the five municipalities surveyed, walking is the most important mode of transport to reach the station and was used by 41% of respondents in total. Fig. 5 shows all modes of transport used on the way to the railway station as an average for all five municipalities. A quarter of the surveyed rail users arrive at the station by car. The high proportion of car passengers (not drivers) is particularly striking. Notably, more rail users arrive to the station by bicycle than by public transport. However, it was not investigated separately to what extent this is connected to the local public transport (bus) offer and coordination of the timetables. It can be assumed that a better bus service would also result in a higher proportion of bus users. A small share of 3% uses "other" modes such as taxis or scooters.

[1] Details on the participants' overall travel behaviour can be obtained upon request.

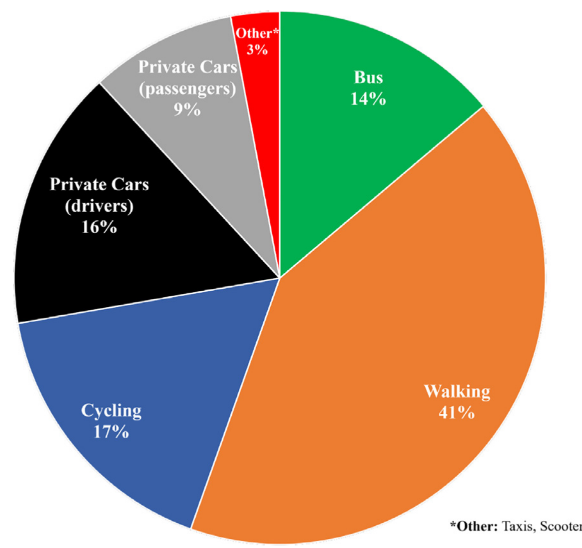


Fig. 5. Modes of transportation used to reach railway stations.

In the following, the factors influencing perceived pedestrian accessibility are presented, each as a summary of all five model municipalities.

4.1. Place

The share of pedestrians (and the overall modal split) depends on how big the town is and where its railway station is located. Although the journey to the station is predominantly made on foot, the composition of the mode of transport choice varies greatly in the five cities studied (see Fig. 6). The statistical analyses (see Table 2 and 3) show that the city size has an influence on the mode choice on the way to the railway station. In small towns, people are 2.41 times more likely to walk because 'it is fast' and they have no alternative (presumably because of the lack of bus connections). In the medium-sized cities, people are 3.22 times more likely to travel by bus.

Smaller towns with central train stations, such as Hilpoltstein and Freilassing, demonstrate very high proportions of pedestrians (56% and 47%). Larger cities such as Landshut, where only a low share of the total population lives within the 10 minute walking catchment area of the railway station, have a lower proportion of pedestrians. This is due to the longer distance that would need to be travelled by foot in order

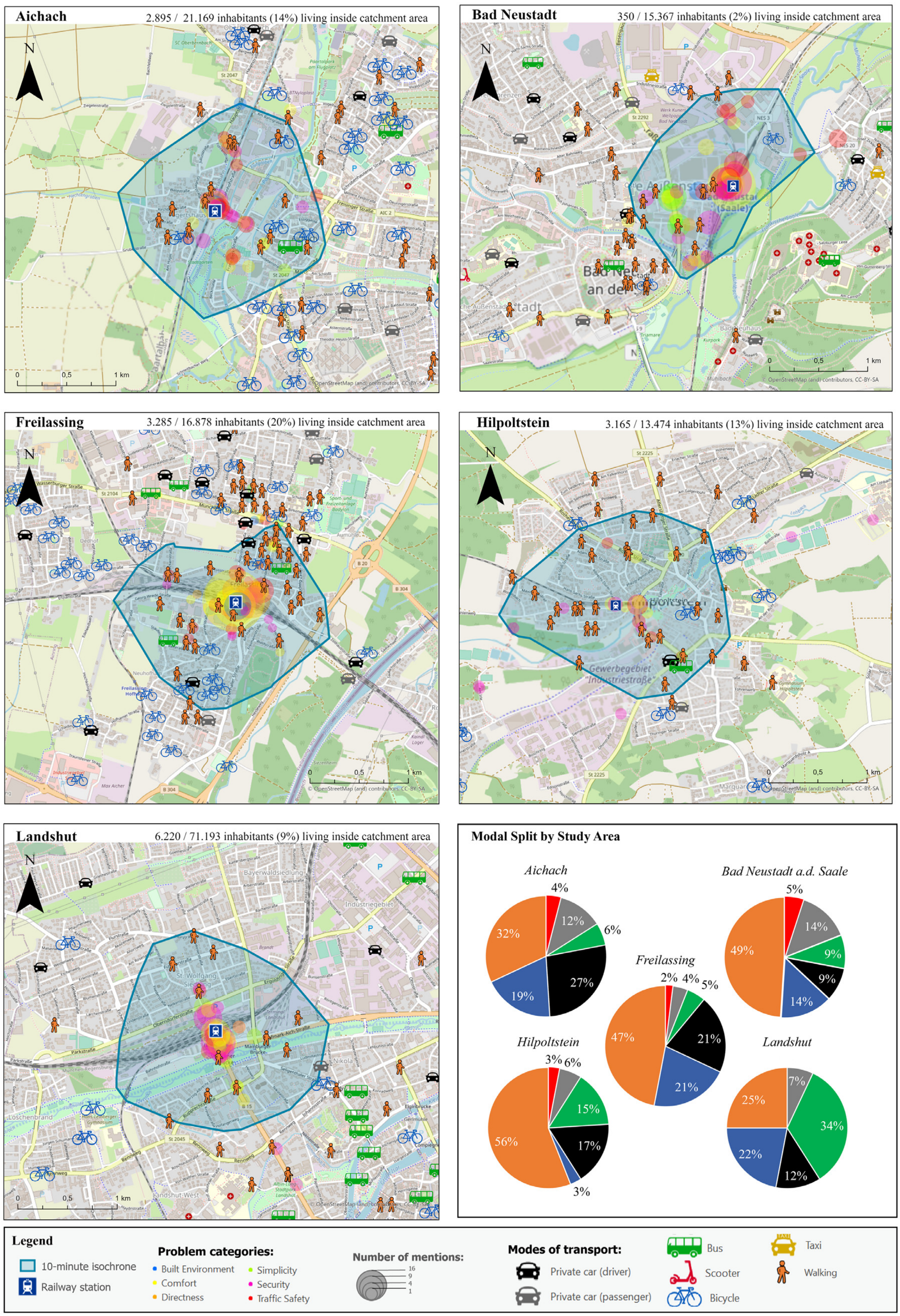


Fig. 6. Catchment areas, starting points, reported problem areas and mode shares for all study areas.

Table 2
Chi-squared test: people, places and mode choice.

		Walking				Cycling			
		total (n = 699) n (%)	**yes (n = 300)** n (%)	**no (n = 399)** n (%)	$\chi^2 - Test$ **p-value**	**total (n = 699** n (%)	**yes (n = 126)** n (%)	**no (n = 573)** n (%)	$\chi^2 - Test$ **p-value**
Age Group	**< 18 (children)**	159 (22.75%)	91 (30.33%)	68 (17.04%)	**< 0.01**	159 (22.75%)	24 (19.05%)	135 (23.56%)	0.16
	18 to < 30 (junior adults)	211 (30.19%)	76 (25.33%)	135 (33.83%)		211 (30.19%)	42 (33.33%)	169 (29.49%)	
	30 to < 60 (senior adults)	255 (36.48%)	95 (31.67%)	160 (40.10%)		255 (36.48%)	52 (41.27%)	203 (35.43%)	
	> 60 (elderly)	74 (10.59%)	38 (12.67%)	36 (9.02%)		74 (10.59%)	8 (6.35%)	66 (11.52%)	
Gender	**female**	332 (47.50%)	142 (47.33%)	190 (47.62%)	0.94	332 (47.50%)	53 (42.06%)	279 (48.69%)	0.18
	male	367 (52.50%)	158 (52.67%)	209 (52.38%)		367 (52.50%)	73 (57.94%)	294 (51.31%)	
Municipality	**medium (> 20.000 inh.)**	271 (38.77%)	79 (26.33%)	192 (48.12%)	**< 0.01**	271 (38.77%)	53 (42.06%)	218 (38.05%)	0.40
	small (< 20.000 inh.)	428 (61.23%)	221 (73.67%)	207 (51.88%)		428 (61.23%)	73 (57.94%)	355 (61.95%)	

		Private Car Driver				Private Car Passenger				Bus			
		total (n = 699) n (%)	**yes (n = 125)** n (%)	**no (n = 574)** n (%)	$\chi^2 - Test$ **p-value**	**total (n = 699)** n (%)	**yes (n = 58)** n (%)	**no (n = 641)** n (%)	$\chi^2 - Test$ **p-value**	**total (n = 699)** n (%)	**yes (n = 90)** n (%)	**no (n = 609)** n (%)	$\chi^2 - Test$ **p-value**
Age Group	**< 18 (children)**	159 (22.75%)	2 (1.60%)	157 (27.35%)	**< 0.01**	159 (22.75%)	16 (27.59%)	143 (22.31%)	**0.07**	159 (22.75%)	26 (28.89%)	133 (21.84%)	**0.02**
	18 to < 30 (junior adults)	211 (30.19%)	34 (27.20%)	177 (30.84%)		211 (30.19%)	24 (41.38%)	187 (29.17%)		211 (30.19%)	35 (38.89%)	176 (28.90%)	
	30 to < 60 (senior adults)	255 (36.48%)	71 (56.80%)	184 (32.06%)		255 (36.48%)	14 (24.14%)	241 (37.6%)		255 (36.48%)	23 (25.56%)	232 (38.10%)	
	> 60 (elderly)	74 (10.59%)	18 (14.40%)	56 (9.76%)		74 (10.59%)	4 (6.90%)	70 (10.92%)		74 (10.59%)	6 (6.67%)	68 (11.17%)	
Gender	**female**	332 (52.50%)	61 (51.20%)	271 (52.79%)	0.75	367 (52.5%)	28 (48.28%)	339 (52.89%)	0.50	367 (52.5%)	44 (48.89%)	323 (53.04%)	0.46
	male	367 (47.50%)	64 (48.80%)	303 (47.21%)		332 (47.5%)	30 (51.72%)	302 (47.11%)		332 (47.5%)	46 (51.11%)	286 (46.96%)	
Municipality	**medium (> 20.000 inh.)**	271 (38.77%)	55 (44.00%)	216 (37.63%)	0.19	271 (38.77%)	27 (46.55%)	244 (38.07%)	0.20	271 (38.77%)	57 (63.33%)	214 (35.14%)	**< 0.01**
	small (< 20.000 inh.)	428 (61.23%)	70 (56.00%)	358 (62.37%)		428 (61.23%)	31 (53.45%)	397 (61.93%)		428 (61.23%)	33 (36.67%)	395 (64.86%)	

Table 3
Logistic regression: people, places and mode choice.

		Walking Odds Ratios (95% C.I.)		**Cycling** Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	0.79 (0.45 - 1.37)	-	0.68 (0.29 - 1.6)	-
	(senior adult/child)	0.44 (0.30 - 0.66)*	0.47 (0.31 - 0.71)*	1.44 (0.85 - 2.45)	-
	(young adult/child)	0.42 (0.28 - 0.64)*	0.49 (0.32 - 0.76)	1.40 (0.81 - 2.42)	-
Gender	**(female/male)**	0.99 (0.73 - 1.33)	-	0.77 (0.52 - 1.13)	-
Municipality	**(small/medium)**	2.59 (1.88 - 3.58)*	2.41 (1.73 - 3.36)*	0.85 (0.57 - 1.25)	-

		Private Car Driver Odds Ratios (95% C.I.)		**Private Car Passenger** Odds Ratios (95% C.I.)		**Bus** Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	25.22 (5.67 - 112.15)*	25.22 (5.67 - 112.15)*	0.51 (0.16 - 1.58)	-	0.45 (0.18 - 1.15)	-
	(senior adult/child)	30.28 (7.31 - 125.4)*	30.28 (7.31 - 125.40)*	0.52 (0.25 - 1.10)	-	0.51 (0.28 - 0.92)*	0.44 (0.24 - 0.81)*
	(young adult/child)	15.07 (3.56 - 63.74)*	15.07 (3.56 - 63.74)*	1.15 (0.59 - 2.24)	-	1.02 (0.58 - 1.77)	-
Gender	**(female/male)**	1.07 (0.72 - 1.57)	-	1.20 (0.70 - 2.06)	-	1.18 (0.76 - 1.84)	-
Municipality	**(small/medium)**	0.77 (0.52 - 1.14)	-	0.71 (0.41 - 1.21)	-	0.31 (0.20 - 0.50)*	0.31 (0.19 - 0.50)*

* = p-value < 0.05

Table 4
Logistic regression: people, places and reasons not to walk.

		Time-consuming Odds Ratios (95% C.I.)		Tedious Odds Ratios (95% C.I.)		Not enough or bad footpaths Odds Ratios (95% C.I.)		Boring Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	0.20 (0.04 - 1.17)	-	3.79 (1.17 - 12.3)*	3.79 (1.17 - 12.3)*	NA	-	0.62 (0.15 - 2.62)	-
	(senior adult/child)	0.20 (0.04 - 0.87)*	0.20 (0.04 - 0.87)*	1.23 (0.59 - 2.58)	-	NA	-	0.72 (0.29 - 1.81)	-
	(young adult/child)	0.40 (0.08 - 1.90)	-	1.26 (0.61 - 2.63)	-	NA	-	1.10 (0.46 - 2.63)	-
Gender	**(female/male)**	1.64 (0.77 - 3.46)	-	1.00 (0.60 - 1.67)	-	0.45 (0.19 - 1.04)	-	0.84 (0.45 - 1.59)	-
Municipality	**(small/medium)**	0.83 (0.40 - 1.71)	-	1.27 (0.76 - 2.11)	-	4.64 (1.81 - 11.09)*	4.64 (1.81 - 11.90)*	0.61 (0.32 - 1.16)	-

		Bad weather Odds Ratios (95% C.I.)		Area not nice Odds Ratios (95% C.I.)		Feeling unsafe (crime) Odds Ratios (95% C.I.)		Feeling unsafe (traffic) Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	0.83 (0.22 - 3.11)	-	5.00 (1.04 - 24.12)*	5 (1.04 - 24.12)*	4.63 (0.69 - 31.05)	-	2.77 (0.50 - 15.49)	-
	(senior adult/child)	1.27 (0.53 - 3.00)	-	2.90 (0.79 - 10.72)	-	3.08 (0.65 - 14.67)	-	1.76 (0.46 - 6.82)	-
	(young adult/child)	1.37 (0.58 - 3.23)	-	1.71 (0.44 - 6.62)	-	5.29 (1.16 - 24.08)*	5.29 (1.16 - 24.08)*	0.80 (0.18 - 3.53)	-
Gender	**(female/male)**	1.14 (0.63 - 2.04)	-	0.64 (0.30 - 1.35)	-	1.67 (0.80 - 3.52)	-	0.63 (0.25 - 1.58)	-
Municipality	**(small/medium)**	0.57 (0.31 - 1.03)	-	1.14 (0.54 - 2.39)	-	1.64 (0.78 - 3.44)	-	1.48 (0.60 - 3.67)	-

* = p-value < 0.05
NA = not enough data

Table 5
Logistic regression: people, places and reasons to walk.

		Free of charge Odds Ratios (95% C.I.)		Fast Odds Ratios (95% C.I.)		No alternative Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	1.38 (0.60 - 3.17)	-	0.29 (0.10 - 0.80)*	0.29 (0.10 - 0.82)*	0.41 (0.17 - 0.98)*	0.41 (0.17 - 1.00)*
	(senior adult/child)	0.98 (0.52 - 1.82)	-	0.61 (0.25 - 1.46)	-	0.47 (0.25 - 0.89)*	0.51 (0.26 - 0.97)*
	(young adult/child)	1.24 (0.65 - 2.36)	-	0.31 (0.14 - 0.71)*	0.38 (0.16 - 0.89)*	0.39 (0.20 - 0.75)*	0.44 (0.23 - 0.88)*
Gender	**(female/male)**	0.89 (0.55 - 1.46)	-	1.06 (0.58 - 1.92)	-	1.15 (0.70 - 1.88)	-
Municipality	**(small/medium)**	1.28 (0.75 - 2.21)	-	2.71 (1.46 - 5.05)*	2.49 (1.31 - 4.74)*	2.18 (1.22 - 3.88)*	1.95 (1.07 - 3.53)*

		Enjoy walking Odds Ratios (95% C.I.)		Nice area Odds Ratios (95% C.I.)		Form of exercise Odds Ratios (95% C.I.)		While running errands Odds Ratios (95% C.I.)	
		Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model	Crude	Adjusted Model
Age Group	**(elderly/child)**	3.10 (1.06 - 9.08)*	3.10 (1.06 - 9.08)*	1.49 (0.57 - 3.90)	-	3.63 (1.42 - 9.28)*	3.63 (1.42 - 9.28)*	1.16 (0.47 - 2.90)	-
	(senior adult/child)	2.53 (1.25 - 5.13)*	2.53 (1.25 - 5.13)*	0.41 (0.21 - 0.80)*	0.47 (0.24 - 0.93)*	2.96 (1.52 - 5.79)*	2.96 (1.52 - 5.79)*	0.58 (0.30 - 1.09)	-
	(young adult/child)	1.14 (0.58 - 2.23)	-	0.42 (0.21 - 0.82)*	0.45 (0.23 - 0.90)*	1.18 (0.61 - 2.29)	-	0.73 (0.37 - 1.41)	-
Gender	**(female/male)**	1.10 (0.64 - 1.88)	-	2.44 (1.45 - 4.11)*	2.27 (1.32 - 3.88)*	0.92 (0.56 - 1.53)	-	1.29 (0.78 - 2.14)	-
Municipality	**(small/medium)**	1.01 (0.56 - 1.81)	-	0.99 (0.57 - 1.74)	-	0.88 (0.51 - 1.53)	-	0.59 (0.91 - 2.77)	-

* = p-value < 0.05

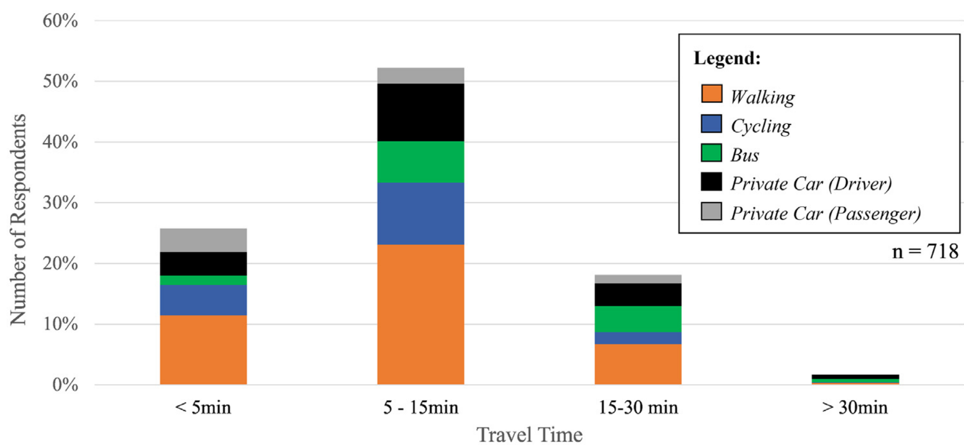


Fig. 7. Travel time required to reach the station, aggregated by mode.

to reach the station. Places such as Aichach, on the other hand, have a large share of rail users that travel to the station by car for the comparatively small size of the town. This may be due to the relatively large free P + R facility with 186 parking spaces (BEG, 2019). Similarly, cities with well-developed B + R facilities, such as Aichach with 168 or Freilassing with 373 bicycle parking spaces, have a higher proportion of cyclists than Bad Neustadt with only 68 bicycle parking spaces (BEG, 2019). This indicates that there is a direct correlation between provided infrastructure and mode choice. Accordingly, it can be assumed that a good walking infrastructure also leads to more pedestrians – or the other way around. In Bad Neustadt, the train station is located next to an industrial area. Thus, only 2% of the population lives within the catchment area. Anyhow, Bad Neustadt has a high share of pedestrians – this may be due to a high proportion of pupils and workers that are commuting to the nearby industrial sites and school campuses.

Fig. 7 shows how much time the respondents need to get to the railway station by their chosen means of transport. More than 50% of the respondents need 5–15 minutes to get to the station, 25% less than 5 minutes and only 2% more than 30 minutes. Journeys of more than 15 minutes are mainly made by bus or car, while 84% of the walking trips were not longer than 15 minutes – which roughly aligns with the numbers found in the literature (see Chapter 3.2.1). But it is noticeable that also many short distances, that could probably have been covered by bicycle or on foot, were travelled by car.

In order to understand the connections between mode choice and the characteristics of the place, Fig. 6 shows all starting points and the respective mode used on the way to the railway station. In addition, the reported problem statements are highlighted. The colour of the circle indicates criteria to which the statement refers (based on Fig. 4), and the size of the circle indicates the number of respondents who mentioned this problem. In total, 860 point-based weaknesses were reported by the participants.[2] The distribution of the problems mentioned per criterion and indicator are summarised in Fig. 8. Many of the weak points are directly located at or in front of the railway station. Especially freedom from barriers was a particular problem at four out of five stations, mentioned not only by elderly respondents but by the whole population. This result is not surprising, as currently only 492 of the 1066 stations in Bavaria are barrier-free (Bayerisches Staatsministerium für Wohnen, Bau und Verkehr, 2021a). Other common issues on the way to and at the railway station were related to security (e.g. dirty appearance of the station, unpleasant underpasses, lack of lighting) and traffic safety (mainly absence of road crossings). For some indicator categories, e.g. “incline” and “visibility of the sidewalk”, no point weaknesses were reported. Interestingly, inadequate or bad footpaths are a significantly more common problem in small towns than in bigger cities.

4.2. People

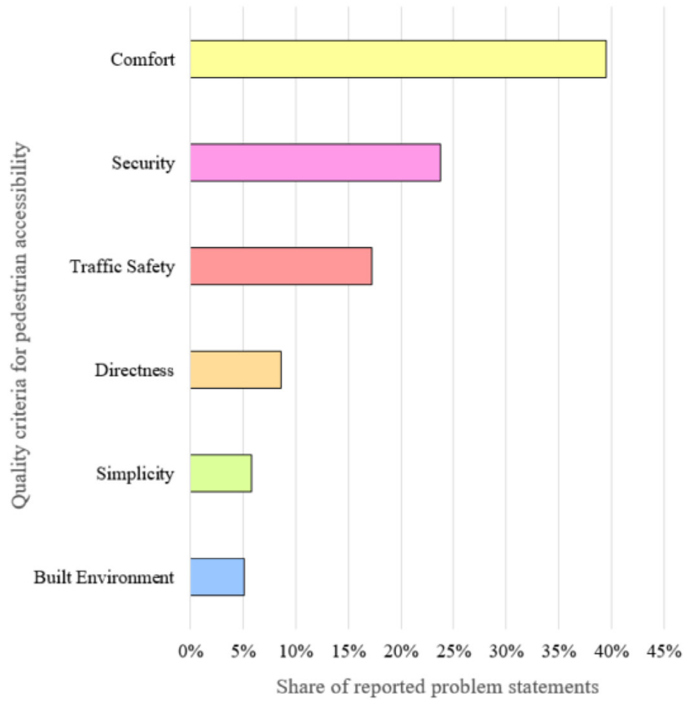
Pedestrians are predominantly found among senior citizens and schoolchildren. Fig. 9 shows the chosen mode of transport in relation to the age of the respondents. Children and elderly have the largest share of walking, while the car and the bicycle are most frequently used by adults. Younger people are the most frequent bus users, and the proportion of bus users decreases steadily with increasing age. Senior adults are 2.27 times less likely to take the bus than children. Between the different gender, mode choice was equally distributed. The only noticeable difference was that men have chosen the bike more often (19%; in contrast to 15% for women; but not significant). Whereas women used the other modes slightly more often. Comparable age- and gender-specific differences were also found in the Germany-wide MiD study (infas, 2018).

When asked about the maximum time people are willing to walk to the station, 40% answered “up to 15 minutes” and another 49% “up to 30 minutes”. The remaining 11% are even willing to walk more than 30 minutes. The discrepancy between the theoretical willingness to walk and the times actually walked suggests that other factors have an influence on this. The assessment reveals that specific point weaknesses, such as poor lighting or unsafe road crossings, present bigger obstacles to perceived pedestrian accessibility than general network connectivity. Comfort, security and safety thus affect route as well as mode choice, for instance some persons claimed to not walk at night due to insufficient street lighting. In this regard, shortcomings were identified in all municipalities surveyed.

Fig. 10 summarises how respondents rated different criteria for walking, with each respondent able to select up to five criteria. Sufficient street lighting at night was rated most important for walking, followed by good street crossings and weatherproof paths (shady in summer, good winter service in winter). Other factors considered important were wide and continuous footpaths, relatively slow moving cars on the route and the presence of other people. The resulting importance of the individual criteria largely corresponds to the proportions of the reported problems. Comfort and security seem to be the most important issues, while the built environment only plays a subordinate role. Directness was not asked about, as we consider this criterion to be rather measured than perceived.

It can clearly be seen that different survey participants perceived the same place differently. Different people have different thresholds of how far they are willing to walk, but also different perceptions of comfort, security and safety. This varies especially due to personal characteristics and individual needs, e.g. mobility-impairedness due to disabilities or heavy suitcases.

[2] All statements in their exact wording (German) can be obtained upon request.



Comfort	Freedom from barriers	31.9%
	Footpath width	2.9%
	Footpath surface	1.7%
	Traffic volume + noise	1.5%
	Weather protection	1.0%
	Speed limit	0.5%
	Footpath inclination	0.0%
Security	Cleanliness and appearance	9.9%
	Lighting	8.8%
	Liveliness and social control	5.0%
	Visibility of the sidewalks	0.0%
Traffic Safety	Availability of crossings	11.9%
	Availability of footpaths	2.2%
	Joint use of footpaths by cyclists and pedestrians	2.1%
	Cars parks on or next to footpaths	0.6%
	Spatial separation of footpaths and roads	0.5%
Directness	Barriers to accessibility	8.6%
	Aerial line distance	0.0%
	Actual route length	0.0%
Simplicity	Delays at traffic lights	4.5%
	Signposting	1.2%
	Lines of sight	0.1%
Built Environment	Surrounding land use	4.2%
	Vegetation and green spaces	0.7%
	Points-of-Interest along the way	0.2%

n = 860

Fig. 8. Reported problem statements, clustered by categories.

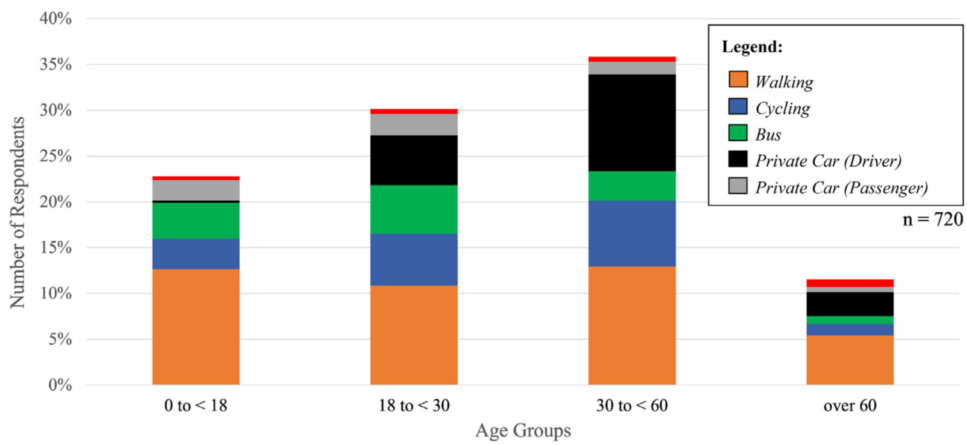


Fig. 9. Mode of transport to railway station, by age.

Fig. 11 summarises the answers of all survey participants who said they do not walk to the station to the questions about the reason therefore. For this purpose, the respondents could affirm or deny various given statements. Time constraints and tediousness were the main reasons given for choosing not to walk to the railway stations. Around half of the respondents that came by car stated that the distance was too far to walk or cycle (in their specific situation). Thus, mode choice is clearly dependent on the route length. For older adults in particular, time is a significantly greater barrier to walking than it is for children (see Table 4). Respectively, elderly are 3.79 times more likely than children not to walk due to tediousness.

But noticeably, the distance does not always determine whether a journey to a railway station is made by car, bicycle or by foot. Also bad weather, boredom, unpleasant areas, unsafe feeling as well as missing or bad footpaths discouraged people from walking – reasons, that are related to comfort, built environment and safety. While unpleasant areas are a barrier especially for older people, young adults are significantly more likely to feel unsafe in terms of crime.

Equally, the reasons why 42% of rail users walk to the station are considered. Fig. 12 shows the questions asked and the corresponding answers. Most respondents walk because it is fast, which is related to the directness. Some participants also see walking as a form of exercise, walk because they enjoy it or simply because they have no (affordable) alternative. Those are reasons, that are not directly linked to the quality criteria but are rather individual conditions and characteristics. Others like the nice area or walk for practical reasons, as they run errands or do activities on the way. Those are linked to the built environment. Interestingly, the built environment seems to be an important factor for mode choice although in terms of pedestrian accessibility, built environment received the lowest priority score. Senior adults and elderly significantly more often walk because they enjoy it and see it as a form of exercise than children (see Table 5). Respectively, young and senior adults walk more often because of the nice area. Same is true for women.

4.3. Individual utilities: connection of place and people

In order to better understand how individual utilities are affected by the place and the peoples' characteristics, the survey results of individual persons whose mode choice is particularly intriguing, was analyzed in depth.

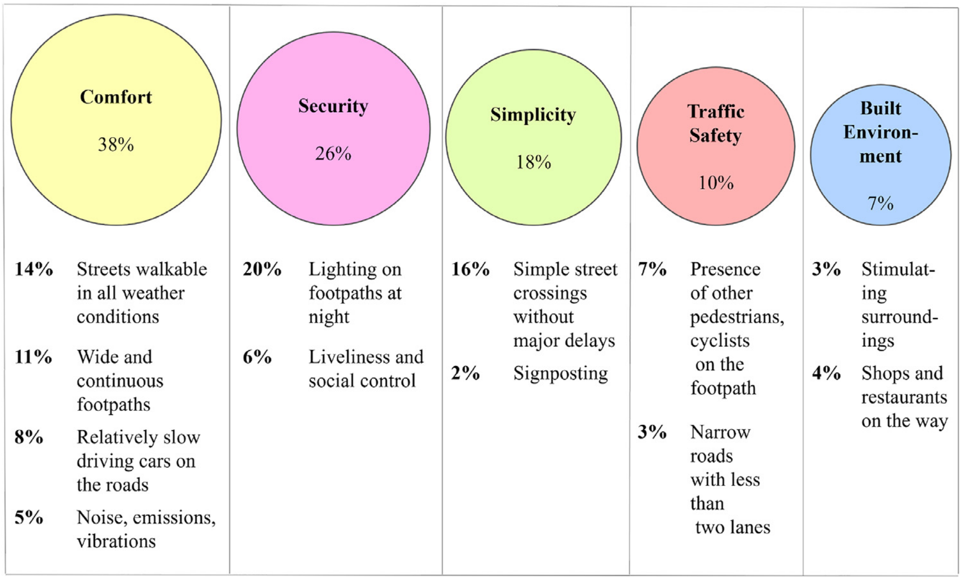


Fig. 10. Prioritisation of pedestrian accessibility criteria.

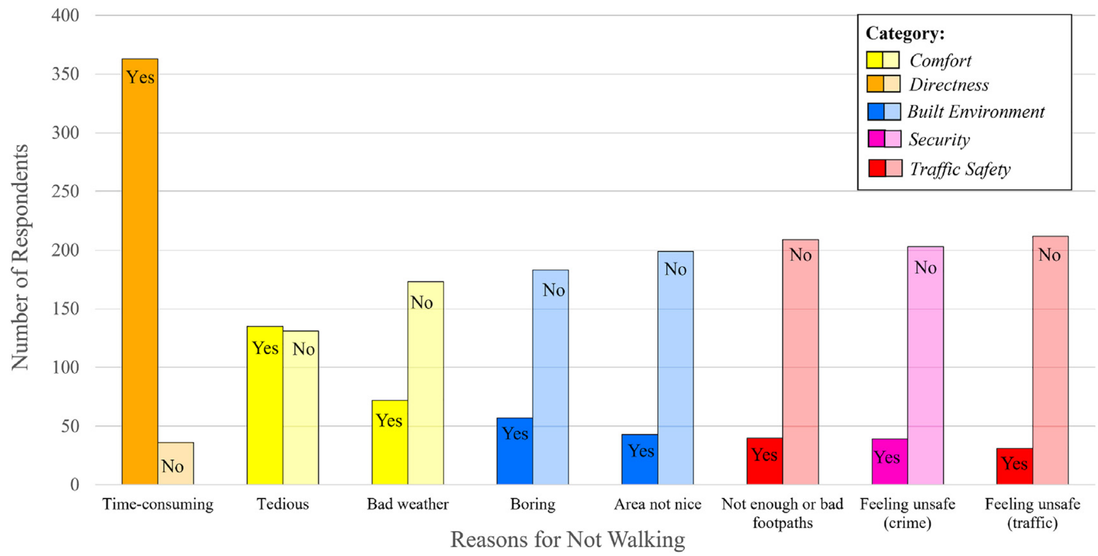


Fig. 11. Reasons why people do not walk to the railway station.

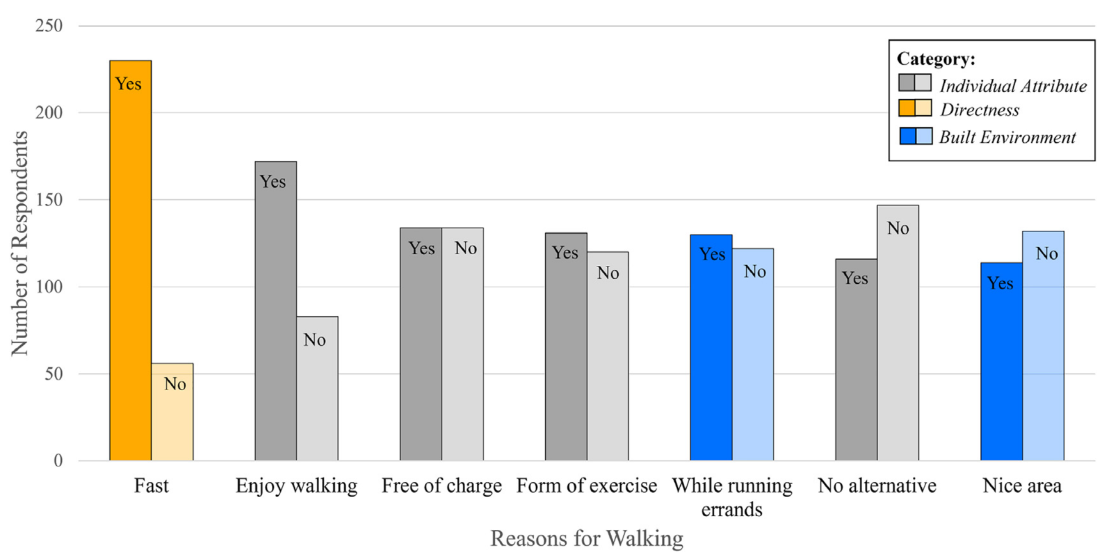


Fig. 12. Reasons why people walk to the railway station.

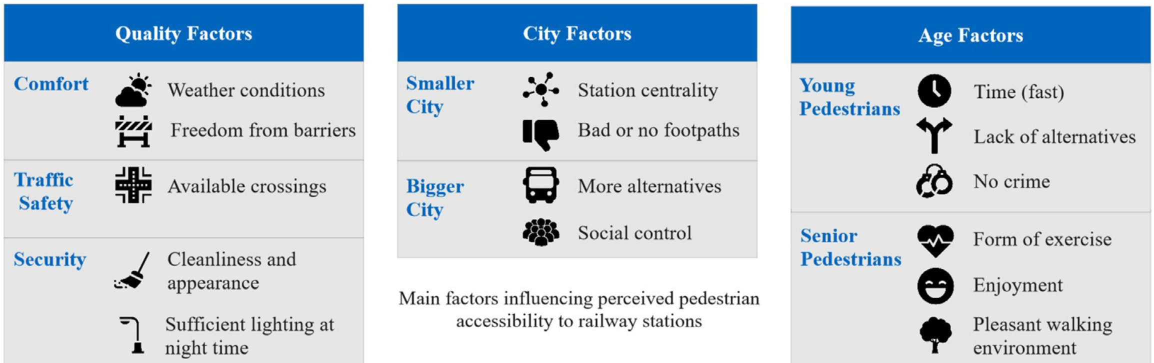


Fig. 13. Main identified factors influencing perceived pedestrian accessibility.

Two persons who started their trip roughly within a 15 minutes walking distance from the train station in Bad Neustadt arrived by taxi. The reason therefor was the carrying of luggage and bad bus connections. But also respondents who started their trip within walking or cycling distance and do not carry heavy luggage use the car or bus for convenience, like one participant in Aichach. In addition, physical limitations (disabilities, illness) hinder people from walking. For example, two persons in Freilassing came to the station by car because they accompanied mobility-impaired persons.

Other reasons for car use were fear of the dark, fear of bike theft or fear of crime in general. For example, one person that lives 10 walking minutes away from Landshuts' station was brought by car as he was afraid of crime. Same applies to one person in Freilassing that preferred the bus therefore.

Some respondents also stated that they walk or cycle primarily when the weather is good, while in bad weather they choose the bus or the car. In some cases also a combination of several reasons can be found, e.g. in Bad Neustadt one person was driving to the station by car due to time, carrying luggage and a baby stroller and in addition, due to bad weather conditions. It is not known whether the omission of one of these criteria would have already resulted in a mode choice change.

Three participants that started their trip roughly within the 10-minute catchment area (two in Hilpoltstein, one in Bad Neustadt and one in Freilassing) have chosen a motorised mode due to bad walking infrastructure, unpleasant route and/or boredom. Interestingly, the two participants from Hilpoltstein started from almost the same place. The route from this starting point to the station was reported by many participants to be unpleasant. Same applies for the routes from the starting points in Bad Neustadt and Freilassing, where bad walking conditions were pinpointed by many other participants. The routes in Bad Neustadt and Hilpoltstein run along busy roads and through monotonous environments which may cause the unpleasant feeling and boredom of the people due to a lack of visual stimuli. The route in Freilassing leads through an car-oriented commercial area with a reported lack of pedestrian infrastructure (missing paths and too few crossing possibilities).

5. Discussion

Within this study, several factors influencing walking were assessed by asking different survey questions. As perceived accessibility can not directly be evaluated, a variety of proxies (mode choice, reasons therefore, rating of pedestrian accessibility criteria, problem statements) were used. Although the answers to most questions show a clear direction for the importance of the six quality criteria, no absolute ranking for the importance of each single factor can be established. The results obtained were very much dependent on the questions asked, which reveals the real problem in this regard: How can we assess perceived accessibility? What question do we need to ask people to find out which factors are the most important? Is there even a universal answer to this, or does perceived accessibility depend primarily on individual capabilities and local external factors? And is there such a thing as the most important factor or is it more about the interactions as a whole?

Due to these still remaining open questions, the authors are aware that this exploratory study does not allow final conclusions to be drawn about the factors influencing perceived pedestrian accessibility to railway stations (in Bavaria), but it does reinforce the assumption (see Section 2.5) that these are largely dependent on people and places (although five different cities were studied here, it is to be expected that further differences will emerge if the study is extended to other places). Anyhow, the comparison of the different questions allows to get a better understanding of the approximate importance of each factor. Factors that were mentioned repeatedly across different questions suggest that they are among the most important. The mismatch between calculated and perceived pedestrian accessibility (Curl et al., 2015; Damurski et al., 2020; Gebel et al., 2011; Lättman et al., 2018; McCormack et al., 2008; Pot et al., 2021; Ryan and Pereira, 2021; Ryan et al., 2016) and the importance of perception in choosing walking as a mode to walk to the railway station (Gehl, 1987; Páez et al., 2020; Pueboobpaphan et al., 2022) could also be confirmed.

Accessibility deficits were identified in all municipalities surveyed, indicating a need for action in this field. This chapter discusses the identified shortcomings and how these can be addressed by future accessibility studies and tackled by the planning practice.

5.1. Time-based factors as prerequisites for walking

Survey participants named time as the most important factor for deciding if they walk or not. Similar to Sarker et al. (2019), it was found that especially the senior adults are more sensitive to time-consumption. Thus, direct and simple walking path networks are prerequisites for walking, although connectivity was rarely mentioned as an concrete issue. The reason for this may also be that simple punctual shortcomings (e.g. unpleasant underpasses, missing street lamps) are easy to grasp while the identification of connectivity issues requires a detailed geographical understanding of the area – and may not be something that participants except to be addressed easily.

But even the best walking path network may not be sufficient if the railway station is located in the 'wrong' place and thus not accessible within an appropriate walking time (which, surprisingly, is even up to 30 minutes for the majority of survey participants – in contrast to the findings of Calthorpe (1993), O'Sullivan and Morrall (1996), and Daniels and Mulley (2013); this high willingness may be due to the lack of alternative transport options, especially in the smaller towns). The size of the town and the centrality of its railway station determine the length, directness and simplicity of its pedestrian routes. A historical obstruction to pedestrian accessibility that remains is the location of many railway stations outside of city centers (see Chapter 3.1), at least in Bavaria.

The solution to this problem is twofold. On the transportation side, supplying attractive pedestrian infrastructure can entice people to travel longer distances by foot (Pueboobpaphan et al., 2022). On the land use side, redeveloping the area around the railway station to include more residential and commercial buildings can bring the origins/destinations closer to the station and therewith shorten travel times. Previous research shows that the more people living and working in close proximity to transit, the more likely it is that they will use the service (Hillnhütter, 2016; Murray et al., 1998; Wenner et al., 2020).

As travel time is paramount, combination of both – building attractive transport infrastructure in the shorter term and redeveloping land in the vicinity of the railway station in the longer term – seems advisable.

5.2. The underestimated role of comfort

However, how time is perceived depends on safety, comfort and environmental aesthetic levels. These results are in line with Pueboobpaphan et al. (2022) who found that pleasant surroundings can increase the willingness to walk. Similarly, areas that are not attractive discourage people from walking. Especially comfort was given a high priority by the survey participants. This result strengthens the certainty that pedestrian accessibility is strongly connected to perceived quality levels of land use and transport (Arslan et al., 2018; Gkavra et al., 2019; Liang and Cao, 2019) but also shows differences to previous studies conducted in India (Bivina et al., 2019; Gupta et al., 2022), in which safety and security were identified as the most influential factors. This may be due to the different spatial contexts, which bring with them different conditions in terms of safety and security. In comparison to India, safety and security may be less bigger issues in Bavaria. This assumption would confirm the hypothesis framework set up in Fig. 4 that sees directness, simplicity and traffic safety as the preconditions for walking. If these prerequisites are fulfilled, comfort and safety are decisive for the attractiveness and perception of the path, with greater attractiveness increasing the willingness to walk - and the built environment as the cherry on the top of the cake.

The calculated catchment areas of 10 minutes thus do not really “catch” the perceived walking conditions. Reported point weaknesses and thus perceived obstacles were primarily comfort and safety factors. In addition, the common destinations/origins of all railway users – the train stations – seam to have severe weaknesses in terms of comfort and security themselves (whereby the comfort issues were mainly caused by the fact that the railway stations are not barrier-free) and are thus mayor bottlenecks in terms of perceived accessibility that could be addressed easily by planning practice. In Bavaria, the issue of the non-barrier-free stations is well known and has been tackled since some years. In this course, also the station of Freilassing was rebuilt in 2021. Therewith, the main obstacle identified in 2017 is now solved. Nevertheless, at this point in time, there are still 492 stations that are not barrier-free and represent a major obstacle in accessing the railway system – not just for the people that walk to the station but for everyone.

For some indicators, e.g. “visibility of the sidewalk”, not a single punctual weakness was reported in the five study areas, although this factor was stated to be important in previous studies (Gehl, 2013; Golan et al., 2019; Hillnhütter, 2016; Jacobs, 1961; Lin et al., 2015; Saelens et al., 2003; Wimbardana et al., 2018). In these cases, the imprecise phrasing chosen by the participants made it difficult for the authors to assign the statement to these specific quality criteria. For example, many participants reported “unpleasant underpasses”. Such a general statement does not allow inferring causation between unpleasantness and dirt or aesthetics. For some people the unpleasantness might also not be linked to a specific feature of the underpass. Those statements were thus categorised as “cleanliness and appearance”. These overlaps and difficulties in delimitation illustrate the ambiguity of transitions between the individual indicators, which often cannot be examined individually but only in connection with other indicators.

In addition, there is a discrepancy between what people stated as their priorities and what they report as problem points in their town. This may be due to the specific local conditions (e.g. the assessed study areas were all topographically flat). Other cities with other walking path networks and other surroundings would certainly generate different punctual weaknesses, as other studies found e.g. that walking in a hilly environment is perceived as barrier (McGinn et al., 2007; Sun et al., 2015). Therefore, a more large-scale study with a wider variety of cities would be needed to validate the results.

Nevertheless, it is clear that perceived factors are of particular importance and should ideally be taken into account when performing accessibility analysis (e.g. by adding them as a generalised cost item to the accessibility formula). There are more criteria that influence pedestrian accessibility but are not mentioned here (e.g. presence of benches (Alfonzo, 2005; Arslan et al., 2018; Hillnhütter, 2016; Whyte, 1980) and aesthetics of building facades (Cervero and Kockelman, 1997; Hillnhütter, 2016; Lin et al., 2015; Lo, 2009; Speck, 2013)). Further studies are needed to obtain a comprehensive picture.

5.3. Travellers’ differing needs and abilities

Mode choice of the participants was not only dependent on the local situation but also very much on the individual characteristics and situations (e.g. age, abilities, carriage of luggage), with age having the strongest influence. Based on the personal situation, in combination with the personal preferences and needs (e.g. in terms of comfort, safety), every person makes its own personal decision on mode choice. Elderly, for example, perceive walking more often as tedious than children, which can be clearly linked to the physical abilities that are changing in the course of ones life. Referring to the capability-approach this means that the internal factors of elderly are not matching with the external factors, which causes this feeling of tediousness. For example, if benches were placed along the path to the station, older people could rest at regular intervals, which would probably make the walk less tedious. Thus, these personal characteristics should be taken into account when making statements of how accessible a place is for certain people (Litman, 2003; Ryan et al., 2019) – and consequently also be reflected in planning practice. As Clifton et al. (2007), Bivina et al. (2020) have pointed out, this also requires a greater focus on micro-features in order to fully understand the needs of individual people and take them into account in the urban setting.

The fact that pedestrians (on the way to the railway station) were in our study case predominantly found among senior citizens and schoolchildren indicates that it could make sense to customise future accessibility analysis according to different user groups and their specific needs. As train stations are important services of general interest, it is particularly important to ensure access for all, which is in line with the individual component of accessibility.

5.4. Temporal and external factors add further complexity

External factors (e.g. weather, time of the day) were stated to have an impact on perceived accessibility, anyhow, only a few studies can be found that took the accessibility effects of nighttime (Chandra et al., 2017; Jehle, 2020) or weather (Erath et al., 2015) into account. These factors are hard to change by planning practice, but can be mitigated through adapted infrastructure (e.g. weather protection, street lamps) and maintenance (e.g. winter service). In accessibility research and application, more attention should be given to external conditions and the temporal component, as lighting at night and weather conditions were among the most important factors for pedestrian accessibility. Thus, perceived accessibility by night and rain can highly differ from perceived accessibility by day and sunshine.

6. Conclusion

This work aimed to understand which factors influence perceived pedestrian accessibility to railway stations and how this may differ for different people and places. It was found that factors related to comfort, traffic safety and security (such as freedom from barriers, availability of street crossings and lighting) are perceived as the most important in terms of pedestrian accessibility. In addition, pedestrian's age as well as the city's size also have a significant influence whether people walk to the railway station or not. With regard to gender, only minor differences were found. Fig. 13 combines the main findings of this study and highlights the factors influencing perceived pedestrian accessibility to railway stations that were identified as the most important ones. Although the importance of several perception factors was determined through various survey questions, these results do not allow quantifying to what extent a specific indicator influences accessibility. But they help in understanding which factors are perceived as important, contribute to the ongoing research on perceived pedestrian accessibility and show where further studies are needed to obtain a more comprehensive picture.

Interestingly, the biggest weaknesses in perceived accessibility to railway stations are found on the stations themselves. But even punctual micro-feature weaknesses such as a broken street light or an unpleasant underpass on a factually short and safe route discourage people from walking to the station. At the same time, it was also found that many people (especially children) are willing to walk long distances to reach the railway station, mostly because they do not have an alternative. So they also accept weaknesses along the way. Older people, on the other hand, care more about the attractiveness of the environment, walk because they enjoy it and see it as a form of exercise, but they also often find it tedious.

The results of the case studies reveal that different people have different needs and abilities based on age, luggage, daytime and weather conditions. These individualities need to be taken into account through people-centred planning in order to provide access to public transport for all. In particular, we see a need for further research into the needs of different user groups. The capability approach can help to assess whether internal and external factors match. In addition, further research in other contexts is needed in order to understand the differences between different places.

The important comfort, safety and individual factors are currently only represented in a few accessibility analyses, which leads to a discrepancy between calculated and perceived pedestrian accessibility. In future, more importance should be attributed to perceived accessibility – of railway stations but also of other destinations. Pedestrian accessibility measures should be enriched by adding an impedance factor for the attractiveness of the route, reflecting the qualities of the paths, trip experience and personal needs. However, to identify the most important quality criteria of pedestrian accessibility and their individual weighing is still a remaining challenge, which may not be possible to solve universally. Ones the crucial factors are found, they can be assessed by the use of proxy indicators. Most of them can be measured or captured objectively (e.g. footpath width, surface, lighting) and then be translated into a quantitative point schema (e.g. no lighting = 0 points; perfect lighting = 100 points). By multiplying the indicators with weights according to their individual importance and then summing them up, an overall attractiveness score can be derived for each path segment. This score can then serve as an impedance factor and be added to the accessibility formula. Ideally, different impedance factors are determined for different user groups, day times and places. However, detailed data on the walking path network and the whole environment are needed therefore. In addition, some indicators (e.g. appearance) may be not 'objectively' measurable. In order to capture those and also to evaluate local context-specific situations and include the individual perceptions of single persons, it seems inevitable to enrich the accessibility analysis by qualitative methods that focus on user-centred feedback.

All in all, this research confirms that ideally all four accessibility components as defined by Geurs and Van Wee (2013) – transportation, land use, temporal and individual – should be included when evaluating perceived accessibility in order to allow comprehensive analyses. In the future – once the perceived accessibility factors are adequately explored – researchers can contribute by developing appropriate measures for perceived pedestrian accessibility that enable planners and policymakers to eradicate the deficiencies in perceived pedestrian accessibility (to railway stations and other destinations). Therefore, the right balance between "rigor (soundness) and their practical relevance (plainness)" (Papa et al., 2015) needs to be found in order to meet the needs from planning practice.

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