Enhancing the Explainability of Urban Walkability Assessments. A 3D Visualization Approach for Elderly Accessibility in Germany

Markus SCHAFFERT, Konstantin GEIST, Mariyan STAMENOV, Klaus BÖHM, Germany

Key words: Walkability, Explainability, Geospatial Visualization. 3D representation

SUMMARY

Walkability metrics, such as the Walk Score, provide valuable insights into the accessibility of amenities but often fail to capture the specific barriers that are significant for different demographic groups. This paper presents a 3D visualization approach based on an adapted Walk Score tailored to the needs of elderly-friendly urban planning. This approach allows planners to visualize walkability metrics alongside demographic data in a single interface, contributing to a more nuanced understanding of the factors influencing walkability and supporting the development of focused interventions.

We apply the proposed visualization prototype to the district and city of Kaiserslautern, Germany. The case study demonstrates the feasibility of this approach. Integrating 3D visualizations into walkability assessments provides a critical information base that can help planners and decision-makers to develop solutions addressing the practical challenges of creating accessible and sustainable urban environments. It highlights the need for effective and understandable walkability metrics to enhance decision-making. However, the assumptions were made under laboratory conditions, and further comprehensive development for practical applications is still needed.

Enhancing the Explainability of Urban Walkability Assessments. A 3D Visualization Approach for Elderly Accessibility in Germany

Markus SCHAFFERT, Konstantin GEIST, Mariyan STAMENOV, Klaus BÖHM, Germany

1. INTRODUCTION

Pedestrian friendliness plays a pivotal role in the design of compact and accessible cities. It is often assessed using geographical network analyses, which are integral to many geographical information systems (GIS) or spatial database management systems. Such software helps generate the data that urban planners rely on to develop strategies for improving a city's walkability and optimizing the provision of key urban services.

Although they are based on similar algorithms, such as Dijkstra's algorithm, the assessment of walkability in urban planning differs significantly from routing applications used in vehicle or pedestrian navigation. The latter focuses on the individual user, answering questions like, "How long will it take me to walk to the selected restaurant?" or "What is the shortest route to this destination?" In contrast, urban walkability assessments usually involve aggregated analyses. A prominent example is the Walk Score (WS), which provides an overall assessment of a city, neighbourhood, or grid cell by evaluating the accessibility of multiple facilities starting from this spatial unit. For instance, a supermarket within reach is one instance in the broader "supermarket" category, and is placed into a weighted context alongside other instances from this and other categories. This aggregation allows urban planners to identify underserved areas efficiently. However, the aggregated nature of these analyses often compromises their explainability, necessitating additional detailed insights to pinpoint exactly which facilities are missing and where.

Another key difference between routing applications and walkability analyses is the consideration of the third dimension. While pedestrian or bicycle navigation applications routinely account for 3D information, such as elevation changes, walkability metrics have only recently begun to incorporate this dimension. Most studies of urban walkability, whether in research or practice, still rely on a flat road or path network. However, factors beyond short distances, such as 3D obstacles like slopes or stairs, can significantly affect the accessibility for older individuals who use mobility aids such as walkers (Schaffert et al. 2023; cf. Bayar & Yilmaz 2023). The gradual integration of 3D information into accessibility assessments reflects growing awareness of the needs of specific population groups, such as seniors (Alves et al., 2020; Merlin & Jehle, 2023). This shift aligns with the "no one left behind" principle of the Sustainable Development Goals (SDGs), which increasingly influences urban development strategies (Bárcena-Martín & García-Pardo, 2022).

Approaches that already integrate the third dimension into urban walkability metrics (e.g., Müller et al., 2024; Jano Reiss & Tchetchik, 2024) utilize 3D data such as Digital Elevation Models. This data is processed through slope calculations and combined with other spatial datasets, such as road objects from OpenStreetMap (OSM) or population data from official census sources. These operations primarily fall within the first three stages of the four-step IMAP workflow—Integration, Management, and Analysis—which is crucial to GIS (Bill, 2016; Clemen & Gründig, 2007). However, the potential of the fourth stage, Presentation, particularly in the context of 3D visualization, remains underexplored when applying walkability metrics. Despite the recognition that 3D geospatial visualizations can significantly enhance the understanding and acceptance of planning initiatives (e.g., Wissen et al., 2009), this potential is not fully realized.

This article proposes a 3D visualization component for walkability assessment to address this gap. We extend the WS for the elderly, as proposed by Schaffert et al. (2023), by incorporating terrain and barrier information through a comprehensive visualization approach. The value of 3D visualization is demonstrated by its ability to simultaneously display accessibility metrics alongside demographic data. Furthermore, we enhance the explainability of the WS for the elderly by supplementing its 3D visualization with detailed views of the individual aspects that contribute to the aggregated WS values. The results show that the WS's strength—its simplicity and suitability for comparative walkability information—can be combined with improved explainability through detailed insights into the WS components, all within a single visualization module. We illustrate the feasibility of this approach using the city and district of Kaiserslautern, Germany.

2. METHODOLOGY AND ILLUSTRATION SITE

2.1 Walkability measurements

The accessibility of shopping facilities and essential services is an important factor for the quality of life of residents at various locations within a city. Therefore, metrics for calculating walkability are gaining increasing interest in urban planning. The walkability index of the ILS – Institut für Landes- und Stadtentwicklungsforschung (Schmitz et al. 2023), for example, is based on the approach of Dobenyšová/Křivka (2012). The latter index consists of four components: 1) density of road intersections 2) household density, 3) the distribution of land uses and 4) the share of retail and commercial areas as destinations for pedestrian mobility.

The ILS approach complements these four components with walking distances to facilities such as supermarkets and schools on a road or path network.

Such networks also form the basis of the alternative WS methodology (Walk Score 2011; Yang et al. 2023). The WS evaluates pedestrian accessibility by considering the proximity to various facilities such as bookstores, libraries, schools, parks, restaurants, and music stores (Hall & Ram 2018). These facilities are assigned specific weights (Horak et al. 2022), reflecting their relative importance in determining the walkability of an area. Additionally, the WS includes a distance function that ensures amenities closer to the assessed location are given more weight. All relevant facilities or service locations that can be reached within a walking time of 20 minutes are taken into account.

By using factors depending on the facility/service category and the distance, variable use scenarios can be modelled (Schaffert et al. 2023). The final score is given as a percentage value compared to the optimal accessibility by summing up all facilities to be reached together with their weight.

$$\frac{\sum(Weight_{Facility} \times Weight_{Distance})}{\sum_{MAX}(Weight_{Facility})} \times 100$$

Figure 1 illustrates an example of a WS calculation displayed on a 2D map. The centroids of the underlying grid serve as the reference points for this calculation. Each grid cell is colour-coded into five categories (0-24, 25-49, 50-69, 70-89, 90-100), with the WS indicated for each cell.

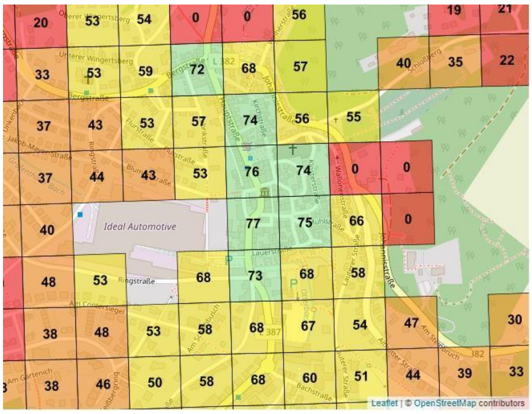

Fig. 1: Walk Score values – displayed within grids

The original WS has been designed with a North American context in mind and provides, just as the ILS´s walkability index, estimates based on an average citizen without focusing on specific population groups. The adaptation of the WS for the elderly (Schaffert et al. 2023) addresses this gap by incorporating walking times for seniors and identifying categories particularly relevant to them. Such categories include, for instance, bus stations, doctors, pharmacies, supermarkets, etc. Additionally, the model integrates gradients on the road network and other age-related barriers, such as stairs. For incline calculations, an official Digital Elevation Model with high spatial resolution is used, while OpenStreetMap (OSM) data is employed for modelling streets, barriers, and facilities. The selection of categories, the weightings, and other model assumptions, such as walking times, can be found in Schaffert et al. (2023) for further reference.

We have designed both the visualization concept that we describe in the following, and a prototypical 3D-visualization client (illustrated in section 3) for supporting urban planners or GIS experts in applying the WS for the elderly and communicating its results to other planners, and local decision-makers.

2.2 Visualization concept

For the visualization, we use a 3D cartographic representation that combines the WS with additional data, such as the number of inhabitants in the area under investigation. In Figure 2, the WS results are presented by colour coding, while other data is illustrated by height extrusions. This approach benefits from the z score, which adds an additional dimension of information that remains clear in a spatial context despite increasing complexity. Depending on the application and data set, alternative visualization techniques may be more effective. For example, using colour gradients and square (exaggerated) extrusions instead of colour categories and linear extrusions could provide more insightful results. Such alternatives can also be offered in the approach and are considered in the concept, although the current prototypical implementation described in the article focuses on the combination of spatial (x,y) and attribute values (z) by simple extrusion.

Another central idea in our concept is the interactive drill-down to understand the parameters influencing the displayed result. Following the principle of "Overview First - Details On Demand" (Shneiderman 1996), the process begins with a general 3D visualization. In the upper layer of Figure 2, following this principle, elevation and colour coding are used to make the interplay between WS (e.g., colour representation) and demographics (e.g., z-value or height to indicate the proportion of older people) easily understandable at a glance. Locations that are noteworthy for a planner due to the combination of their WS and demographic values (e.g., many seniors and poor accessibility), as marked by a blue arrow, can now be examined in more detail: The aggregated WS for this location can be visually broken down (middle layer in Figure 2). Selecting the location displays detailed information on the factors contributing to the WS calculation. This includes the representation of individual routes and the associated instances of a category, such as all supermarkets, which can be reached within 20 minutes and serve as potential destinations. The representation can be complemented by offering additional details, such as route length or the name of a facility. Additional layers, such as the lowest layer in Figure 2, can be added and displayed within the same client, thereby further increasing the information available.

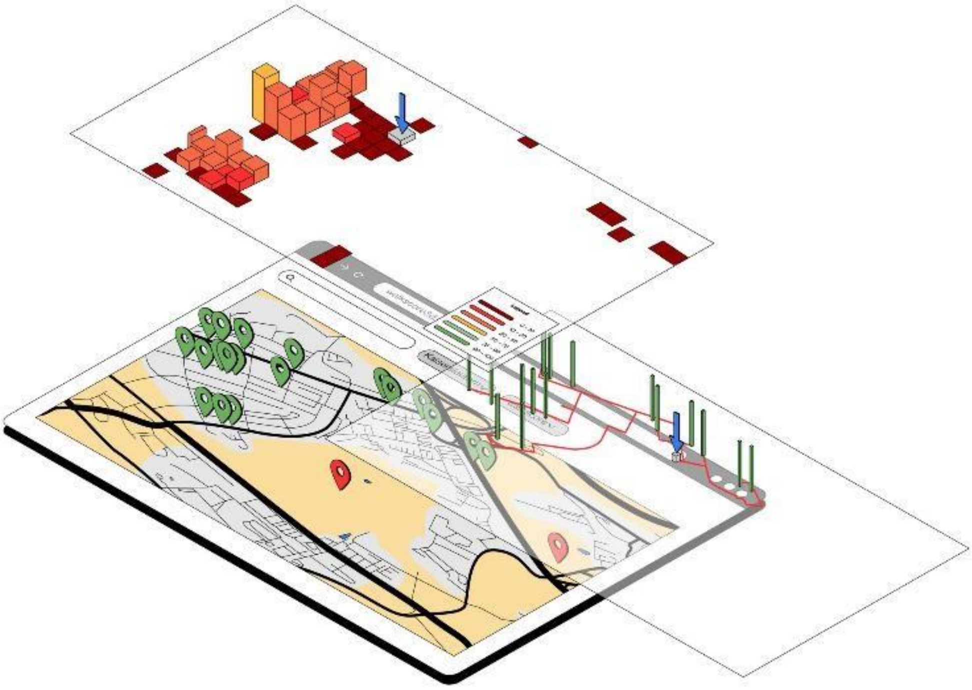

Fig. 2: Visualization Concept showing information layers

2.3 Illustration site

The county district (Landkreis) of Kaiserslautern is located in the German federal state of Rhineland-Palatinate. It has just over 100,000 inhabitants. The district stretches over a length of around 40 kilometres from west to east and around 30 kilometres from north to south. The highest elevation is 528 metres above sea level (two kilometres south of Johanniskreuz near Steinberg). The lowest point of the district is around 205 metres above sea level and is located near Olsbrücken. The district surrounds the city of Kaiserslautern, which is not part of the district and is one of the larger cities in Germany with just under 100,000 inhabitants.

In many studies so far, walkability is assessed in urban areas. Carrying out such analyses in an entire, partly rural district and visualizing the results both for the city and for the much smaller municipalities in the surrounding area is still the exception rather than the rule and represents a specific challenge.

3. IMPLEMENTATION

To prove the concept, we calculated the Walk Scores of the illustration site and stored them in a PostgreSQL database. As data basis for the calculation served the road network as well as available facilities from OSM. The PostgreSQL extension pgRouting was used for the route calculation. As spatial reference points for calculating the WS we used the centroids of the 100 by 100-meter grid cells that comes with the data of Germanys Census (from 2011). Additionally, the number of seniors (65 years and older) can be extracted from this data set for each geometry. All data is retrieved via a web service and displayed in a 3D web application using ThreeJS. A map from OSM, which is provided as a OGC Web Map Service (WMS) and projected as an image onto a plane in ThreeJS, serves as the map basis for the application (Figure 3). A particular challenge is the conversion of geographic coordinates into the local coordinate system of ThreeJS. This depends on the size of the map section and the respective positioning in the local system. In addition, it must be considered that in many geographic coordinate systems, such as WGS84, different distortions occur in the X and Y directions. A further previous transformation into a projected coordinate system can eliminate this problem.

The Walk Score values are displayed for every cell of the 100 by 100-meter grid and shown as a layer over the base map. By applying extrusion and colour-coding, it is possible to integrate two different datasets. For instance, the WS can be represented through colour categories, while extrusion can reflect the number of people in each grid cell, allowing for the identification of areas with poor accessibility and high population density (see Figure 4). By reducing the opacity of the 3D columns, it is possible to make the underlying base map visible and identify the geographic location of each grid cell.

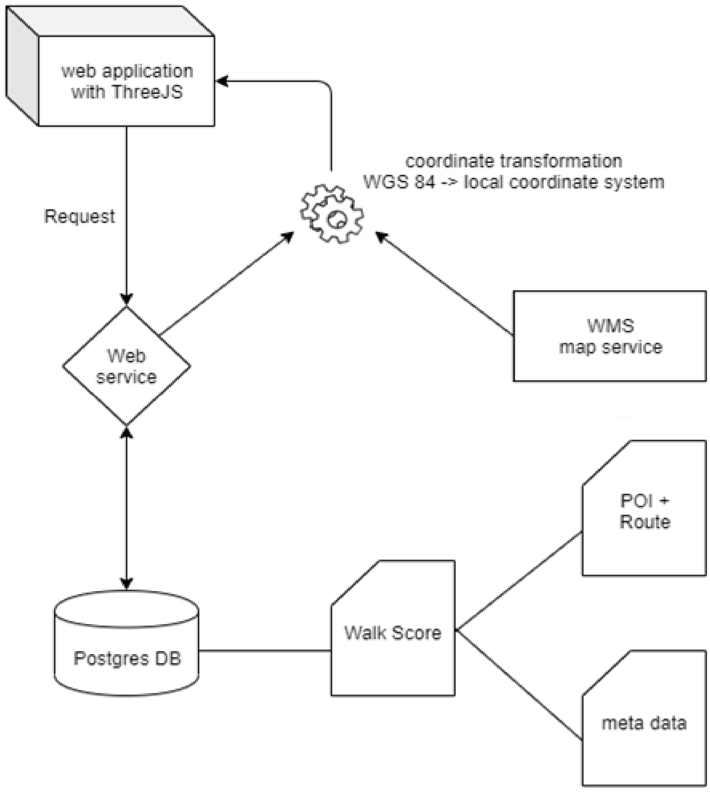

Fig 3. Software Architecture

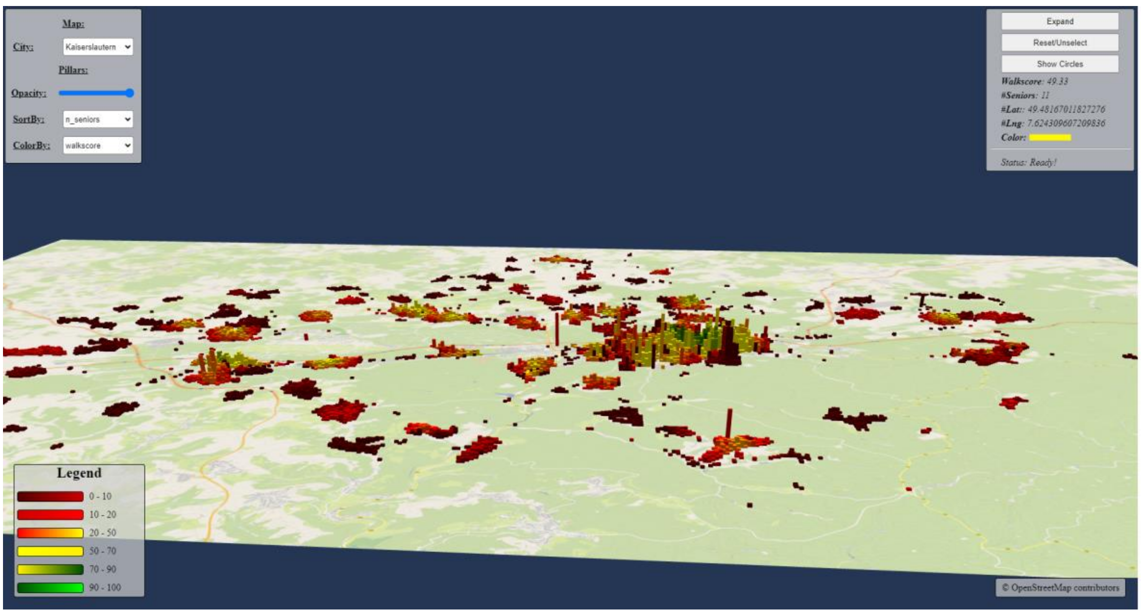

Fig. 4. 3D web client. WS and population figures for the country district and the city of Kaiserslautern.

The map can be zoomed in to focus on WS information for specific areas, as demonstrated in Figure 5 for the city of Kaiserslautern. This detailed view uncovers spatial differences that may be obscured in the broader representation and would be challenging to identify otherwise. Similarly, the software offers the option to change the orientation of the web map from the default north-facing view. This allows, for instance, users to see WS values for the northern part of Kaiserslautern. These areas on the city´s periphery have lower WS values (indicated by reddish colours) but are home to a relatively young population, which is important information for urban planners. Planners could now use this knowledge to prioritize areas in the southeast of the city where low WS values coincide with a comparatively large older population.

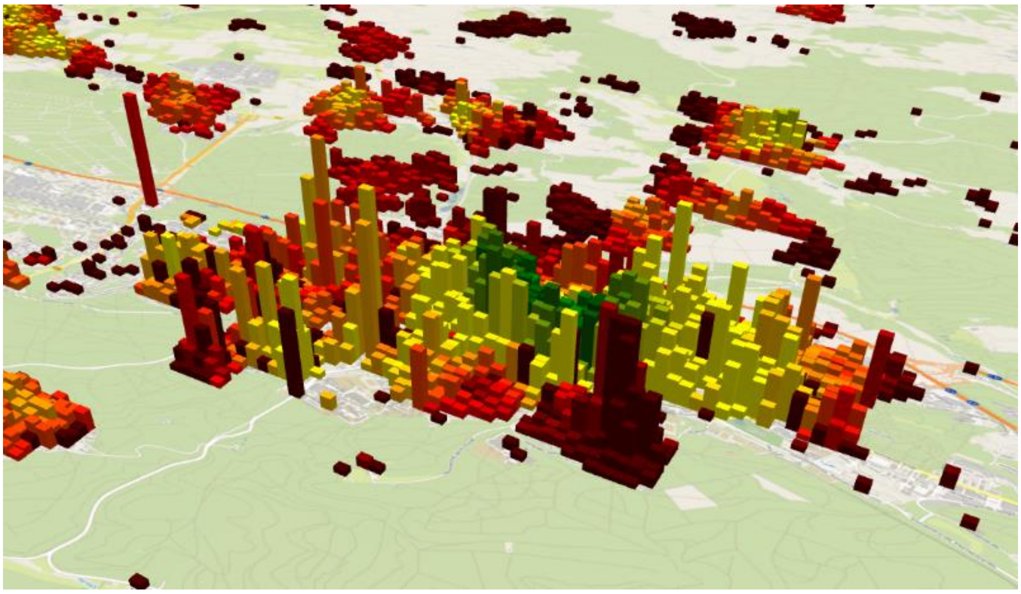

Figure 5. WS and population figures for the city of Kaiserslautern

In addition to the overall display, it is possible to examine individual grid cells in more detail and to visualize the influencing parameters of the WS. For this purpose, a detailed view can be called up by selecting any column. As soon as this is executed, all other grid cells become invisible and all reachable facilities from a location as well as their route are loaded from the database. Routes are added to the map one at a time to give the user feedback on the amount of data. After all routes are visible, all facilities or service locations are visualized by cloumns on the map, analogous to the overall overview but in a smaller size (Figure 6). The reference column (grey column in the middle) should be displayed at an appropriate size to avoid occlusion and to visually stand out from the facilities. In the case of shopping malls or large commercial buildings, facilities may have a similar position and may obscure each other. In this case, a slight shift in position is unavoidable.

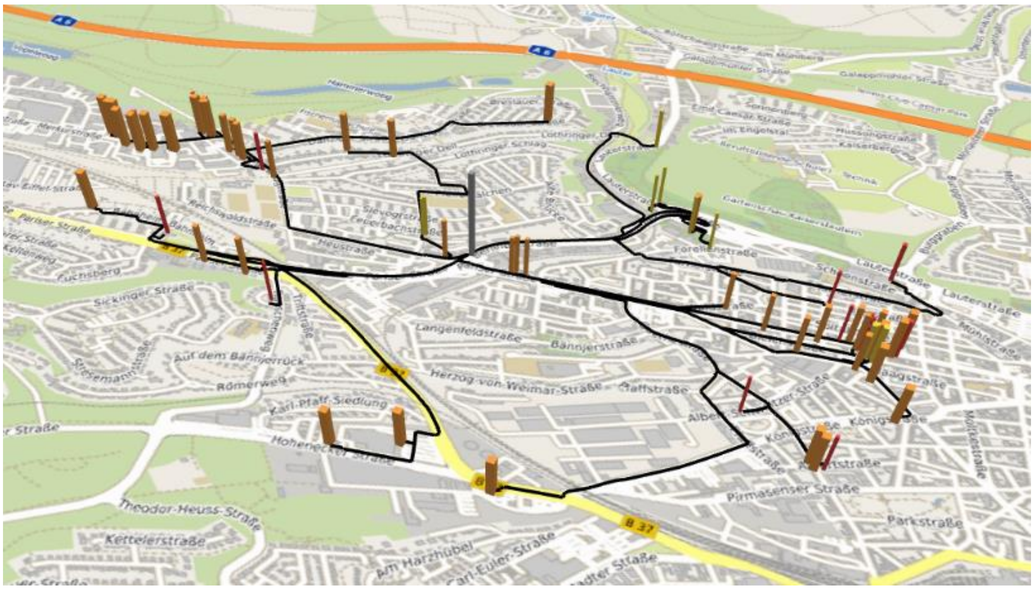

Figure 6. Detail view in the city of Kaiserslautern

In this detailed view, the colour distinction as well as the height of the extrusions are the decisive factors. The colour reflects to which category each facility belongs to and the extrusion indicates which influence a certain facility instance has on the result of the WS index. In Figure 6, for example, red columns stand for the category "entertainment/recreation/sports" (Schaffert et al. 2023), such as restaurants. The grey column in the middle represents the selected column. The impact is calculated based on the adjustment of the original walk score to meet the needs of older people. In this model, all categories together sum to a score of 100, with basic services such as bakeries or supermarkets given a higher weight of 30 than services like hairdressers or post offices, which were given a weight of 12. In addition, the distance of the instances of a category to the starting point is taken into consideration. In this way, all supermarkets that are reachable within a 20-minute walk go into the calculation, but a nearby supermarket to a greater extent than distant ones (see Schaffert et al. 2023).

For each facility, additional data influencing parameters, such as facility name, facility category, coordinates, and route length, can be displayed by selection. In Figure 7, we selected a specific restaurant in the detailed view, causing the corresponding column to change from red to grey in the display, and an additional information window to appear. Additionally, it is possible to highlight the route in green. This is necessary because the route is not always visible due to overlapping with other routes. The overlapping of the routes is also the reason that the route has to be moved slightly upwards.

Figure 7. Detail view and information window.

4. DISCUSSION

We believe that the proposed visualization approach provides a more comprehensive understanding of the accessibility and supply situation of urban spaces, offering greater insight than a display showing only the WS values in 2D. However, the proposed methodology has several limitations, both in terms of the basic model for calculating the WS and the usability of the 3D client. The WS for the elderly was modeled under several assumptions (see Schaffert et al. 2023). For instance, the selection and weighting of facilities and service locations relevant to the elderly were based on earlier studies that provided rather generic information, without detailed local investigations. Further limitations arise from the quality of the datasets used. In particular, OSM data was used not only for the road network, which has shortcomings in the completeness of entries related to amenities, such as care facilities (cf. Brückner et al. 2021).

The 3D client, currently a prototype developed in an academic context, presents several usability issues that must be addressed before it can be adapted for practical use. Initial shortcomings, such as unsuitable font choices and unclear labels (e.g., "n-seniors"), are evident but relatively easy to fix. However, the deployment of this tool in municipal practice may introduce requirements that are less relevant in academic settings, such as integrating the municipality’s logo and considering corporate identity guidelines of municipalities.

More fundamental technical iterations may be additionally necessary. A notable current limitation is the time-consuming loading time for route calculations in the detailed view, which must be addressed before practitioners can adopt the tool. While these technical refinements, which can be evaluated and improved within the lab environment, are important to solve, the most crucial step towards practical application is gathering user feedback. Without insights from planning practitioners, the prototype is unlikely to be taken seriously or considered ready for professional use (cf. Geertman & Stillwell 2020). The gap between academic development and practical application remains significant. To close this gap, early collaboration with practitioners is essential. Only through concrete discussions can the prototype be further refined to meet actual needs and optimize it for specific local challenges. This step is urgent, especially in the context of climate change and sustainability, where time is of the essence. Prototypes, such as the one presented in this paper, are critical tools for fostering dialogue and ensuring that solutions are aligned with practical demands (Kindsvater & Schaffert 2022).

5. CONCLUSION

The integration of 3D visualization techniques into urban walkability assessments marks a significant advancement in the field of urban planning, particularly in addressing the accessibility needs of vulnerable populations such as the elderly. This approach not only enhances the explainability of walkability metrics but also provides urban planners with a more comprehensive understanding of the spatial dynamics that influence pedestrian mobility. By visualizing complex data, including terrain variations and infrastructural barriers, planners can make informed decisions that promote inclusivity and improve the quality of life in urban environments. The insights gained from 3D visualizations can guide targeted interventions that address specific challenges faced by different demographic groups, ensuring that no one is left behind in the urban development process. Furthermore, the ability to present aggregated walkability scores alongside detailed information about individual amenities allows for a more nuanced analysis of urban accessibility, enabling planners to identify underserved areas and prioritize improvements.

In the future, it is crucial to bridge the gap between academic research and practical application. Engaging with municipal practitioners early in the development of 3D visualization tools will be essential for refining prototypes to meet real-world needs. User feedback will play a vital role in enhancing usability and ensuring that the tools align with the operational requirements of urban planning departments.

REFERENCES

Alves, F., Cruz, S., Ribeiro, A., Bastos Silva, A., Martins, J., & Cunha, I. (2020). Walkability index for elderly health: A proposal. Sustainability, 12(18), 7360.

Bárcena-Martin, E., & García-Pardo, F. (2022). An axiomatic approach to measure the 'Leave no one behind'principle. Fuzzy Sets and Systems, 447, 147-154.

Bayar, R., & Yılmaz, M. (2023). Measuring age-friendliness based on the walkability indices of older people to urban facilities. Urban Design International, 28(1), 35.

Bill, R. (1995). Spatial data processing in environmental information systems. In Environmental Informatics: Methodology and Applications of Environmental Information Processing (pp. 53-73). Dordrecht: Springer Netherlands.

Brückner, J., Schott, M., Zipf, A., & Lautenbach, S. (2021). Assessing shop completeness in OpenStreetMap for two federal states in Germany. AGILE: GIScience Series, 2, 1-7.

Clemen, C., & Gründig, L. (2007). The imap principle in building information systems. Proceedings of XXX FIG Working Week. Hong Kong.

Dobešová, Z., Křivka, T. (2012): Walkability index in the urban planning: A case study in Olomouc city. In: Burian, J. (Hrsg.): Advances in Spatial Planning. London, 178–196. https://doi.org/10.5772/36587.

Geertman, S., & Stillwell, J. (2020). Planning support science: Developments and challenges. Environment and Planning B: Urban Analytics and City Science, 47(8), 1326-1342.

Hall, C. M., & Ram, Y. (2018). Walk score® and its potential contribution to the study of active transport and walkability: A critical and systematic review. Transportation Research Part D: Transport and Environment, 61, 310-324.

Horak, J., Kukuliac, P., Maresova, P., Orlikova, L., & Kolodziej, O. (2022). Spatial pattern of the walkability index, walk score and walk score modification for elderly. ISPRS International Journal of Geo-Information, 11(5), 279.

Jano Reiss, M., & Tchetchik, A. (2024). Facilitating Walkability in Hilly Terrain: Using the Geodesign Platform to Integrate Topographical Considerations into the Planning Process. In Geodesigning Our Future: Urban Development Dynamics in Israel (pp. 109-130). Cham: Springer International Publishing.

Kindsvater, M., & Schaffert, M. (2022) Mapping tranquil landscapes with social media data. A case study in the context of sustainable transformation. FIG Peer Review Journal. Copenhagen. 2022 S. 1-19.

Merlin, L. A., & Jehle, U. (2023). Global interest in walking accessibility: a scoping review. Transport reviews, 43(5), 1021-1054.

Müller, H., Geist, K., Schaffert, M., Böhm, K. (2024). Influence of 3d barriers on walkability for the elderly. Tehnički glasnik 18, https://doi.org/10.31803/tg-20240907113323.

Schaffert, M., Geist, K., Albrecht, J., Enners, D., & Müller, H. (2023). Walk Score from 2D to 3D—Walkability for the Elderly in Two Medium-Sized Cities in Germany. Isprs International journal of geo-information, 12(4), 157, https://doi.org/10.3390/ijgi12040157.

Schmitz, J., Fina, S., & Gerten, C. (2023). Wie fußgängerfreundlich sind deutsche Großstädte? Neue Ergebnisse aus der Walkability-Forschung. Raumforschung und Raumordnung/Spatial Research and Planning, 81(4), 327-341.

Shneiderman, B. 1996. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. Proceedings 1996 IEEE Symposium on Visual Languages, 1996, doi: 10.1109/VL.1996.545307.

Walk Score. 2011. Walk Score Methodology. http://pubs.cedeus.cl/omeka/files/original/b6fa690993d59007784a7a26804d42be.pdf

Wissen, U. (2009). Virtuelle Landschaften zur partizipativen Planung: Optimierung von 3D-Landschaftsvisualisierungen zur Informationsvermittlung (Vol. 5). vdf Hochschulverlag AG.

Yang, Y., Qian, Y., Zeng, J., Wei, X., & Yang, M. (2023). Walkability measurement of 15-minute community life circle in Shanghai. *Land*, *12*(1), 153.

Zhou, Q. & Homma, R. 2022. Estimating Walk Score and Examining Its Association with Safety Factors of Neighborhood Environment in Kumamoto, Japan. International Review for Spatial Planning and Sustainable Development.

BIOGRAPHICAL NOTES

Markus Schaffert, ORCID: 0000-0002-7970-9164, https://i3mainz.hs-mainz.de/team/markusschaffert/

Konstantin Geist, ORCID: 0000-0002-2753-7655, https://i3mainz.hs-mainz.de/team/konstantingeist/

Mariyan Stamenov, https://www.i3mainz.hs-mainz.de/team/mariyanstamenov/

Klaus Böhm, https://i3mainz.hs-mainz.de/team/klausboehm/

CONTACTS

Markus Schaffert
I3mainz, Hochschule Mainz
Lucy-Hillebrand-Str. 2
55128 Mainz
GERMANY

markus.schaffert@hs-mainz.de
https://i3mainz.hs-mainz.de/team/konstantingeist/