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Beyond Walking and Biking: Expanding the 15-Minute City Area through Public Transport

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Abstract. The concept of the "15-minute city" has recently attracted notable attention and is being widely discussed in urban planning and policymaking. The original idea focuses solely on active modes, thus walking and biking, without considering the role of public transport, which is, in fact, essential for accessing amenities of daily needs in urban areas. Additionally, most studies exploring this concept model walking and biking with constant average speeds. While this simplification is considered reasonable in flat urban environments, it may result in inaccurate estimations for cities on more hilly terrain. This study aims to address these two drawbacks by integrating public transport into the 15-minute concept and incorporating speed as a function of street inclination. The results for the case study of Vienna indicate only small differences in average accessibility when modelling walking speed in a slope-dependent manner. In contrast, for biking the difference is notable. Secondly, incorporating public transport as a valid mode option decreases the average duration to access all daily needs from 23.25 minutes (walking only) to 16.80 minutes and the median duration from 15.20 minutes to 13.22 minutes. The main finding of this work is that adding public transport extends the 15-minute city area rather than optimizing travel times within the existing walkable area. Furthermore, the presented analyses provide the means to uncover categories that limit the area of the 15-minute city.

Submission Type. Case Study

BoK Concepts. [TA12-6] EO for infrastructure & transport; [GS4-3b] Citizens and volunteered geographic information

Keywords. 15-minute city, public transport, street inclination

1 Introduction

The term "15-minute city" gained a lot of interest among researchers, urban planners and policy makers in the past decade. The concept was initially formed by Carlos Moreno in 2016, advocating that a person - in less than 15 minutes - should be able to access all of their basic living needs by foot or bike (Moreno, 2016). These basic needs are divided into six broad categories: living, working, commerce, healthcare, education and entertainment (Moreno et al., 2021). The core principle emphasizes proximity, a longstanding concept previously mentioned in other planning approaches (see Table 9 of EIT Urban Mobility (2022)). Additionally, the concept focuses on travel time, which has also been part of previous concepts such as "time geography" and "chrono-urbanism" (Osman et al., 2020). What sets the 15-minute city apart is its simplicity, its memorable name and the ease of measuring its outcome.

In the last years, several studies have attempted to analyse and quantify the current state of different neighbourhoods or cities through the lens of the 15-minute concept (Murgante et al. (2024) for the two Italian cities Terni and Matera, Birkenfeld et al. (2024) for Montreal (Canada), Jin et al. (2024) for 12 American cities and Liu et al. (2024) for Hong Kong). The authors agree that the concept of the 15-minute city is a valuable tool for promoting more sustainable, fairer and more liveable urban development. At the same time, some cities such as Paris, Portland and Melbourne have already incorporated the vision in their policy-making. Pozoukidou and Chatziyiannaki (2021) compare and rank their strategies under the three pillars of inclusion, health and safety. They come to the conclusion that the concept offers a new perspective on how to efficiently allocate resources on a citywide scale, while also allowing local participation.

Although the concept receives a lot of positive resonance, some work critiques the concept, arguing that it is utopian, detached from reality, and overly simplistic as a one-size-fits-all approach (Khavarian-Garmsir et al., 2023; de Leániz and Lobo, 2023; Caprotti et al., 2024). A recent review article identifies “the seven pitfalls of the 15-minute city” (Mouratidis, 2024), examining its limitations as a theoretical concept and as a tool for spatial analysis.

One of the raised concerns is the exclusion of public transport from the concept. Indeed, only a limited number of studies include this form of sustainable transport in their analysis of the 15-minute concept (Poorthuis and Zook, 2023; Wolański, 2023; Gao et al., 2024). The studies emphasize public transport both as a green mode of urban mobility as well as for its stations serving as central nodes in multifunctional neighbourhoods.

Another drawback of how the 15-minute city concept is often modelled are the walking and biking speeds, which are simplified to single average values. Several papers highlight this limitation and advocate for more representative and inclusive models (Hosford et al., 2022; Willberg et al., 2023). It is known, that both walking and biking are impacted by many different factors such as age, temperature, trip purpose and inclination of streets (Buchmüller and Weidmann, 2006; Flügel et al., 2019). A step towards a more inclusive speed model has been taken by Willberg et al. (2023). They consider age, diurnal and seasonal variations in walking speeds and report, that diurnal variation has the largest effect. To the best of our knowledge, street slopes have not been addressed in the context of the 15-minute city yet, but Daniel and Burns (2018) add steepness in their computation of pedestrian catchments. The authors show that walkable catchment areas are around 20% smaller once topography is included and they highlight the importance of considering the slopes of the street network.

Taking into account the existing literature, we add to this body of work by including public transport in the analysis of the 15-minute concept for the case study of Vienna and, in particular, quantify the differences between the two conditions of walking and walking *plus* public transport. Additionally, instead of setting average values for walking and biking speed, we model both speeds as a function of street inclination and thereby account for variations in active movement across uphill, downhill and flat terrain. It is expected that considering different speeds for inclined streets will have an impact on the average walking and biking accessibility. Also, we hypothesise, that the average duration is significantly lower when taking public transport into account and that more city area meets the 15-minute goal. However, it must be emphasized that the current state of the city remains unchanged, regardless of how its accessibility is assessed. This work contributes by refining the computation method to better integrate all sustainable transport modes and highlights the importance of choosing the model according to its purpose.

The rest of the work is organized as follows. First, the methods are introduced, delineating the data and software availability and the processing steps, with an emphasis on public transport and slope-adjusted walking and biking speeds. Furthermore, details regarding the accessibility analysis are outlined. Then, the results are provided, followed by a thorough discussion of the findings. Finally, the work concludes with a summary of the main findings, together with limitations and suggestions for future research.

2 Methods

This section outlines the methods used to conduct the expanded 15-minute city analysis (integration of public transport and topographic information) and to compare the expanded concept with the conventional 15-minute city analysis (only active modes as well as average speed values). The section is organised as follows: First, the data sources, their availability, and the specifications of software and code are detailed. Next, the necessary processing steps are described, including the study area, the graph preparation, details on the public transport network and walking and biking speeds, as well as a summary of the included Points of Interest (POIs) and their categorisation. Finally, the last subsection, "Accessibility Analysis", explains the accessibility computation and specifies the various comparisons made.

2.1 Data and Software Availability

All data used in this work is openly accessible. OpenStreetMap (OSM) serves as the main data source for deriving the street network and the Points of Interest. A data snapshot from 2024-10-02 is used, which covers the entire bounding box around the study area. Topographical information, i.e., the street slopes for adjusting walking and biking speed, is derived from a Digital Elevation Model (DEM). General Transit Feed Specification (GTFS) data is used to include public transport timetable information. Additionally, the city's boundary geometry is utilized. The latter three sources are available through Open Data Austria[1]. To reproduce the analysis, we provide the following datasets: the full OSM download (nodes, ways and relations), tag lists of relevant POIs, snippets of the preprocessed graphs (which already incorporate topographic and timetable information) and the city's boundary geometry. The accessibility analysis is done with Python 3.10 and custom scripts. Both the data and code, along with the requirements for the processing environment, are available on our website[2].

2.2 Processing

Study Area. The study area of the current work focuses on the urban area of Vienna, the capital of Austria. The city is known for its great liveability as well as its well-developed public transport network, making it an ideal setting to expand the accessibility analysis by public transport. We consider the walking network, the biking network as well as four public transport modes: bus, tram, subway and train. For the accessibility analysis, the city's boundary geometry is tessellated into a regular grid of hexagons, each with a side length of 200 m.

[1] https://www.data.gv.at/
[2] https://geoinfo.geo.tuwien.ac.at/resources/

Graph Preparation. The graph preparation involves processing the downloaded OpenStreetMap (OSM) data to create clean, mode-specific networks with the attribute *time* assigned to all edges. For the "walk" (respectively "bike") network, OSM ways are filtered based on their *highway* tag, including all walkable (respectively bikeable) segments. For the full list of considered tag values see Fogliaroni et al. (2018), ("walk" aligns with the class **path**, while "bike" extends the class **road** to additionally include *cycleway*). The filtered data is merged into a graph structure with nodes and edges, where the nodes represent junctions, and the edges correspond to walkable (bikeable) street segments.

Public Transport. The public transport networks (bus, tram, subway and train) are extracted by filtering the OSM relations by the *route* tag for their respective values *bus*, *tram*, *subway* and *train*. For the public transport networks, the nodes are stops or stations, and the edges indicate the links between two stops or stations. The *time* attribute assigned to the public transport edges is derived from the General Transit Feed Specification (GTFS) data. GTFS is a common format for sharing timetable information of public transport. For each link between two stations (e.g. from station A to station B), the *time* attribute is computed by averaging all trip durations between A and B. Additionally, the waiting times for the next vehicle are approximated with the GTFS data and added to the graph. The average waiting time is computed as half the headway (Ansari Esfeh et al., 2021). The derived values for the different modes of transport are the following: bus = 6.2 min, tram = 4.0 min, subway = 2.0 min and train = 5.9 min.

Walking and Biking Speeds. Unlike previous studies, we do not use a fixed average walking (biking) speed. Instead, we model the speeds as a function of the slope, taking into account the impact that the terrain topography has on active movement. The walking and biking speeds for non-inclined segments are set to 4.8 km/h (Buchmüller and Weidmann, 2006) and 21.6 km/h (Parkin and Rotheram, 2010), respectively. For walking, the speed is adjusted in the range of -15% to 15% inclination, in steps of 5% (see Table 9 of Buchmüller and Weidmann (2006)). For inclinations exceeding the specified range, the speed is set to the respective minimum or maximum value. The biking speed is modified in steps of 1% (see Table 4 of Parkin and Rotheram (2010)). Following their model, for every 1% of downhill (negative) slope, the speed is increased by 0.86 km/h and for every 1% of uphill slope, the speed is reduced by 1.44 km/h. For slopes with an inclination of 12% or more, the speed is set to the minimum speed derived for the walking model, since it is the threshold where the biking speed would be lower than the walking speed (i.e., the biker will likely push the bike). The *time* attribute of the graph edges is then calculated by dividing segment length by segment speed. The segment lengths are obtained directly from the OSM data, while the segment speeds are determined according to the inclinations of the edges. These inclinations are calculated using elevation differences between nodes, which are in turn derived from the Digital Elevation Model (DEM). The DEM used for this work has a spatial resolution of 1 m and an elevation accuracy of ± 10 cm for the streets.

Points of Interest (POIs). The Points of Interest (POIs) that reflect and represent people's basic needs are obtained from OpenStreetMap (OSM). All three basic OSM components are taken into consideration: nodes, as well as ways and relations. The nodes are already provided with a point geometry, whereas the geometries of ways and relations are simplified by computing their centroids. The derived point geometries are spatially matched to the nearest node of the graph, to allow successful routing to the POIs. The present study considers the same nine POI categories as Bruno et al. (2024): healthcare, services, transport, outdoor, supplies, restaurant, culture, education and physical. Additionally, we use the same list of key-value pairs for each category. For more details and a complete reference, the reader is referred to the supplementary information of Bruno et al. (2024) or to our provided OSM tag lists (see Section 2.1).

2.3 Accessibility Analysis

The accessibility analysis is designed to replicate parts of the work of Bruno et al. (2024). Similar to the measures outlined in their accessibility calculation, we compute the hexagon-level accessibility $\langle t \rangle_{c,k}$ and the city-level accessibility PT_k as follows:

$$\langle t \rangle_{c,k} = \frac{1}{n} \sum_{i=1}^{n} t_i^{c,k} \tag{1}$$

$$PT_k = \frac{1}{m} \sum_{c=1}^{m} \langle t \rangle_{c,k} \tag{2}$$

Equation 1 computes the hexagon-level accessibility $\langle t \rangle_{c,k}$ as the average duration required to reach POI *i* of category *c* starting from the centroid of hexagon *k*. To enable uninterrupted routing, the hexagon centroids are matched to the nearest nodes of the walking (biking) graph which will serve as starting nodes. The 20 nearest POIs (*n* = 20, as proposed by Bruno et al. (2024)) are considered as destinations. The duration *t* from a starting node (hexagon centroid) to a destination (POI) is computed using Dijkstra's shortest path algorithm (Dijkstra, 1959) with the weight set to *time*. Equation 2 depicts the city-level accessibility as proximity time (PT) index per hexagon *k* as the average hexagon-level accessibility $\langle t \rangle_{c,k}$ over all *m* POI categories.

The analysis consists of two main components. The first part investigates the influence of speed modelling by comparing two scenarios: (1) accessibility computed using constant average speeds for walking (4.8 km/h) and biking (21.6 km/h) and (2) accessibility computed with slope-adjusted speeds. The second part focuses on the integration of public transport, comparing three scenarios: walking, biking, and walking *plus* public transport. In both parts of the analysis and all investigated scenarios, the same methodology is applied: accessibility is assessed by calculating hexagon-level and city-level accessibility. The only difference lies in the underlying graph and its modified edge attribute *time*, which is used to compute the fastest paths to the POIs. For the second part of the analysis (i.e., integrated public transport), the speeds of active modes are modelled as a function of street slopes, as described above.

3 Results

This section presents the results of the accessibility analysis in two parts: First, the findings for adjusted walking and biking speeds by street inclination compared to average speeds, and second, the impact of incorporating public transport compared to walking only.

3.1 Adjusted Walking and Biking Speeds

The first part of the presentation of the results focuses on the comparison of the average walking and biking speed model with the slope-adjusted speeds as proposed in this work. The results averaged over all hexagons can be seen in Table 1. For the walking mode, only minor differences between the two modelling approaches can be seen. The slope-dependent model consistently results in a higher average time required to reach any of the nine POI categories, but the differences only range from a minimum of 0.10 minutes for *outdoor* POIs to a maximum of 0.27 minutes for *culture* and *education* amenities. For the city-level accessibility considering the joint proximity to all POI categories, the model with the average walking speed value results in 23.05 minutes average time, whereas the model including the street slopes yields an average time of 23.25 minutes, resulting in a difference of 0.20 minutes. The area percentage that is below 15 minutes changes from 49.91% for the average speed model to 49.31%. For biking, however, the differences are more remarkable. Again, the slope-dependent model results in higher values for all categories, with the smallest changes for *outdoor* POIs (an increase from 2.37 minutes to 3.96 minutes) and the biggest difference for category *healthcare* (from 8.10 minutes to 12.38 minutes). The difference in city-level accessibility is 2.84 minutes, with a value of 5.11 minutes for the average speed model and an average of 7.95 minutes for the slope-dependent model. The area that corresponds to a 15-minute city is 95.05% for the average speed model and 88.77% for the slope-dependent model.

Table 2 depicts the median accessibility over all hexagons, instead of the average. Again, the slope-dependent models result in longer times needed to reach any of the POI categories, for both walking and biking. Compared to the averages shown in Table 1, however, the values are lower overall, reflecting a data skewness to the right. For walking, the city-level accessibility is 15.01 minutes for the average speed model and 15.20 minutes for the slope-dependent model, whereas for biking, it is 3.62 minutes and 5.80 minutes, respectively.

3.2 Integration of Public Transport

The second part of the results concentrates on the integration of public transport into the 15-minute city analysis. Table 1 reports the average hexagon-level accessibility as well as the average city-level accessibility for the three scenarios walk, bike and public transport. In this context, walk and bike refer to the slope-dependent models, thus the right part of the table. For the city-level accessibility, biking results in the lowest average of 7.95 minutes, walking has the highest amount at 23.25 minutes, whereas adding public transport results in 16.80 minutes. The decrease in average time between walking only and added public transport is hereby 6.4 minutes. The table also indicates the increase or decrease of biking and public transport values with respect to the slope-dependent walking results (i.e., the percentage values in parentheses). Regarding the individual categories, the strongest differences between walking and public transport can be seen for the categories *supplies* (-38.01%), *restaurant* (-32.21%), *services* (-30.46%), *education* (-28.30%) and *healthcare* (-27.89%). The smallest difference is present for the *outdoor* category with still a notable decrease from walk to public transport of -14.13%. The area of the city that corresponds to a 15-minute city (thus is below a city-level accessibility of 15 minutes) is about 50% for the walking mode (49.31%). It increases to 57.18% if public transport is also added. For the biking mode, 88.77% of the city area is below the threshold of 15 minutes.

Table 2 is structured similarly to Table 1, but it depicts the results for the median over all hexagons, rather than the average. Overall, the values are lower, with a city-level accessibility of 5.80 minutes for biking, 15.20 minutes for walking and 13.22 minutes for walk *plus* public transport. Also, the decreases from walking to walking *plus* public transport appear more diverse for the different categories than for the average results. The *outdoor* category shows the lowest decrease of only -0.78%, whereas for *healthcare* and *education* the decrease is highest with -25.77% and -20.57%, respectively.

Finally, Table 3 shows both mean and median hexagon-level accessibility and city-level accessibility for walking, biking and public transport, but filtered only for hexagons where the city-level accessibility is below a 15 minute threshold.

Table 1. The **average** hexagon-level accessibility per POI category, the **average** city-level accessibility and the area percentage corresponding to a 15-minute city are shown, first for the model with average walking and biking speed and then for our proposed slope-dependent speed model and the included public transport. The percentages in parentheses refer to the increase or decrease with respect to the slope-dependent walking results.

		average speed		slope-dependent speed		
		WALK	BIKE	WALK	BIKE	PUBLIC TRANSPORT
hexagon-level accessibility	healthcare [min]	32.21	8.10	32.47	12.38 (-61.86%)	23.41 (-27.89%)
	services [min]	22.28	4.89	22.44	7.46 (-66.74%)	15.60 (-30.46%)
	transport [min]	16.20	3.39	16.33	5.46 (-66.56%)	12.25 (-24.98%)
	outdoor [min]	11.38	2.37	11.48	3.96 (-65.47%)	9.86 (-14.13%)
	supplies [min]	27.80	5.43	28.04	8.23 (-70.64%)	17.38 (-38.01%)
	restaurant [min]	27.27	5.72	27.52	8.80 (-68.03%)	18.66 (-32.21%)
	culture [min]	18.65	4.06	18.92	6.60 (-65.11%)	15.25 (-19.41%)
	education [min]	33.81	8.04	34.08	12.29 (-63.94%)	24.44 (-28.30%)
	physical [min]	17.84	3.99	18.01	6.37 (-64.64%)	14.38 (-20.13%)
city-level accessibility [min]		23.05	5.11	23.25	7.95	16.80
area of 15-minute city [%]		49.91	95.05	49.31	88.77	57.18

Table 2. The **median** hexagon-level accessibility per POI category, the **median** city-level accessibility and the area percentage corresponding to a 15-minute city are shown, first for the model with average walking and biking speed and then for our proposed slope-dependent speed model and the included public transport. The percentages in parentheses refer to the increase or decrease with respect to the slope-dependent walking results.

		average speed		slope-dependent speed		
		WALK	BIKE	WALK	BIKE	PUBLIC TRANSPORT
hexagon-level accessibility	healthcare [min]	26.19	6.11	26.54	9.53 (-64.11%)	19.70 (-25.77%)
	services [min]	11.51	2.77	11.61	4.52 (-61.04%)	11.26 (-3.05%)
	transport [min]	7.30	1.66	7.37	3.03 (-58.93%)	7.26 (-1.48%)
	outdoor [min]	6.66	1.46	6.78	2.82 (-58.48%)	6.73 (-0.78%)
	supplies [min]	12.79	3.04	12.95	4.93 (-61.93%)	12.31 (-4.98%)
	restaurant [min]	16.09	3.80	16.26	6.16 (-62.14%)	14.75 (-9.30%)
	culture [min]	14.38	3.45	14.65	5.73 (-60.87%)	13.84 (-5.50%)
	education [min]	25.63	6.03	25.92	9.25 (-64.32%)	20.59 (-20.57%)
	physical [min]	9.96	2.30	10.14	4.11 (-59.48%)	10.02 (-1.16%)
city-level accessibility [min]		15.01	3.62	15.20	5.80	13.22
area of 15-minute city [%]		49.91	95.05	49.31	88.77	57.18

Table 3. The average and median hexagon-level accessibility per POI category and the average and median city-level accessibility, solely for the hexagons that correspond to a 15-minute city (city-level accessibility < 15), for the slope-dependent speed model and the included public transport. The percentages in parentheses refer to the increase or decrease with respect to the slope-dependent walking results, for mean and median, respectively.

		slope-dependent speed					
		WALK		BIKE		PUBLIC TRANSPORT	
		mean	median	mean	median	mean	median
hexagon-level accessibility	healthcare [min]	14.27	13.18	9.87 (-30.83%)	8.29 (-37.06%)	13.46 (-5.69%)	13.45 (+2.08%)
	services [min]	6.31	6.06	4.88 (-22.60%)	4.01 (-33.75%)	7.03 (+11.41%)	6.86 (+13.28%)
	transport [min]	5.18	4.77	3.55 (-31.38%)	2.80 (-41.21%)	5.41 (+4.58%)	5.00 (+4.88%)
	outdoor [min]	4.41	4.04	3.26 (-26.12%)	2.66 (-34.11%)	4.81 (+9.12%)	4.34 (+7.34%)
	supplies [min]	7.03	6.66	5.51 (-21.59%)	4.41 (-33.77%)	7.76 (+10.37%)	7.46 (+12.06%)
	restaurant [min]	9.72	9.86	6.45 (-33.64%)	5.63 (-42.96%)	10.03 (+3.15%)	10.26 (+4.03%)
	culture [min]	11.85	11.55	6.23 (-47.41%)	5.69 (-50.72%)	11.67 (-1.55%)	11.87 (+2.74%)
	education [min]	15.87	16.03	9.80 (-38.27%)	8.39 (-47.67%)	14.95 (-5.81%)	15.02 (-6.32%)
	physical [min]	6.95	6.55	4.67 (-32.73%)	3.71 (-43.31%)	7.22 (+3.88%)	6.75 (+3.14%)
city-level accessibility [min]		9.07	9.25	6.03	5.33	9.15	9.31

As the current analysis focuses on walking and walking combined with public transport, biking is excluded from the following figures. Fig. 1 and Fig. 2 show a heatmap of the city-level accessibility for walking and walking *plus* public transport, respectively. The scale ranges from 0 to 30 minutes, where blue colours depict values below 15 minutes and red coloured values above the threshold. Both figures showcase a blue city centre, thus average accessibility times below 15 minutes. Towards the outskirts, the values get closer to 20 minutes, with some dark red spots in the west and south-east. Fig. 2 (walking *plus* public transport) seems to have a bit lower values on average, with more hexagons depicted in orange colours rather than dark red. To highlight the changes introduced by public transport, Fig. 3 depicts the differences between walk minus walk *plus* public transport. It is emphasized that the bins have different ranges. Almost no changes (purple colour) can be seen in the city centre. Towards the outskirts of the city, the differences get bigger (blue, green and yellow). The biggest differences (more than 10 minutes, depicted with orange colour) are located in the west as well as in the south-east and partially in the north-east.

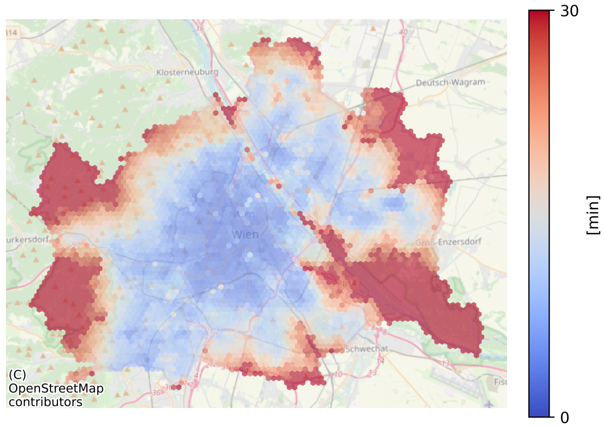

Figure 1. Heatmap of the city-level accessibility for the walking mode.

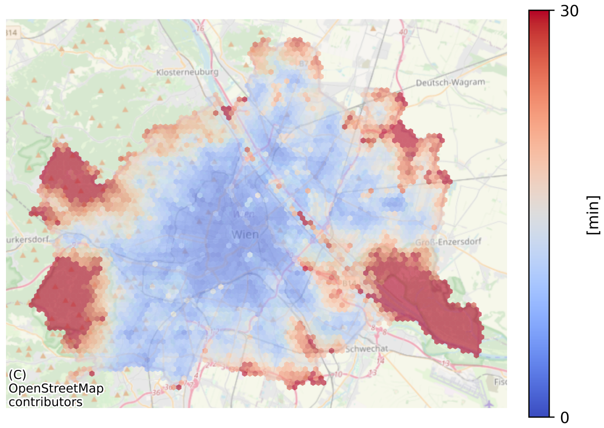

Figure 2. Heatmap of the city-level accessibility for walking *plus* public transport.

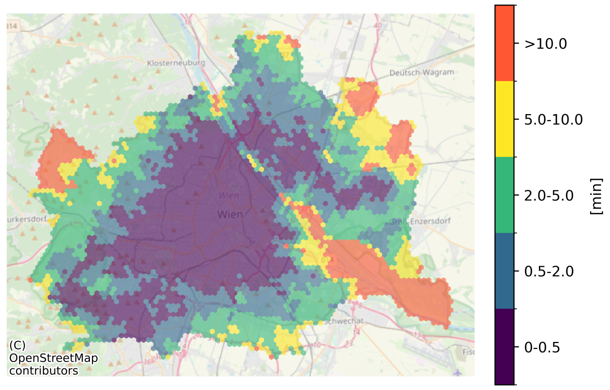

Figure 3. Heatmap of the differences in city-level accessibility for walking and walking *plus* public transport. Please note that the bins do have varying sizes.

To allow a more detailed analysis of the individual POI categories, Fig. 4 and Fig. 5 depict them separately. The figures show the averaged hexagon-level accessibility per category, with an increasing radius around the city centre. Additionally, the 15 minute-threshold is highlighted with a horizontal black line. For the walking scenario (Fig. 4), all categories are below the threshold up until approximately 6 km distance from the centre. For added public transport (Fig. 5), this increases to about 7.4 km. Additionally, one can see, that the average time grows slower for all categories when public transport is included. What stands out in both figures are the categories *education* and *heathcare*. They have notably higher average times than the other categories for increasing distance from the centre.

4 Discussion

The results presented in the previous section are discussed first in an overarching manner with respect to the 15-minute concept, and then the two modifications (adjusted speeds and integration of public transport) are examined. The accessibility analysis, as adopted by Bruno et al. (2024), is considered a reasonable model to investigate the current status of a city. It provides information beyond the 15-minute threshold while also permitting the application of a cutoff value when necessary. Nonetheless, no initial threshold is required, as the approach calculates the average accessibility per hexagon. However, this average value should also be treated with caution. As with any averaged value, it is affected by outliers and might be misleading. Furthermore, for the specific computation of proximity time (see equation 2), it might be of more interest to know the maximum (rather than the average) duration required to reach all nine categories that are considered basic needs, thus the worst-case scenario. Based on the specific question, this might hide or highlight certain aspects of a city, so one should be careful when using the 15-minute concept as a decision-making tool.

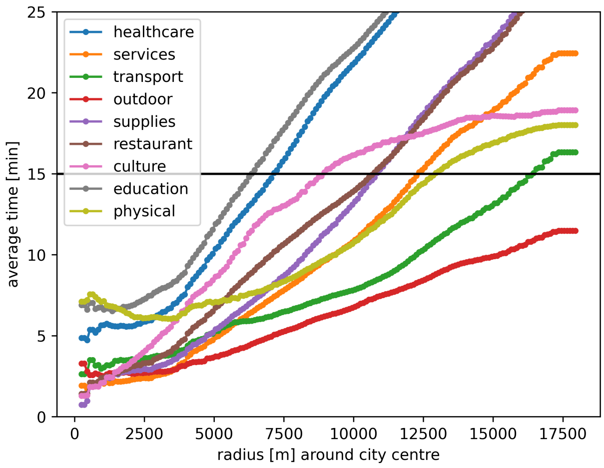

Figure 4. Walk scenario: Average hexagon-level accessibility per category, with increasing radius from the city centre.

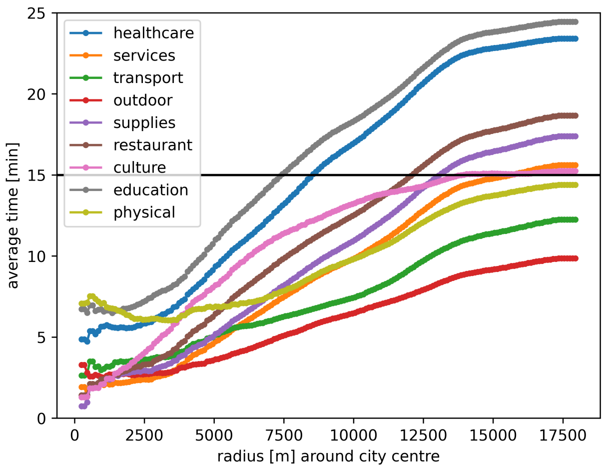

Figure 5. Walk *plus* public transport: Average hexagon-level accessibility per category, with increasing radius from the city centre.

4.1 Adjusted Walking and Biking Speeds

The comparison of the simplistic model with the proposed expanded model does not show large differences in walking. This could be caused by the rather flat terrain of the city of interest, especially in the city centre and central districts. Biking, however, is impacted more severely, which could be caused by a faster change in the speed values for uphill or downhill slopes. Since cities are known to expand and the average slope of this urban land expansion presents an upward trend (Zhou et al., 2021; Shi et al., 2023), we emphasize the benefit of adding topography to have a more accurate model. Also, we believe that increasing the complexity of the speed model, in general, is beneficial for the 15-minute concept since it takes a step towards a more comprehensive accessibility analysis. We want to highlight, that the speed values that are selected for a model have a considerable impact and should be set with care and with the purpose of the model in mind. For instance, an inclusive model, accounting also for the population age, should adjust to an average walking speed of 3.8 km/h for people over 60 (Buchmüller and Weidmann, 2006). This is 1 km/h slower than what we modelled as walking on flat terrain and even further away from what other studies consider as average walking speed (e.g. 5 km/h in the works of Olivari et al. (2023) and Bruno et al. (2024)). Since both walking and biking speeds are impacted by several other parameters (not just topography), we argue that even more inclusive speed models or adjusted speeds are necessary, as also highlighted by Mouratidis (2024).

4.2 Integration of Public Transport

The second part of the analysis provides valuable insights into the benefits of incorporating public transport in the 15-minute city analysis. As hypothesised, both the average and median duration decrease when adding public transport to the walking mode. This is reasonable, as public transport enables faster travel across the city and thus also makes it easier to access daily needs. Moreover, the results indicate that integrating public transport expands the area corresponding to a 15-minute city by 7.87%. Including public transport contributes to a more inclusive model of a 15-minute city, as it not only serves as a sustainable alternative to private cars and other motorized vehicles but also plays a vital role for individuals who cannot or choose not to use active modes of transportation. This makes public transport a key element for an inclusive 15-minute city. Furthermore, the detailed category-based analysis reveals notable differences which, if adressed and optimized, result in the extension of the 15-minute city area. Particularly, the categories *healthcare* and *education* as seen in Fig. 5 force a 15-minute cut-off at 7.4 km. Without these two categories, the cut-off radius would be at $\sim$ 12 km. Thus, a viable improvement could be achieved by increasing the number of facilities for both categories on the city's outskirts or enhancing public transport speed and coverage towards the existing amenities. Finally, by considering Fig. 1-3 one can detect areas where public transport makes a difference or rather where improvements are necessary. If the walking accessibility is bad (i.e., red areas in Fig. 1), but the differences are high (see Fig. 3), then the public transport helps to improve accessibility. However, if the differences are low, public transport has little impact which indicates areas where improvements would be advisable. One of these areas is located in the south-west part of the city.

5 Conclusion

The 15-minute city is a memorable, ease-to-grasp concept, that gains a lot of attention. This study expands the original concept by addressing two of its limitations: the exclusion of public transport and the oversimplification of constant average speeds for walking and biking. We change the speed model to be dependent on the street slopes and thus include topography which is known to be an impacting factor on walking and biking speed. The slope-dependent modelling of walking and biking speed yields small differences in the accessibility analysis. The inclusion of public transport reveals interesting insights. One key conclusion of this work is that adding public transport extends the 15-minute city area rather than optimizing travel times within the existing walkable area. Both modifications are a step towards a more personalized and inclusive 15-minute city analysis.

The work is subject to several limitations. First of all, as in many other 15-minute analyses, it relies on a limited key-value list for each category. We rely hereby on former work, but we cannot rule out the possibility that some POIs were not captured by this list. Additionally, the presence and accuracy of the considered POIs are highly dependent on the quality of OpenStreetMap (OSM) data. When using the 15-minute city as a planning tool, this data should be carefully checked. Furthermore, while we do modify walking and biking speeds according to the street slope, we still use fixed baseline speeds for flat terrain, which could differ in reality and do not include any of the other factors known to impact the speed. Lastly, we accounted for an average public transport frequency with averaged waiting times for the next vehicle, even though service availability can vary significantly during peak and off-peak hours.

Several areas for future work can contribute to improving the current analysis, also taking into account the limitations mentioned above. Integrating population distribution data would offer a more comprehensive understanding of accessibility across the city. Comparing our proposed speed model with average speeds in a more hilly city could provide further valuable insights into terrain influence. E-bikes are a rapidly growing form of urban mobility and could be included in future analyses using appropriate speed models that differ from those of conventional bikes. Additionally, increasing the complexity of speed modelling by incorporating more parameters known to affect walking and biking speeds would lead to a more realistic representation. Finally, to better understand why some areas have easy access to necessary amenities while others do not, one could explore the underlying network and its properties.

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