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Influence of 3D Barriers on Walkability for the Elderly in a German City

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Abstract: Walking is a sustainable, safe, and active mode of transportation. The benefits that the elderly in particular gain from outdoor walking are manifold, be it free and independent access to stores and services of all kinds or the opportunity to socialize, enjoy parks, et cetera. This article depicts one particular factor that affects outdoor walkability, namely the gradient of walking paths. Steep slopes can be a serious obstacle to walkability, primarily for older people. The evaluation of available geospatial data sources formed the basis for a geospatial analysis of walkability in the larger city of Kaiserslautern, located in southwest Germany. The concept of Walk Score was used to quantify the results obtained. The results demonstrate that the Walk Score can be refined to better address the mobility needs of older adults. The methodology was implemented for the German city of Kaiserslautern by integrating volunteered geographic information with high-quality official datasets.

Keywords: Authoritative Geospatial Data; Geospatial analysis; OpenStreetMap; Volunteered Geographic Information; Walkability

1 INTRODUCTION

When it comes to the ideal of a walkable city, there are many good reasons for it. Walkable neighbourhoods, among other objectives, foster physical mobility and thus promote residents' health [1-4]. Consequently, walkability plays a key role in concepts such as 20-minute neighbourhoods and the 15-minute city (cf. [5, 6]).

Walkability indices provide objective benchmarks as a base for rating neighbourhoods and cities [7-9].

However, most studies have only partially addressed the needs of specific groups, such as the elderly [10-12].

Additionally, factors like city size and structure have rarely been considered in pedestrian mobility studies [13-15].

This article presents a case study on urban walkability with a focus on elderly populations. The approach is based on the generic Walk Score model, which the authors adapt to account for older individuals' needs. The authors consider obstacles such as sloping terrain and stairways, adjusting walking time calculations to reflect these challenges for older people. In addition, the weighting of supply services are tailored to senior citizens' requirements.

The walkability index was implemented for the city of Kaiserslautern, located in the south-west of Germany, as a case study. In the following sections, details of the methodology are given and the results obtained using the adjusted Walk Score in the study area are discussed. Lastly, the conclusions highlight the benefits and limitations of the methodology and suggest areas for future enhancements.

2 METHODOLOGY

The study area was subdivided into a grid of square 100 meter cells. This grid system is used by official statistics in Germany and is also a reference system as defined by the Infrastructure for Spatial Information in Europe INSPIRE [16, 17]. It is therefore possible to link the results of our work with statistical data available in this spatial reference system. Walkability can then easily be further detailed by age or other socio-demographic variables of the population.

Walking time depends on the inclination of the walking paths. After Weidmann [18], the average horizontal gait speed of a pedestrian can be set at 1.34 m/s (metres per second). A gradient of 5% slows the speed uphill to 1.29 m/s and slightly accelerates the speed downhill to 1.38 m/s. The corresponding figures for a 10% gradient are 1.19 m/s uphill and 1.40 m/s downhill. For a 15% gradient, Weidmann estimates 1.07 m/s uphill and 1.40 m/s downhill. All these figures refer to the average population and are not specifically tailored to older people. Artmann et al. [19] set the walking speed of seniors on a horizontal surface at 1 m/s. Assuming the same influence on gait speed on inclined walking paths on a percentage base, the figures reported by Weidmann can be reduced by a factor of 1/1.34. The resulting gait speeds for senior citizens are then: at 5% incline uphill 0.96 m/s, downhill 1.03 m/s, at 10% incline uphill 0.89 m/s, downhill 1.04 m/s and at 15% incline uphill 0.80 m/s, downhill 1.04 m/s. Similarly, the speed value for climbing stairs was set at 0.65 m/s, using the same factor derived from Artmann. Gradients of more than 15% are considered to be obstacles that cannot be overcome.

The authors have calculated Walk Score, WS, values, see [20], for the 100 × 100 meter grid of the study area. Following [21], a predefined walking time limit of 20 minutes is applied. Using a standard network routing algorithm, the number of facilities accessible on foot within this time frame is determined. Unlike the original WS, this approach accounts for path inclines, addressing the specific mobility challenges faced by elderly individuals. The maximum WS value of 100 represents the scenario where all facility types (as outlined in Tab. 1) are reachable within a 5-minute walk. The WS value decreases as the walking time increases or fewer facilities can be accessed within 20 minutes. A WS value of 0 indicates that no facility is accessible within a 20-minute walk. Walking time is a linear function of walking speed, which, in turn, depends on the route's incline. The methodology of this Walk Score approach, more specifically tailored to the needs of the elderly, is detailed further in [22].

Most existing walkability models that factor in terrain utilize freely available, low-resolution data such as the SRTM DEM. However, the relatively low 1-arc-second resolution and limited height accuracy of such data make them insufficient for this application. In the model, inclines are calculated using a high-resolution Digital Terrain Model (DTM), in Germany known as DGM, provided by official German mapping agencies [23]. The highest level DGM 1 model describes the terrain surface with a 1-meter grid of ground points and height accuracy of 0.15 meters. This high-quality data, both in terms of spatial resolution and elevation accuracy, is crucial for calculating meaningful gradients over short distances.

3 STUDY AREA AND DATA SOURCES

The main objective for selecting the study area was its suitability to demonstrate the importance of 3D barriers to walkability, particularly for older people. The data sources used include both official and unofficial databases.

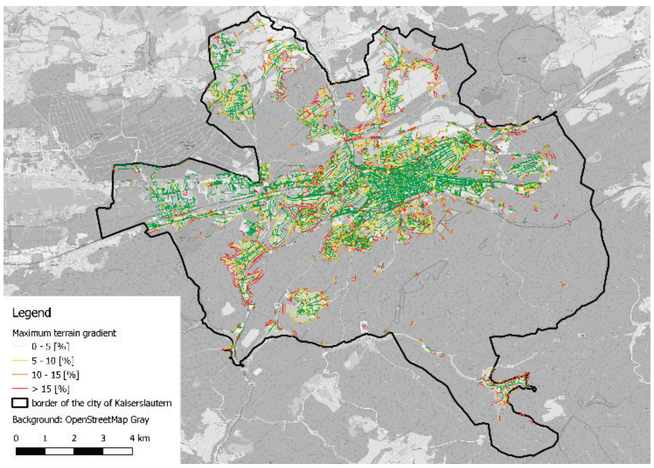

Figure 1 Maximum terrain gradient in the built-up area, in percent

3.1 Study Area

Kaiserslautern, with a population of 100,000, is one of the larger cities in Germany. The city's varying elevation significantly influences citizens' mobility. While the central areas are mostly flat, the peripheral regions are characterized by sloping terrain (see Fig. 1). Kaiserslautern shows the typical pattern of German cities, a spatially coherent city centre and disjoint neighbourhoods that have been created by the absorption of surrounding villages. In Kaiserslautern, the pattern of flat areas in the centre and sloping terrain on the periphery is repeated in the separate settlements, though on a smaller scale.

3.2 Data Sources

To calculate the Walk Score, it's necessary to create a network of walkable paths and roads. Despite its unofficial status and well documented regional variations, the quality of OpenStreetMap (OSM) road data in Central Europe is deemed sufficient for our analysis, as referenced in [24, 25]. Therefore, OSM data is used to construct the network model, encompassing all walkable pathways within the study area.

The network routing algorithm starts from each of the centre points of the 100 × 100 m grid and calculates the number of supply facilities reachable within the predefined walking time. The endpoints for the routing are based on OSM features, as detailed in Tab. 1. The network routing algorithm then outputs an individual WS value for each grid cell (see Figs. 2 and 3).

Table 1 Supply facility categories

Entertainment Recovery Sports	*Food*	*Healthcare*	*Public Transport*	*Service*	*Social*
Bar/Pub	Bakery	Pharmacy	Train station	Bank/ATM	Seniors' community centre
Library/Bookstore	Kiosk	Doctors/Hospital	Bus stop	Hair-dresser	
Church	Supermarket	Nursing home		Post	
Cinema	Butcher			Cleaning	
Museum/Theatre/Gallery	Other food			Cobbler/Lock-smith	
Restaurant/Café				Tailor Optician	
Swimming pool/Bathing place				Hearing aids	
Sports centre				Other facilities	

Categories are OSM key values
https://wiki.openstreetmap.org/wiki/Map_features, accessed 15 Aug 2024

4 RESULTS AND DISCUSSION

In the following section, the results obtained for the walkability of the inhabited areas in the study area using the original Walk Score classification framework (see Tab. 2) are presented.

Generally speaking, the walkability of Kaiserslautern neighbourhoods is not very high (see Tab. 3). Most grid cells are categorized as 'Car dependant', regardless of whether one takes sloping terrain into account or not. The number of grid cells classified as 'Walker's Paradise' remains unchanged when slopes are included in the calculations. The areas ranked as 'Very Walkable' and 'Somewhat walkable' decrease by –12.2 and –12.8 percent, respectively. The lowest classes of walkability 'Car dependent' show an increase in area size of +1.1 and +10.0 percent.

Table 2 Walk Score classification framework

Walk Score WS value	
90 - 100	*Walker's Paradise* Daily errands do not require a car
70 - 89	*Very Walkable* Most errands can be accomplished on foot
50 - 69	*Somewhat walkable* Some errands can be accomplished on foot
25 - 49	*Car Dependent* Most errands require a car
0 - 24	*Car Dependent* Almost all errands require a car

Source: https://www.redfin.com/how-walk-score-works, accessed 15 Aug 2024

Tab. 3 provides a statistical overview of walkability in the study area, with Fig. 2 visualising the results in their spatial context.

Table 3 Impact of pathway sloping on the Walk Score

Walk Score		*Number of grid cells*		*Difference 2D – 3D in percent*
		2D	*3D*	
90 - 100	Walker's Paradise	117	117	0
70 - 89	Very Walkable	286	251	–12.2
50 - 69	Somewhat walkable	765	667	–12.8
25 - 49	Car Dependent	1088	1100	+1.1
0 - 24	Car Dependent	1208	1329	+10.0

Unsurprisingly, Kaiserslautern's city centre achieves the highest WS values. The so-called Walker's Paradise encompasses an almost circular area with a diameter of more than one kilometre (each spot represents a 100 × 100 m grid cell), followed by a very walkable area in the city centre. The scores decrease as one moves further into the suburban settlements, ending in areas almost entirely dependent on motorized transport in some peripheral settlements. Some red spots are even visible in areas with high WS values. Data errors in the walking path network may be one reason for this, but other reasons cannot yet be ruled out. This issue must be investigated further on a case-by-case basis.

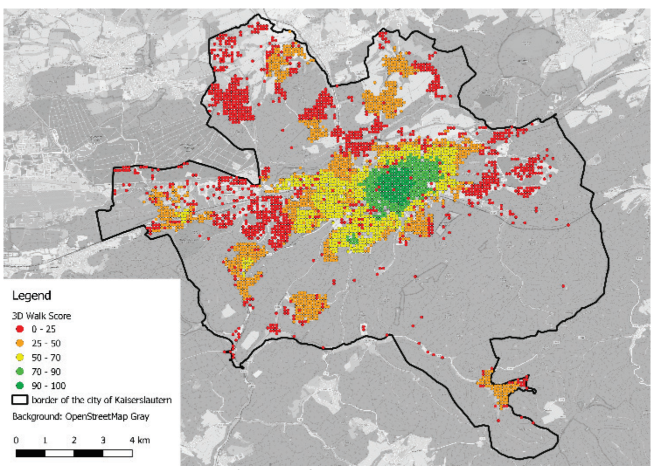

Figure 2 3D Walk Score values, in percent

The city extends in an east-west direction along a river valley; the inner city is flat, with sloping areas on both sides of the valley. The impact of slopes on the Walk Score shown in Fig. 3 reflects this situation. There is no apparent influence in the inner city, while in some areas the influence of slopes reaches values of up to 20 percent. The periphery, which tends to be less well-served anyway, is adversely affected by steeper walking routes. In some districts north of the city centre, WS values of less than 50 percent suffer an additional reduction of more than 10 percent and thus show even more clearly the disadvantageous situation, especially for older people.

Fig. 4 exemplifies the detailed insights that can be drawn from a high-resolution spatial analysis. The neighbourhood Hohenecken is one of Kaiserslautern's settlements detached from the contiguous inner city (see Fig. 2). Accessibility to services on foot is quite limited, but still available, with some errands being able to be done on foot, but most, if not almost all errands having to rely on other modes of transport.

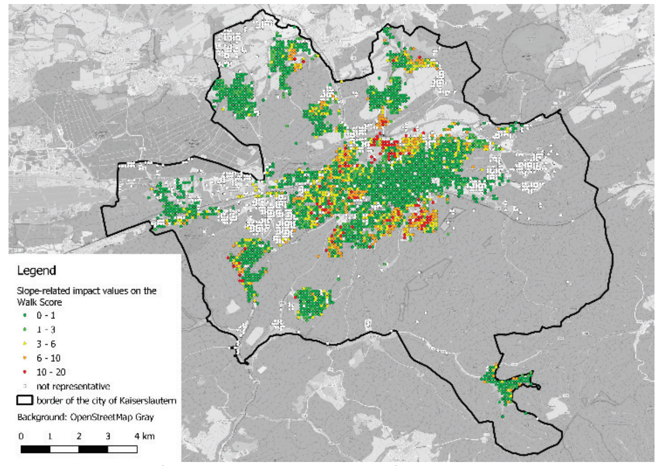

Figure 3 Slope-related impact on Walk Score values, in percent

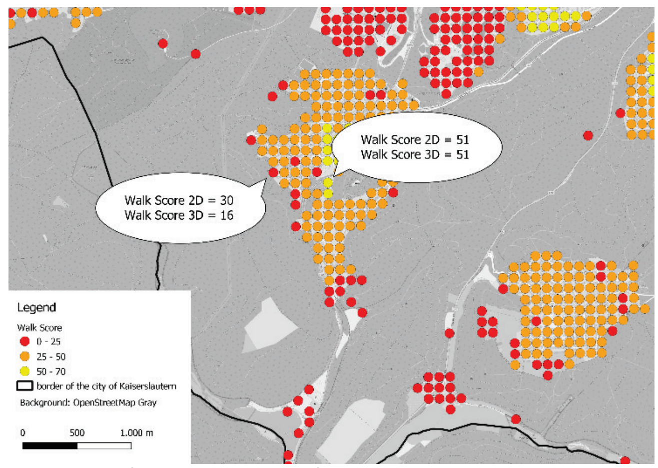

Figure 4 Walk Score in Kaiserslautern South Western neighbourhood Hohenecken

The marked cell in the centre of the village has a WS value of 51, the second marked cell on the western periphery only achieves a WS value of 30 without considering slopes, 16 with slopes included. The sharp decrease between the two cells is due to two reasons. The first is the location, the second is the slope. The location, about 500 metres west of the main service road, is for the major part the cause of the decrease, from WS value 51 down to WS value 30. But steep slopes in this area (see Fig. 1) account for another decrease, further reducing the WS value from 30 down to 16. The average effects of slopes listed in Tab. 3 provide an overall picture. However, when looking at the local situation, a different picture may emerge, namely a considerably higher impact not only of the location, but also of the slopes.

5 CONCLUSIONS AND FURTHER WORK

The results presented demonstrate that the slope of walking paths can have a significant impact on the accessibility of facilities such as shops and services on foot. This is a particular problem of senior citizens, who may be limited their ability to use different modes of transport and are therefore more dependent on reaching services by foot. The topographical conditions of the built-up areas of cities and municipalities are decisive factors that determine accessibility on foot. For the study area of the city of Kaiserslautern, the impact of terrain gradients amounts to more than 11 points out of a maximum of 100 points for the Walk Score value, which is an established indicator of walkability of areas. The peripheral areas of the city are particularly affected, which amplifies the negative impact of a typically low-density of services in these areas. The significant differences between 2D and 3D accessibility suggest that urban planning would benefit from a 3D perspective that more adequately considers the needs of all, but in particular the elderly. With the increasing use of the Walk Score WS in spatial planning, this becomes particularly relevant.

Whether there are differences between 2D and 3D analyses or how substantial these are must be examined individually for each real case scenario. In particular, the quality of available data on terrain slope and distribution of services must be examined in detail. While data on accessible roads and paths is generally available with sufficient accuracy, this cannot be assumed for the other required data. This issue must therefore be addressed separately in each case, as the quality of the initial data always has a decisive influence on the validity of the results obtained.

Further work is needed to investigate other factors that affect accessibility for older people in particular, such as the surface of the path, barriers that prevent use by people who rely on walking aids, the safety of crosswalks and more. In addition, the integration of barriers outside and inside buildings within walkabiltiy estimates should be considered in future. From the perspective of the individual senior citizen, it is probably of secondary importance whether the stairs that prevent access to the supermarket are located inside or outside a building. From a technical point of view, this requires improved interaction between building information models (BIM) and geospatial information models (GIM), which could enable integral accessibility analyses in the future.

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