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hiWALK and hiBIKE: Co-created Indices to Foster Active Mobility for All

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1 ABSTRACT

Current accessibility analyses, which underlie the 15-minute city concept, assume that all streets are equally walkable and bikeable for everyone. This assumption implicitly neglects the needs of people with special mobility requirements, i.e. of the old and very young, people with disabilities, and risk-averse bikers. Stakeholders working to improve urban active mobility, e.g., NGOs such as Radlobby Austria or traffic planners such as PLANUM Fallast & Partner, require detailed information on the bikeability and walkability of the urban path network to lobby and/or plan for infrastructure that promotes active mobility and provides inclusive accessibility to essential services. To address this gap, HeiGIT's climate action team works with practitioners and NGOs to co-create street-level indices of walkability (hiWalk) and bikeability (hiBike) with direct practical applications. Going beyond summary values at the level of cities or neighborhoods, our street-level indicators facilitate integrating bikeability and walkability information into routing engines, thereby supporting accessibility analyses of "15-minute cities for all". Both hiWalk and hiBike incorporate indicators describing the urban street and path network in terms of user-friendliness, attractiveness, and safety. For example, the indicators identify walkable/bikeable paths and analyse their surface quality in terms of smoothness and type of material. hiBike also includes an indicator of "dooring" risk, based on street-side parking information. Both indices rely on open data sets, mainly OpenStreetMap (OSM), and can be tailored and applied across cities worldwide.

Since both hiWALK and hiBIKE are still under development, rather than presenting the indices' results, this paper will discuss the challenges encountered (1) during their application to starkly differing urban environments worldwide, and (2) due to the variability in OSM's data quality and completeness across regions. Additionally, we present our co-creation approach and discuss its benefits for index usability and policy impact. Besides continuing to refine the two indices, future research will also focus on assessing whether the results of our analyses align with the perceived walkability and bikeability in different streets, neighbourhoods, and cities. We conclude that several unique features of hiWalk and hiBike distinguish them from existing indices of active mobility. hiWalk and hiBike prioritise accessibility for all, explicitly considering users with special mobility needs. Moreover, through our plan to integrate our indicators into OpenRouteService (ORS), the mobility needs of the most vulnerable will be effectively captured in accessibility analyses and routing decisions. Finally, and most importantly, our co-creation approach renders feedback from stakeholders during the development process, which ensures the relevance and usability of the indicators in real-world urban planning and advocacy applications.

Keywords: open data, 15-minute city, biking, walking, planning

2 INTRODUCTION: WHY AIM FOR CO-CREATING INDICES FOR ACTIVE MOBILITY?

Cities around the world are grappling with the challenges of reducing carbon emissions, enhancing public health, and improving urban liveability, all while addressing the people's diverse mobility needs. Since the transport sector is a major source of CO_2 emissions and progress in reducing these emissions has been limited (Friedlingstein et al., 2023), advancing sustainable mobility has become a pressing priority. Walking and cycling (collectively referred to as "active mobility") are highly efficient, low-impact urban transport options, making their enhancement crucial for fostering healthier, more liveable cities. Active mobility, together with accessibility to the amenities required in daily life, are the two fundamental characteristics of a "15-minute city", in which daily essential services are within a short (e.g., 15 minutes) walking distance from any location in the city.

Interest in 15-minute cities – a novel framing of older urban planning principles – has exploded in recent years (Mouratidis, 2024). Cities in various continents started implementing initiatives to promote active mobility and local accessibility (Allam et al., 2024; Teixeira et al., 2024). Academics have conducted spatial analyses and developed indicators to assess how walkable and bikeable cities are, and how close they are to being 15-minute cities. So far, however, many of these analyses and indicators fail to consider the needs and perspectives of people with limited mobility, marginalized communities, and other stakeholders (Alves et al., 2020; Rhoads et al., 2023; Willberg et al., 2023).

Including diverse perspectives into mobility analyses is especially important given the potential of data-driven indicators to support urban planning and policymaking (Blečić et al., 2020; Đorđević et al., 2023). By combining a suite of indicators, active mobility indices typically assess one or more aspects of the environment that promote walking and cycling, often summarized as the 5 D's – density, diversity, design, destination accessibility, and distance to transit (Ewing & Cervero, 2010). Thereby, indices can – for example – help identify problematic areas, allocate limited resources to the infrastructure with the greatest potential to improve active mobility, and address social inequities (Su et al., 2019).

Despite their importance and relevance for urban planning and policymaking, active mobility indices are often developed for commercial purposes (e.g., WalkScore and Walkonomics) or academic research (e.g., Alves et al., 2020; Buck et al., 2011; Frank et al., 2005), and rarely incorporate input from actual urban planners or other key stakeholders, potentially limiting their usefulness in practice. At the same time, studies underscore the value of co-creation in research and software development (Abelein & Paech, 2015; Deserti et al., 2021; Stier & Smit, 2021). Co-created walkability and bikeability indices are collaboratively developed by diverse stakeholders, including urban planners, scientists, advocacy groups, associations, and local initiatives, combining data, expertise, and lived experiences. Therefore, co-created indices can be an important tool to support a shift in the urban traffic infrastructure towards sustainable mobility as one building block for healthier, climate-friendly, and more liveable communities.

In this paper we demonstrate our unique approach to co-create open-source indicators of walkability (hiWalk) and bikeability (hiBike). Our partners include non-governmental organisations (e.g., Radlobby Austria and Lagos Urban Development Initiative) and traffic planners (e.g., PLANUM Fallast & Partner). Our indicators' street-level perspective can lead to actionable insights, producing concrete and targeted recommendations for planners that help foster active mobility for all, going beyond generalized metrics of neighbourhood accessibility. While our indicators are still being refined through a continuous feedback loop with our partners and are still not aggregated into indices, we describe our plans for next steps, including the integration of the indicators into an online dashboard with global coverage. We also discuss some of the challenges of using open data such as OpenStreetMap, our scalable, local to global approach, the advantages brought by co-creation, as well as the potential implications for designing 15-min cities.

3 METHODOLOGY

3.1 Co-creation approach

Co-creation describes the process of collaborative problem solving for the design and content of products and services (cf. Prahalad & Ramaswamy, 2000). In the case of hiBike and hiWalk, stakeholders work together with HeiGIT's climate action team to define the respective index, outline its elements, and test and enhance our prototypes. Specifically, our collaborative approach is based on a prominent co-creation method called "design thinking" (Rösch et al., 2023). This method entails a shift in perspective to prioritize the partner's viewpoint. Rather than perceiving stakeholders as customers, we engage with them in a partnership as equals. This pivotal element of our co-creation approach facilitates the reciprocal exchange of diverse expertise, experiences, and approaches that prove mutually beneficial. Through frequent contact with our partners, our indices undergo short, regular and direct feedback loops, which allow for direct application and checking of the results in practice.

In order to establish a structured environment conducive to active, creative, concrete, and solution-oriented work on the development of indices, we create virtual collaborative workspaces for our partner workshops. The objective is to leverage a variety of viewpoints and competencies to create indices that indeed make a difference, as these indices are intended to be used by a diverse array of stakeholders, including city and traffic planners, administrative bodies, NGOs, citizen initiatives, and other communities of practice. In a series of ideas incubation workshops, our partners work with us to define what we are trying to achieve, how we measure success, define potential indicators, and prioritise them. An important asset is the joint formulation of user stories and a clear definition of the content and the type of data outputs required for a given version of the index, as well as their fitness for purpose.

Whilst the benefits for the respective co-created indices are obvious and foster knowledge growth for all partners, there also is a certain price to be paid. Co-creation means an additional workload, not only because of workshops to incubate indicator ideas, but also meetings to align and manage expectations, usefulness, and feasibilities between all collaborators. Different sources of knowledge, i.e. reaching from "on the ground" and in different urban environments up to theoretical and conceptual research, need to be synchronised and checked for validity. Furthermore, there might be an increased risk of example-based development that might limit the generalisation of results.

In addition to these individual virtual collaborative workshops, we are planning to have one or more in-person sandpit workshops. Sandpit workshops are especially designed to foster collaborative problem solving and idea generation. In comparison with regular workshops, they are more immersive, designed for inter- and multidisciplinary contexts, facilitated by experts, and via iterative ideas incubation highly outcome-oriented (Alber, 2020). In a typical sandpit workshop, participants initially engage in open-ended thinking for the first few days, setting aside their usual disciplinary and institutional boundaries to explore how collaboration could unfold without these constraints. The later stages focus on refining and narrowing down these creative concepts, and transforming them into concrete project ideas, which are further developed in a more conventional manner after the event. A sandpit workshop is an experimental space that allows us to go beyond traditional disciplinary boundaries and to pursue novel research and software development approaches.

3.2 Open data and open source

To maximize the potential impact and usefulness of our indices, we aim to base them on open and, as far as possible, also freely accessible data and software tools. Our primary source of spatial data is OpenStreetMap (OSM), a database of crowdsourced geographic information sometimes referred to as the 'Wikipedia of Maps'. Contributors from around the world can add all types of spatial information to OSM, as long as it is not private information and it can be verified independently on the ground. A distinguishing feature of OSM is the wealth of meta-information in the form of tags that its contributors can add to the OSM data. As such, OSM not only displays the network of cycling paths in a city, for example, but can also show the properties of each path, such as their width, number of lanes, surface material and smoothness.

Since OSM was created with a strong focus on car navigation and routing, it has very complete data on the global street network, but relatively poor and heterogeneous coverage of data relevant for active mobility analyses (Mobasheri et al., 2015, 2018; Vierø et al., 2025). This focus is due partly to the more apparent importance of streets for navigation and transportation, but also to the fact that non-car data means many more paths, complexity, and diversity, so the task of getting a decent database is much bigger than for streets. A particular challenge for hiWalk is the lack of a universally preferred method for mapping sidewalks in OSM. Contributors can either tag sidewalks as attributes of roads or map them as separate ways. The lack of standardisation as well as the sheer complexity of the topic can lead to inconsistencies and omissions in sidewalk data. However, in well-mapped areas, OSM contains a wealth of information about the presence and quality of infrastructure for walking and cycling, as well as about points of interest, land use, green spaces, and other urban features that affect active mobility. To enrich and complement spatial data in OSM and its meta-information, we use publicly available Sentinel 2 satellite imagery from Copernicus and SRTM (Shuttle Radar Topography Mission) data. In addition, we investigate the potential of street level imagery as well as other community-sourced datasets to improve the database of our indicators.

In the first half of 2025, our indices of bikeability (hiBike) and walkability (hiWalk) will be available to the public through a dedicated online dashboard in which users can conduct tailored analyses for their area of interest anywhere in the world. We use Python for all spatial data processing, analyses, and visualisations and will publish our code under an Open Source license along with the online dashboard. Open source code can be checked, reused, modified, and redistributed by others, increasing our indices' usefulness and impact.

3.3 Indicators

Harnessing the power of open spatial data, and guided by the requirements and experience of our partner stakeholders, hiBike and hiWalk have evolved to include a series of metrics (i.e., indicators) describing aspects relevant to active mobility at the street segment level. To produce inclusive assessments of bikeability and walkability, our indicators take the perspective of the most vulnerable, such as children, the elderly, and people with disabilities.

Note that both hiBike and hiWalk are still work in progress and the description of the indicators below refers only to their current version, and may change in the future. Also, in sake of conciseness, we focus the methods and results of this paper on hiWalk, but similar and equivalent indicators exist in hiBike.

3.3.1 Classifying urban cycling and pedestrian infrastructure: Who do I share this path with?

The first step in our assessment classifies walking or cycling infrastructure by accounting for with which other users a pedestrian or cyclist has to share the infrastructure. This classification and ranking, based on OSM tags, is meant to serve as a proxy for the safety and comfort of road segments for walking and cycling, as well as for the overall quality of a city’s walking and cycling infrastructure. For example, previous studies have proposed to classify urban streets based on traffic stress levels (Huertas et al., 2020), which aligns with how we define bikeability categories in hiBike. Table 1 displays the walkable path categories and their explanation. hiBike classifies bikeable paths into equivalent categories, with an extra group for paths where cyclists are required to dismount (e.g., train platforms, certain bridges, and pedestrian zones).

Walkable path category	Description
Designated	Sidewalks, pedestrian streets, and other walkable areas where no motorised vehicles are allowed. They are considered the safest and most comfortable for walking.
Designated, shared with bikes	Paths where both walking and cycling is allowed. These paths are also generally safe, but many walkers feel uncomfortable sharing their path with cyclists.
Shared with motorised traffic low speed (walking speed)	Streets without sidewalks in which pedestrians need to share the street with cars. In these the risk of much more serious traffic accidents and potentially more noise and air pollution is generally higher. Streets shared with cars but with a speed limit up to 5 km/h (e.g., living streets) are still considered safe and comfortable for active mobility.
Shared with motorised traffic medium speed (<= 30 km/h)	Streets without sidewalks in which pedestrians need to share the street with cars. In these the risk of much more serious traffic accidents and potentially more noise and air pollution is generally higher. Streets shared with traffic up to 30 km/h are at the edge of being too dangerous to walk on, depending on their traffic volume.
Shared with motorised traffic high speed (>= 50 km/h)	Streets without sidewalks in which pedestrians need to share the street with cars. In these the risk of much more serious traffic accidents and potentially more noise and air pollution is generally higher. Streets shared with traffic up to 50 km/h are uncomfortable and, most importantly, dangerous for walkers.
Shared with motorised traffic of unknown speed	Streets without sidewalks in which pedestrians need to share the street with motorised vehicles, but where the speed limit is unknown.
Not walkable	Streets shared with traffic faster than 50 km/h are considered too dangerous and grouped as unwalkable, with other streets where pedestrians are not allowed (e.g., due to access restrictions).
Unknown	Streets and paths without enough tag information in OSM to be categorised.

Table 1: Definition and rationale of hiWalk’s walkable path categories

3.3.2 Analysing path surface type and smoothness: Who can safely and comfortably walk here?

Even if a street has a sidewalk or a cycle path, other factors may hinder active mobility. Sidewalks and paths can be poorly maintained and too bumpy, muddy, or slippery to be used safely by everyone. A smooth path surface is especially important for people in wheelchairs or requiring walking frames (Pearlman et al., 2013).

The surface quality indicator is based on the values of the OSM tags “smoothness”, “surface”, and “tracktype” (in order of their evaluation). While the values of “smoothness” correspond directly to the surface quality, they are only sparsely mapped. We therefore also use “surface” and “tracktype” as a proxy to complement the data. In doing so, we consider that for a given surface type there might be a wide variety in the maintenance status and thus only yield a conservative estimate for the surface quality. This is to reflect our commitment to creating our indicators from the perspective of the most vulnerable, for whom a poor surface quality can become a major obstacle. To highlight the uncertainty of the maintenance status, we add the prefix "potentially" to values of the surface quality that are derived from the surface type. Exceptions are surface types like sand, which can be confidently categorised to be poor in any case. Table 2 presents a full list of the surface quality categories and their explanation.

Surface quality	Description
Good	Relatively smooth surface (e.g., asphalt with minor cracks and holes). Thinly wheeled vehicles – such as wheelchairs, walking frames, and prams – can roll with only minor vibrations.
Potentially good	Surface smoothness is unknown, but inferred based on surface material. For example, asphalt paths are classified as “potentially good”.
Mediocre	Irregular surface where walking and particularly using thinly wheeled vehicles is challenging and uncomfortable. Some surface types, such as cobblestones, are assigned to this category.
Potentially mediocre	Surface smoothness is unknown, but inferred based on surface material. For example, paths covered with gravel are classified as “potentially mediocre”.
Poor	Surface is so bumpy and irregular that walking is very uncomfortable and potentially dangerous.
Unknown	Paths and streets without enough tag information in OSM to be categorised into any of the groups above.

Table 2: Surface quality categories in hiWalk

After developing this indicator for hiWalk and receiving feedback from diverse partners, we decided to disaggregate surface quality in hiBike into its different components: surface smoothness, surface material, and maintenance state. Breaking down surface quality into its components is important to understand the results and find out what interventions are needed to address surface quality issues.

3.3.3 Measuring street connectivity: How big of a detour must I take to reach my surroundings?

Beyond having safe, comfortable, and attractive paths, urban environments fostering active mobility must arrange these paths into a dense and well-connected network, facilitating access to surrounding locations. Since active mobility is typically slower than motorized traffic, detours have a greater impact on travel time. This can be compensated for by dense networks and, in particular, good network connectivity, which gives pedestrians the opportunity to shorten their journey by taking more direct routes. Good connectivity is important to promote pedestrian accessibility to basic services and daily needs (i.e., 15-minute cities).

hiWalk's “detour factor” indicator divides the area of interest into a hexagonal grid and, for each grid cell, it shows how much longer it takes on average to walk to the center of the six neighboring cells compared to traveling in a straight line. The optimal value is 1, meaning that a grid cell is connected with straight paths to all its surroundings. A value of, for example, 2, means that on average one needs to walk twice as long as the straight distance to the surrounding cells.

We plan to implement this indicator in hiBike as well, where it will function in the same way except that the neighborhood of analysis will be much larger in most cases, since cyclists can travel faster than pedestrians can.

3.3.4 Integrating satellite imagery to assess green and blue infrastructure: How “natural” are this street’s surroundings?

Comfort and safety are fundamental for active mobility, but a street might have a smooth sidewalk or cycling lane and still be unattractive for pedestrians and cyclists if the surrounding environment is perceived as ugly, stressful, or uninteresting (Adkins et al., 2012; Borst et al., 2008). One of the most important factors influencing the attractiveness of environments for active mobility is the presence of vegetation, water bodies, and other natural environments (Bialkova et al., 2022; Borst et al., 2008; Yang et al., 2019). Urban vegetation and water bodies also can have positive effects on mental health (Hidalgo, 2021; Sousa-Silva et al., 2025; Völker & Kistemann, 2011), air quality (Kumar et al., 2024; Leung et al., 2011), and heat island mitigation (Lin et al., 2020; Melaas et al., 2016). To quantify the abundance of vegetation on and next to streets, we use Sentinel-2 satellite imagery to measure the annual median Normalized Difference Vegetation Index (NDVI) in a 10-m buffer around each road segment. High values correspond to areas with trees and natural vegetation, such as forests and parks, while low values indicate streets surrounded by built-up areas with little greenery. While the naturalness indicator is currently only available in hiWalk, we plan to incorporate the exact same metric into hiBike.

3.3.5 Considering topography: How steep is this street?

The slope indicator displays the slope of a street or path as a percentage value, using Shuttle Radar Topography Mission data with a resolution of approximately 90 m. The indicator uses this data to calculate the elevation difference between the two ends of a street segment, and thereby the street's average slope. The indicator categorises inclines from "steep" (greater than 12 % gradient) to "manageable" (less than 6 %). It takes into account research suggesting that a 1 % increase in slope makes walking about 10 % less attractive (Alves et al., 2020; Meeder et al., 2017). Similarly, slope generally has a negative effect on bikeability (Ito et al., 2024), while steep slopes can even endanger cyclists due to higher speeds when descending (Castañon et al., 2024). The slope indicator is currently only available in hiWalk, but will be incorporated in hiBike as well because steep paths can hamper bikeability even more strongly than walkability.

4 RESULTS & DISCUSSION

4.1 Results for different cities and what they can tell us about the fitness for purpose of OSM

As a research institute based in Heidelberg, we usually carry out the first tests of our indicator prototypes in our hometown. One reason for this is our own experience as pedestrians and cyclists in this city. Another reason is the active OSM community in and around Heidelberg, which has created a comparatively complete database on street smoothness (Fig. 1a) that allows us to highlight the potential of OSM for mobility indicators in well-mapped regions. However, in contrast to streets, the smoothness of sidewalks is only sparsely mapped even in Heidelberg. As described above in the methods section, we therefore use "surface" (indicating surface type, such as asphalt or cobblestones) and "tracktype" (indicating maintenance state) as proxies to complement the data. As this information is comparatively frequently available in Heidelberg, our surface quality indicator reveals that most walkable infrastructure in Heidelberg is potentially smooth enough for comfortable walking (Fig. 1c), although there are clusters of paths with poor surface quality near the train station and in the forest area east of the city. In contrast, in Amersfoort, OSM smoothness data is rare for streets and entirely absent for sidewalks (Fig. 1b). Even "surface" data is frequently missing in Amersfoort, and as a result hiWalk categorizes the surface quality of most paths as "unknown" (Fig. 1d).

This paucity of data about the quality of the pedestrian infrastructure highlights the need to use additional data sources to complement OSM and improve the consistency and global coverage of our indicators.

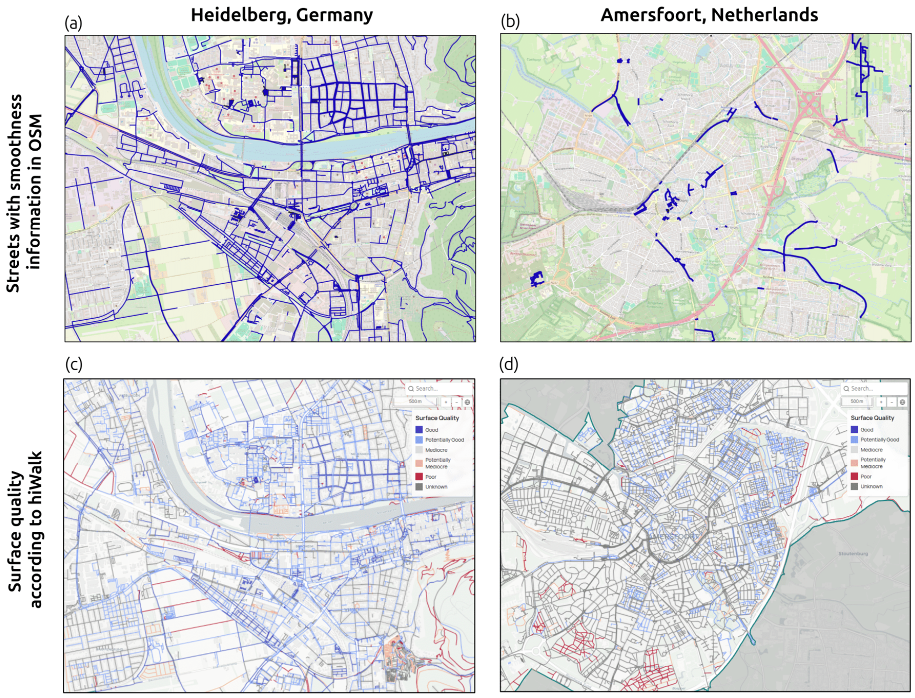

Fig. 1: Map of Heidelberg (a) and Amersfoort (b) showing streets with road smoothness information in OSM (blue lines). Data coverage in well-mapped cities like Heidelberg enables the creation of useful indicators to inform active mobility planning (c), in contrast to sparsely mapped cities like Amersfoort (d).

The same pattern, albeit less markedly, emerges when classifying pedestrian infrastructure according to the users that share the path/street. Information about the presence of sidewalks alongside streets is very important for this indicator, but the coverage of this indicator also varies starkly across different cities (Fig. 2). In its current version, hiWalk assumes that streets without sidewalk tag information in OSM do not have sidewalks in the real world, which is often not true. As a result, hiWalk currently underestimates the quality of walking infrastructure in in poorly mapped cities such as Amersfoort.

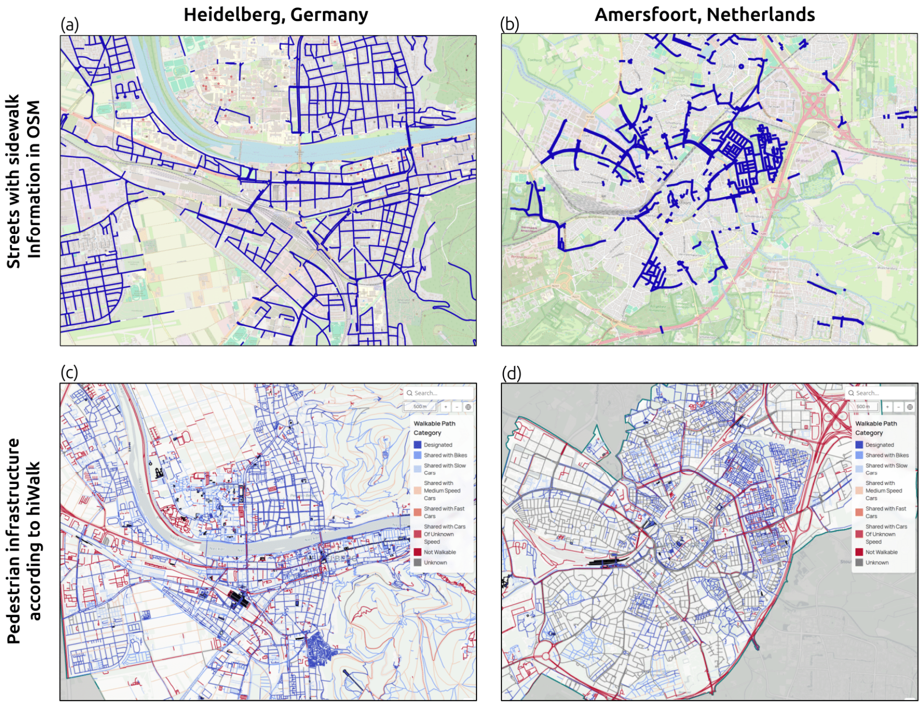

Fig. 2: Map of Heidelberg (a) and Amersfoort (b) showing streets with sidewalk information in OSM (blue lines). More complete sidewalk information in well-mapped cities like Heidelberg results in less uncertain indicators of pedestrian infrastructure (c), in contrast to sparsely mapped cities like Amersfoort (d).

4.2 Results for two extremely different cities: Why transferability matters

Researchers, urban and transport planners, and other stakeholders inadvertently tend to transfer their everyday experiences and realities to other places. Many of the current active mobility indices are applied to cities and regions around the world. However, these indices' underlying assumptions do not necessarily apply to other regions, especially when they have been developed in and for one context and are then transferred to a very different one.

Like many other indices of bikeability or walkability, hiBike and hiWalk aspire to be globally applicable. However, our approach is different in that we work with local stakeholders to adapt our indices regionally. For hiWalk, for example, we were able to collaborate with LUDI (Lagos Urban Development Initiative) in Nigeria, an organisation with a large interest to improve walkability in Lagos. In the following paragraphs, we will demonstrate why our Walkable Path Categories indicator within hiWalk is a prime example for the importance of this approach and for the significant difference it will ultimately make.

hiWalk categorises streets with sidewalks as having designated pedestrian infrastructure – interpreted as safe and comfortable – and streets without sidewalks as requiring pedestrians to share the road with motorised traffic – interpreted as unsafe and uncomfortable. This is based on the assumption that motorised traffic occurs more or less everywhere in a city so that designated pedestrian infrastructure makes a big difference in terms of safety and comfort. However, this assumption does not hold true everywhere. Comparing car density, income inequality, and average income between Heidelberg (Germany) and Lagos (Nigeria) will give us more insight into why this is so.

Car density is the ratio between the number of cars and the number of inhabitants in a given geographical area. In 2021, there were 388 cars per 1000 inhabitants in Heidelberg (Stadt Heidelberg, 2024), and around 322 cars per 1000 inhabitants in Lagos (cf. https://www.ceicdata.com/en/indicator/nigeria/motor-vehicleregistered, https://worldpopulationreview.com/cities/nigeria/lagos; note that the calculation of car density in Lagos is uncertain due to contradicting official population numbers). At first glance, car density seems very similar in both cities. However, differences in income level and distribution, with lower and more unequal incomes in Lagos, also need to be taken into account. Lagos is among the cities with the greatest income inequality, with a Gini coefficient of 0,64 (WorldAtlas, 2019). While there is no Gini coefficient available for Heidelberg, for its federal state (Baden-Württemberg) it is 0,29 (Statistische Ämter des Bundes und der Länder, 2023). Moreover, the average monthly income in Lagos is $207,61 (median income in Heidelberg in 2022: $4250) and by 2026 the city could have a poverty rate of more than 50 % (EARLY, 2024). As a result, the distribution of car ownership within Lagos is very uneven, resulting in congested districts on the one hand and more or less car-free districts on the other. These figures highlight the need for local knowledge when interpreting data: We cannot assume that 'shared with motorised traffic' means poor pedestrian safety and comfort in those largely car-free districts and areas of Lagos. Therefore, we also cannot assume that the interpretation of hiWalk's pedestrian infrastructure categories is valid in cities with uneven spatial distributions of car ownership and traffic volume, such as Lagos. We were made aware of our wrong assumptions during our collaboration with LUDI, and are currently co-developing a version of hiWalk tailored to Lagos, which could potentially be applied to other West African cities.

4.3 hiBike and hiWalk results and the 15-min city: Just because a route is short, doesn't make it good

A future task of HeiGIT's climate action focus group is to integrate our active mobility indicators into OpenRouteService (ORS, https://openrouteservice.org/), an open-source routing engine built on OSM data. Current routing services and accessibility analyses, which underpin the popular 15-minute city concept (Moreno et al., 2021), typically assume that all streets are equally bikeable and walkable for everyone. As a result, they focus solely on travel time, overlooking not only the diverse experiences and specific needs of different population groups, such as older adults or children, but also that subtle urban design elements influence walkability (Ewing et al., 2006). However, urban planners require detailed insights into how the bikeability and/or walkability of street networks influences active mobility across all citizens to implement effective measures that ensure equitable access to essential services.

Fig. 3: Implementing hiBike and hiWalk into OpenRouteService (ORS) to generate routes optimised for active mobility rather than just the shortest or fastest paths. Considering walkability and/or bikeability in routing can help quantify how close cities are to being a "15-minute-city for all".

To bridge this gap, we take first steps toward integrating hiBike and hiWalk into a routing engine (cf. Fig. 3). This integration will enable us to generate routes optimised for active mobility rather than just the shortest or fastest paths. By incorporating hiBike and hiWalk into accessibility analyses, it becomes possible to calculate a truly "bikeable and walkable 15-minute city". To this end, we will adjust the routing algorithm's cost function to incorporate bikeability and walkability alongside cycling/walking duration, prioritising safer and more pleasant routes even if they are slightly longer. With this enhanced routing service, accessibility analyses can account for safer and more pleasant active mobility routes when determining access to essential services such as supermarkets or healthcare facilities.

5 CONCLUSIONS

Our findings show the opportunities and challenges of developing active mobility indices that can be applied to cities worldwide. While OSM serves as a good baseline for data-driven active mobility analysis, our results stress that OSM data has to be complemented with other (open) data sources to obtain a more complete understanding of the infrastructure for active mobility. Global analyses of accessibility and active mobility must account for the stark differences in data availability, recency, and completeness in cities around the world.

Another key finding of our work is the influence of regional disparities on the applicability of bikeability and walkability indices. The case of Lagos shows that basic assumptions, such as the impact of pedestrian infrastructure on walkability, cannot necessarily be extended to widely varying urban settings. This underscores the need for co-creation with local stakeholders to ensure the indices are applicable and relevant. Our approach of co-creating hiWalk for West African cities with its consideration of local context illustrates that inclusive and context-aware mobility assessments are needed for sustainable traffic planning in urban areas worldwide. At the same time, these findings raise questions concerning the ethics of transferring data-driven models across different socio-economic and infrastructural contexts. Although universal applicability is desirable, the potential for misinterpretation and misapplication underscores that an iterative validation with local experts is essential.

The integration of hiBike and hiWalk into an open routing service algorithm will be started soon. The current state of accessibility analyses often overlooks the qualitative aspects of walking and cycling experiences, focusing instead on travel time efficiency. By integrating active mobility indicators into ORS, we aim at a more holistic understanding of urban mobility that will enable planners to design truly accessible (15-minute) cities.

hiBike and hiWalk demonstrate the potential of co-created, open-data-informed indices of active mobility. Even more than that, they highlight the challenges in constructing active mobility indices that are applicable worldwide. With the help of local insights and by integrating multiple data sources, we are sure it is possible to create more effective indices to support sustainable and equitable mobility worldwide.

Despite the challenges and limitations that we currently face while developing hiWalk and hiBike, the co-created nature of these pilot indicators offer a unique and important innovation in the field of active mobility analyses. Our co-creation approach renders real-world feedback from stakeholders during the entire development process, from the conception of indicators, to their prioritization, implementation, and refinement. This synergistic transdisciplinary process ensures the development of indicators that are relevant to stakeholders, directly applicable, easy to understand, and based on sound methods and the latest science. Several innovative aspects of hiWalk and hiBike show the early fruits of this co-creation process.They focus on mobility and accessibility for all, explicitly considering people with special mobility needs. They harness high-resolution open geodata to assess mobility at the street-segment level. And last but not least, they will soon be integrated into a routing engine (OpenRouteService) to account for walkability and bikeability in accessibility assessments and routing.

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