University of Münster

Department of Information Systems

Walking Accessibility to Supermarkets in Münster: A District- and Cell-Level Analysis of Accessibility Patterns and Elderly Vulnerability

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Abstract

This paper examines walking accessibility to supermarkets in Münster and investigates how accessibility varies across statistical districts with a specific focus on elderly residents. Using 100-m grid cells, an OpenStreetMap-based network, r5py-based routing and statistical district boundaries, the analysis first calculates cell-level accessibility indicators, including walking time to the nearest supermarket and the number of supermarkets reachable within 15 minutes. These indicators are then aggregated to the district level using population-weighted area assignments. The results show clear spatial differences in supermarket accessibility across Münster. Districts with higher population density tend to have shorter walking times and more supermarkets reachable within 15 minutes. A regression-based under-/overperformance analysis further identifies districts that deviate from this general density-accessibility relationship. Finally, the paper considers potential accessibility vulnerabilities for elderly residents by linking the spatial distribution of older population groups with poor walking accessibility. The findings reveal unexpected accessibility outliers and critical districts, demonstrating that supermarket accessibility cannot be explained by centrality alone.

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1 Introduction

Health and environmental problems associated with car-dependent urban structures, such as rising obesity and air pollution (Lelieveld et al., 2020; Phelps et al., 2024), have intensified the search for planning concepts that foster healthier and more sustainable ways of living. Improving walking accessibility to everyday destinations is increasingly regarded as an important component of such urban development, as it can encourage active mobility while reducing dependence on private cars (Baobeid et al., 2021). Among these destinations, supermarkets occupy a particularly important role. Although many cities provide generally good access to food retail, walking accessibility may still vary considerably between neighbourhoods. Such spatial differences are particularly relevant for older residents, whose daily mobility may be constrained by reduced physical mobility or limited access to private cars. Identifying critical areas with comparatively poor access to supermarkets therefore contributes to a better understanding of potential inequalities in everyday accessibility. Against this background, this paper investigates walking accessibility to supermarkets within the city of Münster and thereby addresses the following research questions:

1. How does walking accessibility to supermarkets vary across Münster's neighbourhoods?

2. Where do older residents face particular accessibility vulnerabilities?

To answer these questions, a network-based accessibility analysis is conducted using population grid data, supermarket locations, senior facility locations and the street network of Münster. Accessibility indicators are calculated at the grid-cell level and subsequently aggregated to statistical districts. In addition, accessibility patterns for elderly residents are analysed using three-dimensional visualisations. The results indicate that Münster generally provides comparatively good walking accessibility to supermarkets. Nevertheless, clear spatial differences exist between neighbourhoods, and several locations with concentrations of older residents experience comparatively poor accessibility. By providing a detailed neighbourhood-level assessment, this study contributes empirical evidence on supermarket accessibility within a medium-sized city and demonstrates how combining population distribution with accessibility measures can support the identification of vulnerable areas.

The subsequent sections are structured as follows: First, Chapter 2 reviews the relevant literature and develops the theoretical background of the study. Chapter 3 presents the data sources and methodological approach. Chapter 4 reports the em-

pirical results of the accessibility analysis, which are then discussed in Chapter 5. Finally, Chapter 6 concludes the paper and outlines the main implications.

2 Related Work

As outlined in the introduction, walking accessibility to everyday destinations is an important component of healthier and more sustainable urban development. This idea is reflected in the 15-minute city concept, in which Moreno et al. (2021) emphasise that residents should be able to access essential everyday destinations within a 15-minute walk or bicycle ride. Within this framework, walkability represents a key characteristic of successful neighbourhoods, as it enables residents to accomplish daily activities on foot while reducing dependence on motorised transport. Baobeid et al. (2021) confirm and broaden this perspective by showing that walkability is not only relevant for mobility behaviour, but also contributes to public health, environmental sustainability and urban vitality.

Among the various destinations that contribute to neighbourhood walkability, supermarkets play a particularly important role. Previous research has therefore already examined walking accessibility to supermarkets in different contexts. Apparicio et al. (2007) showed that different accessibility indicators capture different dimensions of supermarket accessibility and may therefore lead to different conclusions regarding neighbourhood accessibility. Hosford et al. (2022) evaluated walking and cycling accessibility to grocery stores in the context of the 15-minute city in Vancouver and found inequalities in access across populations and neighbourhoods. Christofa et al. (2023) further showed that food accessibility varies strongly by transportation mode, with driving providing substantially higher and more equitable access than walking, cycling, or public transit. Their findings indicate that households without access to a car are particularly disadvantaged, highlighting the importance of evaluating supermarket accessibility from a non-automobile perspective. In a more recent study, Hartung et al. (2025) find that perceived walking times to supermarkets largely correspond to objectively measured distances and that both measures are strong predictors of older residents' satisfaction with local shopping opportunities. These findings support the use of objective, network-based accessibility measures as a valid approach for assessing supermarket accessibility among residents. That walking accessibility to supermarkets remains a relevant challenge is further shown by Horton et al. (2025), who demonstrate that many cities in the U.S. would require substantial numbers of additional grocery outlets to achieve walkable access to food provision.

Taken together, previous research has examined supermarket accessibility from multiple perspectives. However, comparatively little attention has been paid to how walking accessibility varies within a medium-sized city at the neighbourhood level. In particular, evidence on local spatial differences between neighbourhoods and their

implications for older residents remains scarce. A detailed neighbourhood-level assessment is therefore needed to identify areas where good city-wide accessibility may conceal local accessibility disadvantages. This study addresses this gap by analysing network-based walking accessibility to supermarkets across Münster at both the census grid-cell and statistical district levels.

3 Methodology

3.1 Data Collection

Population data were obtained from the German Census 2022[1], which provides population information on a 100 m × 100 m grid. For each grid cell, the dataset includes the centroid location, the total population, and age-specific population counts in ten-year age groups, ranging from 0–9 years up to 70–79 years, with the oldest group reported as 80 years and above.

Senior facility locations were collected manually from current information provided by the City of Münster[2]. For each facility, the name, address, geographic coordinates, and capacity were recorded, and all locations were checked manually to ensure that they fall within Münster's statistical district boundaries.

Supermarket locations were extracted from current OpenStreetMap data using OSMnx within a 2 km buffer around Münster's outer district boundary. Polygon geometries were converted into representative points using GeoPandas and Shapely for use as routing destinations.

To enable a neighbourhood-level analysis of supermarket accessibility, the study uses Münster's 45 statistical districts as spatial reference units. The corresponding boundary data were obtained from the Open Data Portal of the City of Münster[3] and reflect the current official district structure. These polygon geometries form the basis for all district-level calculations and visualisations.

The walking network used for the routing analysis was derived from OpenStreetMap data and extracted via BBBike[4], a platform that allows OpenStreetMap data to be downloaded for a selected geographic area. This network provides the basis for calculating walking travel times from both population grid-cell centroids and senior facility locations to supermarkets.

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1 Statistisches Bundesamt (2025). *Zensus 2022: Alter in 10er-Jahrsgruppen in Gitterzellen.* https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Zensus2022/_publikationen.html#1403950 (accessed 6 June 2026).

2 Stadt Münster (2026). *Alten- und Pflegeheime in Münster.* https://www.stadt-muenster.de/pflege/leben-im-alten-und-pflegeheim/alten-und-pflegeheime-in-muenster (accessed 19 June 2026).

3 Stadt Münster (2021). *Geokoordinaten der Stadtteil-Grenzen / Geometriedaten der kleinräumigen Gebietsgliederung.* https://opendata.stadt-muenster.de/dataset/geokoordinaten-der-stadtteil-grenzen-geometriedaten-der-kleinr%C3%A4umigen-gebietsgliederung-5 (accessed 6 June 2026).

4 BBBike (2026). *OpenStreetMap Network of Münster.* https://extract.bbbike.org/ (accessed 6 June 2026).

3.2 Data Preparation

Before the accessibility analysis could be conducted, the datasets had to be cleaned, spatially harmonised, and transformed into a common analytical structure. In the Census data, some values were represented by hyphens instead of numerical values. These hyphens were replaced with zeros to allow consistent numerical processing. The Census grid data were then combined with the statistical district boundaries. Grid-cell polygons were reconstructed from the Census centroids and intersected with the district boundaries. For cells overlapping multiple districts, population values were assigned proportionally according to the respective area shares, following area-weighted areal interpolation (Goodchild & Lam, 1980). Shares outside Münster were not reallocated. The district-specific population contribution of each grid cell was calculated as follows:

$$P_{i,d}^{g} = s_{i,d} \cdot P_{i}^{g}$$

with $P_{i,d}^{g}$: population of group g assigned from grid cell i to district d,
$s_{i,d}$: area share of grid cell i located within district d,
P_{i}^{g} : total population of group g in grid cell i.

The population group g refers either to the total population or to one of the age-specific Census groups provided in ten-year intervals. After the proportional allocation to districts, these age-specific values were aggregated to derive broader population groups, such as residents aged 60 and above, 70 and above, 80 and above, and under 60. The prepared dataset therefore combines district geometries, grid cell geometries, total and age-specific population values, and proportional area shares in one analytical structure.

3.3 Data Analysis

The core of the analysis is the calculation of walking accessibility to supermarkets. Accessibility was first measured at the level of Census grid cells and then aggregated to the district level. Each grid cell centroid was used as an origin point, while the supermarket point locations were used as destinations. Walking travel times were calculated with r5py (Fink et al., 2022) using the OpenStreetMap-based walking network. r5py was chosen because it has been used in previous accessibility studies and is designed for large-scale routing analyses involving many origin-destination combinations (Fink et al., 2024; Hosford et al., 2022; Willberg et al., 2024). In addition, it provides routing-related functionality such as snapping origins and destinations to the street network, which is relevant when point locations are not located directly

on network edges or nodes (r5py contributors, 2026). To compare supermarket accessibility across districts and population groups, two accessibility indicators were defined:

I_1 : walking time to the nearest supermarket

I_2 : number of supermarkets reachable within 15 minutes on foot

Similar to Hartung et al. (2025), I_1 captures basic proximity to food retail infrastructure by focusing on the nearest supermarket. Following the cumulative-opportunities approach used by Hosford et al. (2022), I_2 counts the number of supermarket destinations reachable within a predefined walking-time threshold. It therefore captures not only whether a supermarket is nearby, but also the degree of choice available to residents within a reasonable walking distance, using a 15-minute threshold that reflects the logic of the 15-minute city concept (Moreno et al., 2021). Since some grid cell centroids are not located directly on the walking network, origin points had to be connected to the network before routing. Following the functionality provided by r5py (r5py contributors, 2026) and similar routing procedures used in previous accessibility research (Fink et al., 2024), each centroid was snapped to the nearest walkable network point. The distance between the original centroid and the snapped network point was included in the final travel time by converting it into an additional walking time using the Euclidean distance and an assumed walking speed of 1.4 metres per second, corresponding to approximately 5 km/h. This provides a practical approximation for connecting off-network origin points to the walking network, with its methodological limitations addressed in Chapter 6. In total, 6,845 grid cell centroids and 115 supermarkets were included, resulting in 787,175 origin-destination combinations. For each grid cell without a valid route, the centroid was shifted in eight directions at one-metre intervals up to 49 m until a valid route was found. The corrected route was then used for the accessibility analysis. The resulting cell-level accessibility indicators were mapped to analyse the spatial distribution of supermarket accessibility across Münster.

In a second step, the cell-level accessibility values were aggregated to the district level using a population-weighted average, following an established approach in accessibility research that has been used, for example, by Chen and Botta (2025) and McGaughey and Peters (2024). This weighting reflects the aim of describing accessibility from the perspective of residents rather than land area, so that cells with more residents have a stronger influence on the district-level accessibility value. The population-weighted average walking time to the nearest supermarket was calculated as follows:

$$\bar{T}_d = \frac{\sum_{i \in d} P_{i,d} \cdot T_i}{\sum_{i \in d} P_{i,d}}$$

$$\begin{aligned} & \bar{T}_d : \text{population-weighted average walking time in district } d, \\ \text{with} \quad & P_{i,d} : \text{population assigned from grid cell } i \text{ to district } d, \\ & T_i : \text{walking time from grid cell } i \text{ to the nearest supermarket.} \end{aligned}$$

Analogously, $\bar{R}_d$ denotes the population-weighted average number of supermarkets reachable within 15 minutes in district d. $\bar{R}_d$ was calculated using the same weighting logic, replacing walking time T_i with the number of reachable supermarkets R_i. For each of the 45 districts, this resulted in two aggregated values for I_1 and I_2. These district-level indicators were then mapped to compare accessibility patterns between districts. To examine the relationship between urban structure and supermarket accessibility, population density was correlated with the two district-level accessibility indicators. Population density was treated as a contextual urban characteristic, following Christofa et al. (2023), who consider community characteristics such as density when analysing differences in food access. For each district, population density was calculated by dividing the expected population derived from the proportional allocation of Census grid cell values by the area reported in the district boundary dataset. Following Hauke and Kossowski (2011), both Pearson's and Spearman's correlation coefficients were calculated. Pearson's coefficient measures linear association, whereas Spearman's rank coefficient captures monotonic relationships without assuming linearity. Considering both measures was appropriate because accessibility may improve with increasing density without following a strictly linear pattern. The relationships were visualised using scatterplots with logarithmic trend lines, reflecting the possibility that accessibility gains are stronger at lower density levels and diminish in already dense districts. In line with similar log-based approaches in accessibility-density research (Janatabadi et al., 2026), residuals were used to identify spatial mismatches. Districts were labelled when their absolute standardised residual exceeded 1.5, indicating substantially higher or lower accessibility than expected based on population density.

For the elderly accessibility analysis, five groups were compared: all residents, residents aged 60 and above, residents aged 70 and above, residents aged 80 and above, and senior facility residents. For the population-based groups, accessibility was calculated using the same population-weighting logic applied in the district-level aggregation (Chen & Botta, 2025; McGaughey & Peters, 2024). The elderly age groups were weighted by their respective age-specific population counts, so that the result-

ing values reflect the spatial distribution of elderly residents. Senior facilities were analysed separately and aggregated using a capacity-weighted average to account for differences in facility size. For each group, the analysis was conducted for both I_1 and I_2, allowing supermarket accessibility to be compared across age groups and residential settings and helping to identify whether elderly residents, especially those living in senior facilities, are particularly vulnerable to limited access.

Finally, a 3D visualisation was created to illustrate elderly supermarket accessibility by mapping elderly population grid cells and senior facilities. Although the elderly accessibility analysis was conducted for both I_1 and I_2, the visualisation focuses on I_1 to keep the map readable and within the scope of this study. Walking time to the nearest supermarket was selected because it provides a direct and easily interpretable measure of basic proximity to food retail infrastructure. The 3D map combines elderly population size, facility capacity, and walking time, allowing areas where high elderly population concentrations or large senior facilities coincide with longer walking times to be identified more easily.

4 Analysis and Results

4.1 Cell-Level Analysis of Supermarket Accessibility

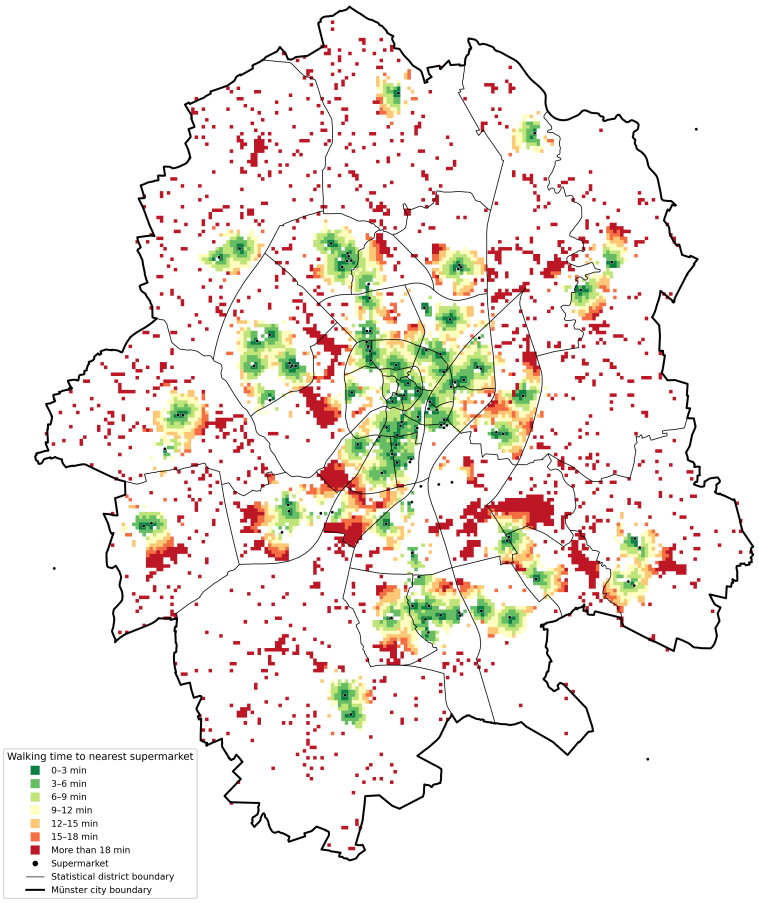

Figure 1 Cell-level walking accessibility to the nearest supermarket in Münster

Figure 1 shows the cell-level walking accessibility to the nearest supermarket in Münster. The map reveals a clear spatial pattern, with a high concentration of supermarkets in and around the city centre. This is reflected in generally good accessibility in the central area, where most populated grid cells are located within a maximum walking time of 9 minutes to the nearest supermarket. In contrast, more rural districts located farther away from the city centre show larger areas with longer walking times. Accessibility in these outer areas is more fragmented and often limited to smaller clusters around individual supermarkets. Empty areas without coloured grid cells indicate grid cells without recorded population, which occurs more frequently in rural parts of the municipality. A closer view of the city centre also shows some smaller gaps, for example around larger open spaces such as Domplatz. Overall, the

figure highlights a strong contrast between the continuous accessibility pattern in the city centre and weaker area-based accessibility in more peripheral parts of Münster.

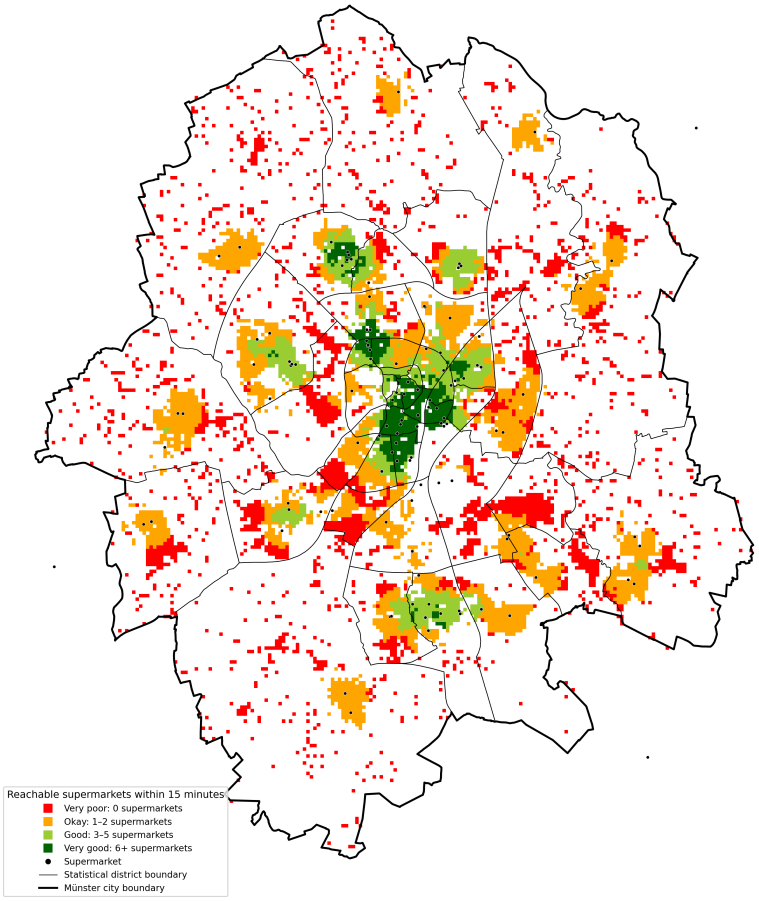

Figure 2 Number of supermarkets reachable within 15 minutes on foot at cell level

While Figure 1 focuses on basic proximity to the nearest supermarket, Figure 2 adds a second perspective by showing the number of supermarkets reachable within 15 minutes on foot. The spatial pattern is similar to the walking-time map, but the contrast between the city centre and the outer districts becomes even more visible. In the city centre and adjacent inner districts, many populated grid cells have access to three or more supermarkets within 15 minutes, with the highest values concentrated in the central area. In contrast, many peripheral and rural parts of Münster are classified as having no reachable supermarket or only one to two supermarkets within the same walking-time threshold. This indicates that residents in central areas not only reach a supermarket more quickly, but also have a wider range of supermarket options within walking distance.

4.2 District-Level Aggregation of Supermarket Accessibility

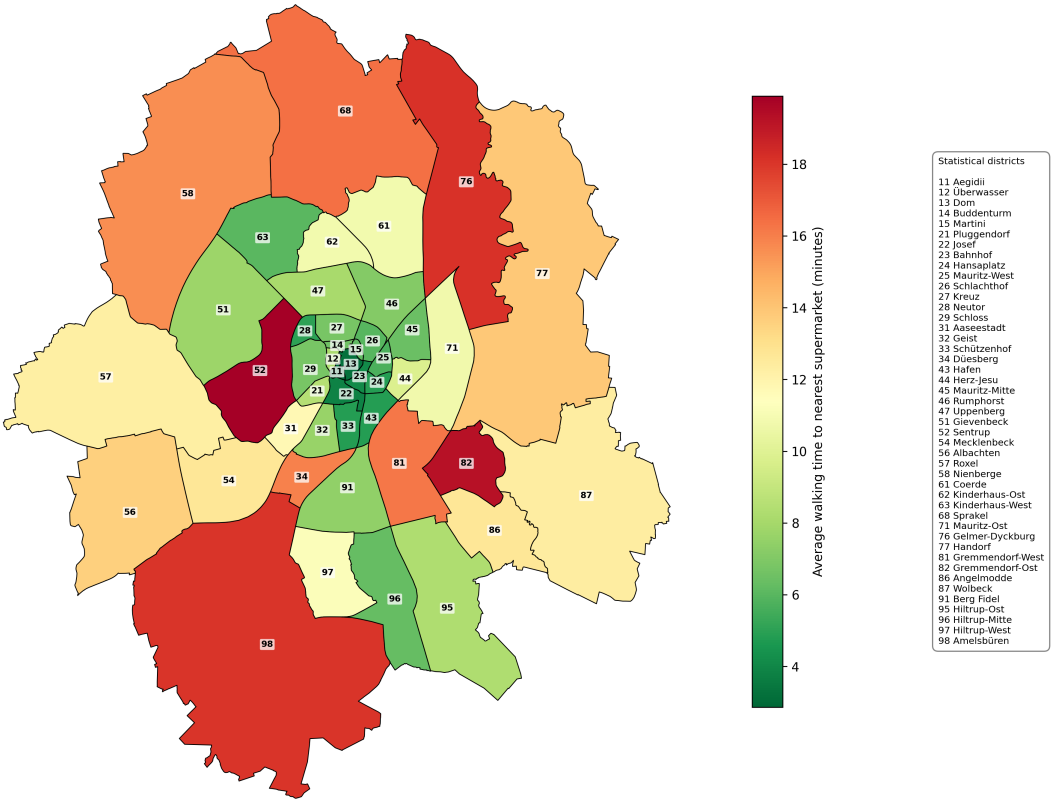

Figure 3 Population-weighted average walking time to the nearest supermarket by statistical district

When shifting the perspective from the cell level to the aggregated district level, Figure 3 shows the population-weighted average walking time to the nearest supermarket for each statistical district. Overall, the spatial pattern confirms the cell-level results, with the shortest average walking times concentrated in the central and adjacent inner-city districts. Districts such as Aegidii, Überwasser, Dom, Buddenturm, Martini, Pluggendorf, Josef, Bahnhof, Hansaplatz, Mauritz-West, Schlachthof, Kreuz and Neutor show particularly good accessibility, mostly with average walking times below 6 minutes. However, the district-level results also show that supermarket accessibility does not follow a simple centre-periphery pattern. While several outer districts, such as Albachten, Coerde, Gelmer-Dyckburg and Gremmendorf-Ost, show substantially longer average walking times, good accessibility is not limited to the city centre. Berg Fidel, Hiltrup-Ost, Hiltrup-Mitte, Gievenbeck and Kinderhaus-West also show comparatively short average walking times despite being located farther away from the centre. Similarly, Nienberge, Wolbeck and Angelmodde show acceptable accessibility values, although they are peripheral districts. By contrast, some districts that are

closer to the city centre, such as Sentrup, Düesberg and Gremmendorf-West, perform worse than these more distant districts. This suggests that proximity to the city centre alone does not fully explain district-level supermarket accessibility. Instead, the spatial distribution of residents within each district appear to play an important role.

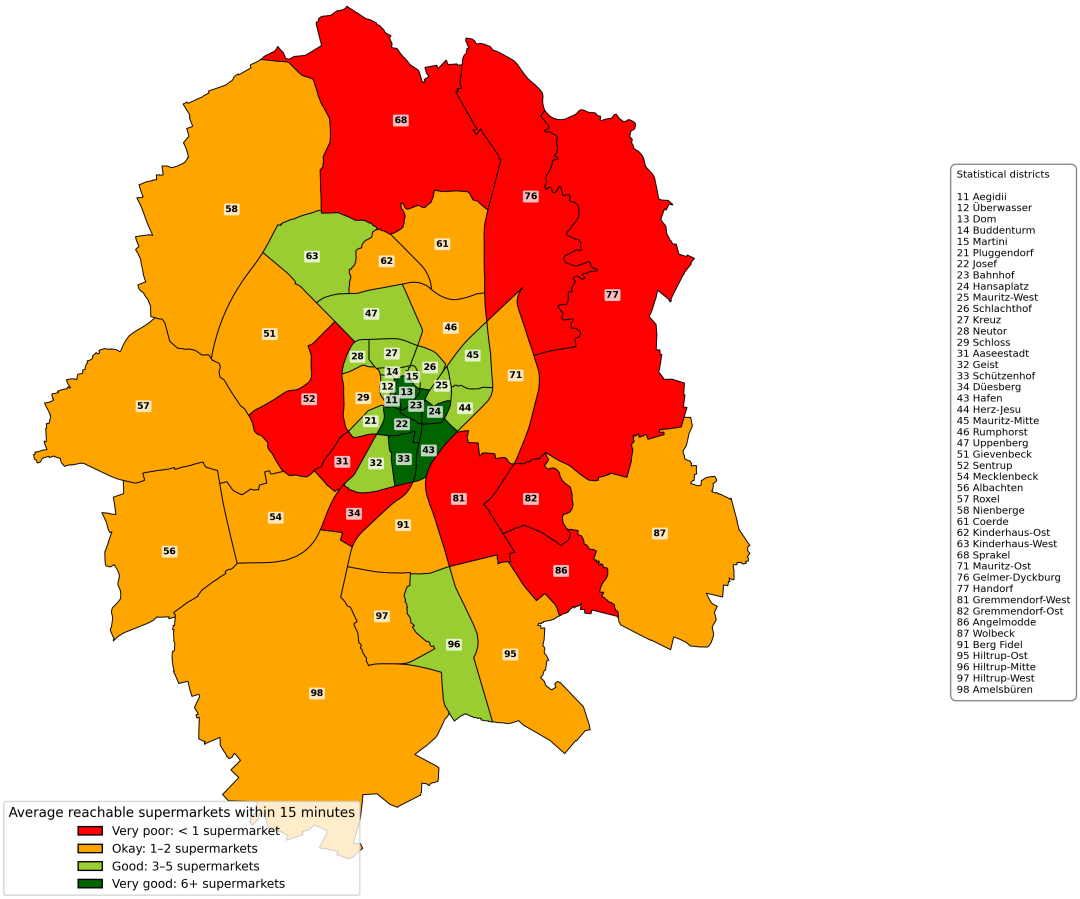

Figure 4 Population-weighted average number of supermarkets reachable within a 15-minute walk by statistical district

Figure 4 extends the district-level analysis by focusing not on the nearest supermarket, but on the number of supermarkets reachable within a 15-minute walk. The map largely supports the pattern shown in Figure 3, as districts with short average walking times often also provide a broader supermarket choice. However, it also reveals additional local differences that are less visible when only the nearest supermarket is considered. In particular, Schloss and Aaseestadt, located west of the city centre, show unexpectedly limited supermarket choice despite their acceptable average walking times in Figure 3 and their relatively central location. Especially striking is Gremmendorf-West, which offers fewer than one reachable supermarket on average while directly bordering Hafen, where the average exceeds six. This sharp contrast

shows that aggregated supermarket choice can differ abruptly even between directly neighbouring districts.

4.3 Population Density and District Accessibility Performance

The district-level results suggested that proximity to the city centre alone does not explain accessibility differences. Population density offers a possible explanation, as denser districts tend to support more supermarkets within shorter distances.

Correlation between population density and accessibility:

x	y	pearson_r	pearson_p	spearman_rho	spearman_p	n
population_density_per_km2	average_walking_time_min	−0.623	< 0.001	−0.711	< 0.001	45
population_density_per_km2	average_reachable_supermarkets_15_min	0.696	< 0.001	0.731	< 0.001	45

Figure 5 Pearson and Spearman Correlation Results

Figure 5 shows the relationship between population density and both accessibility indicators. The correlation analysis confirms a clear relationship between population density and both accessibility indicators. Population density is negatively correlated with the average walking time to the nearest supermarket (Pearson $r = -0.623$, Spearman $\rho = -0.711$), meaning that more densely populated districts tend to have shorter average walking times. At the same time, population density is positively correlated with the number of supermarkets reachable within 15 minutes (Pearson $r = 0.696$, Spearman $\rho = 0.731$), indicating that higher density is associated with a wider supermarket choice within walking distance. All four coefficients are highly significant ($p < 0.001$) and point to a moderate-to-strong association, suggesting that population density is a relevant structural factor in explaining the accessibility differences between districts. For both indicators, the Spearman coefficients are slightly higher in absolute terms than the Pearson coefficients (0.711 vs. 0.623 for walking time and 0.731 vs. 0.696 for reachable supermarkets), indicating a slight tendency towards a monotonic rather than strictly linear pattern. Although the correlations are strong, they are not perfect, which shows that population density, while a meaningful predictor, does not fully account for district-level accessibility. Some districts therefore deviate from the overall trend, which is examined more closely in the following scatterplots.

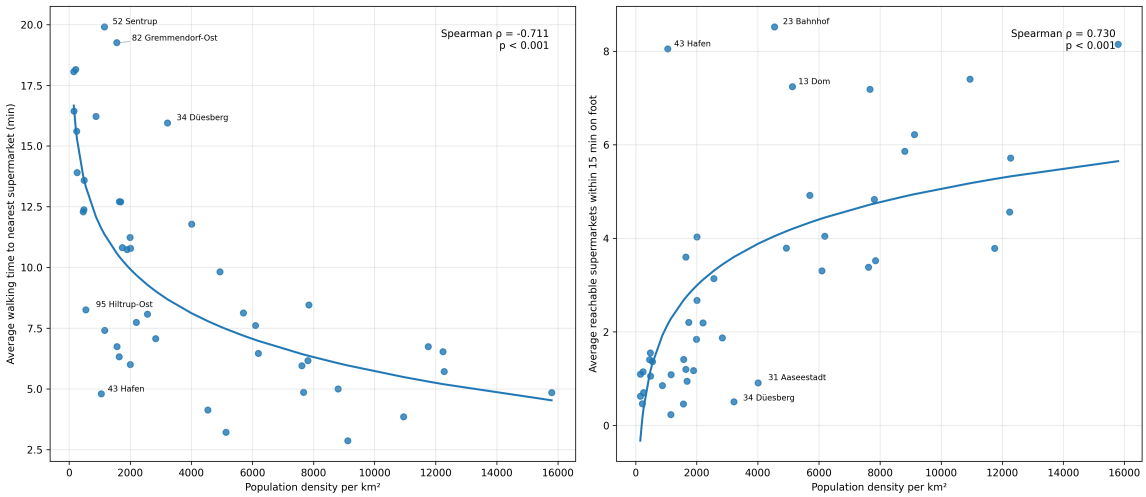

Figure 6 Relationship between population density and supermarket accessibility

The scatterplots in Figure 6 visualise the two correlations and highlight the districts that deviate most strongly from the general trend, identified through their standardised residuals. In line with the correlation coefficients, both plots confirm the pattern: the average walking time to the nearest supermarket decreases with increasing population density, while the number of reachable supermarkets within 15 minutes increases.

Several districts stand out as clear deviations from the general density-accessibility relationship. In the walking-time plot, Hafen and Hiltrup-Ost show better accessibility than would be expected based on their population density, as both districts have comparatively short walking times despite low-to-moderate density levels. The reachable-supermarkets plot shows a similar positive deviation for Hafen, as well as for Bahnhof and Dom. These districts offer a high number of reachable supermarkets within 15 minutes despite only low-to-moderate population density. At the same time, Sentrup, Gremmendorf-Ost and Düesberg show clearly longer walking times than their population density would suggest. Düesberg also stands out in the reachable-supermarkets plot, together with Aaseestadt, as both districts have fewer reachable supermarkets than would be expected based on their population density. This indicates that limited accessibility in these districts is not only a matter of distance to the nearest supermarket, but also of limited supermarket choice within walking distance. Overall, the scatterplots support the conclusion that population density is a meaningful but incomplete predictor of supermarket accessibility. This indicates that accessibility is shaped not only by residential density but also by the internal spatial distribution of residents and retail infrastructure within each district.

4.4 Elderly Accessibility Vulnerability

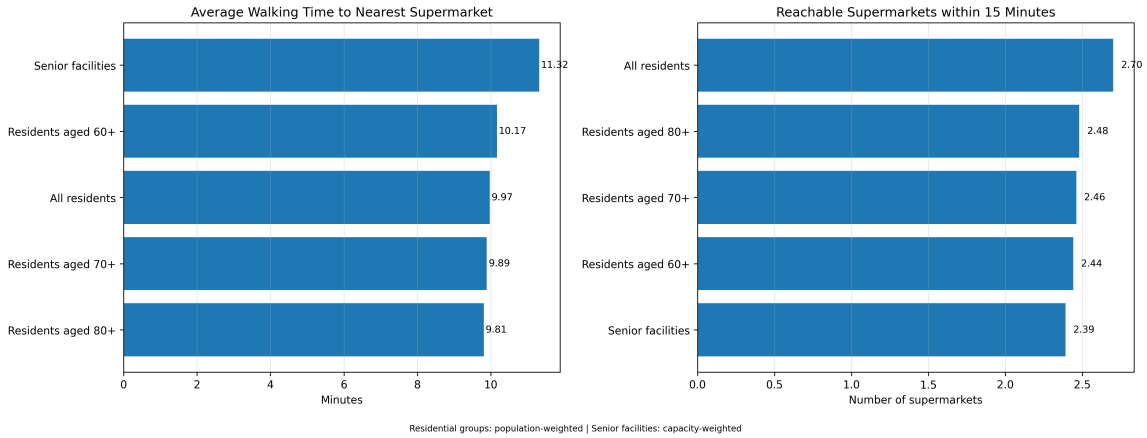

Figure 7 Supermarket accessibility by age group

Building on the district level patterns identified above, the analysis now turns to differences in supermarket accessibility between the population as a whole, older age groups, and residents of senior facilities. Figure 7 shows both accessibility indicators for these five groups. Average walking times among the population based groups are similar: 9.97 minutes for all residents, 10.17 minutes for residents aged 60 and above, 9.89 minutes for those aged 70 and above, and 9.81 minutes for those aged 80 and above. These values provide no clear indication that walking time increases with age. The second indicator, however, shows a more consistent difference between the general population and older residents. All residents can reach an average of 2.70 supermarkets within 15 minutes, compared with 2.44 for residents aged 60 and above, 2.46 for those aged 70 and above, and 2.48 for those aged 80 and above. The general population can therefore reach approximately 0.22 to 0.26 more supermarkets on average, indicating a somewhat greater level of choice within walking distance. Senior facilities show the least favourable average values for both indicators, with a walking time of 11.32 minutes and 2.39 reachable supermarkets. The clearest difference is their longer walking time, which exceeds the population average by 1.35 minutes, whereas their number of reachable supermarkets is only slightly lower than that of the older population groups. As the results are descriptive and use population weights for residential groups but capacity weights for senior facilities, they indicate average accessibility patterns rather than independent effects of age or residential setting.

While the average values in Figure 7 identify senior facility residents as a disadvantaged group, they do not show where limited accessibility affects the largest number of elderly residents. The following excerpts of the 3D visualisation highlight these crit-

ical areas, where high elderly population concentrations coincide with comparatively poor supermarket accessibility.

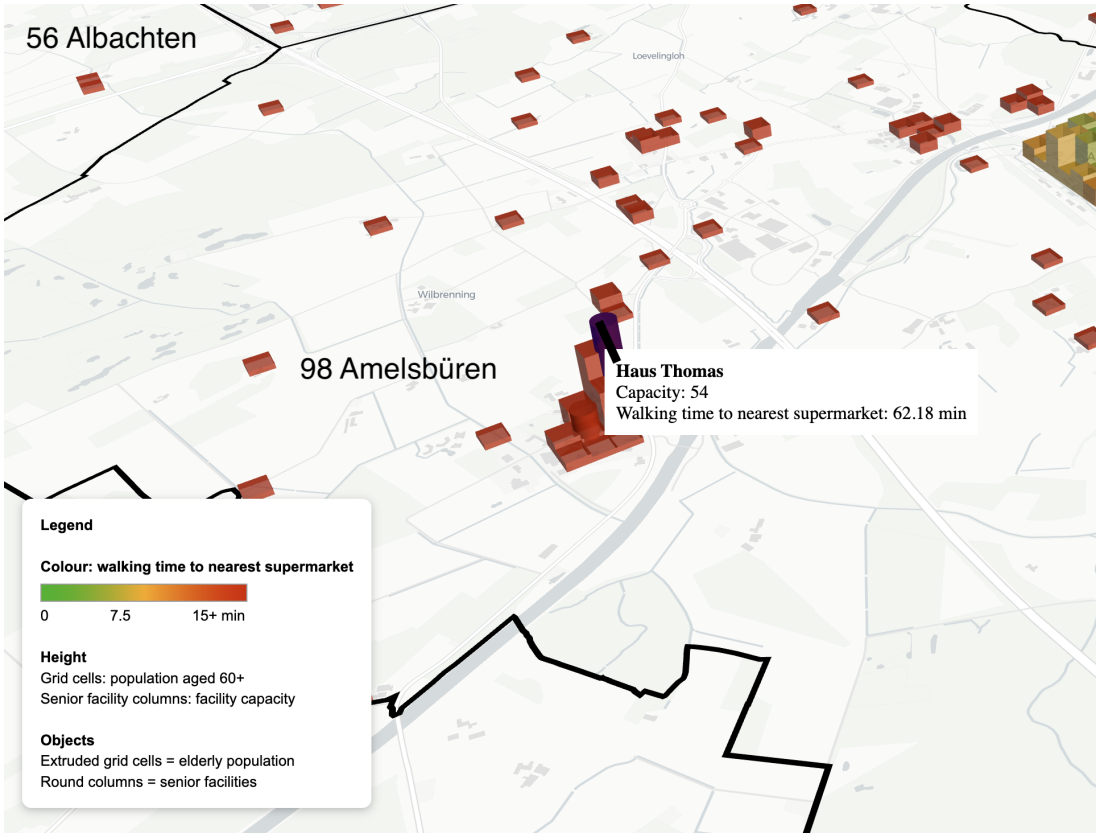

Figure 8 Selected perspective of the 3D visualisation: Haus Thomas

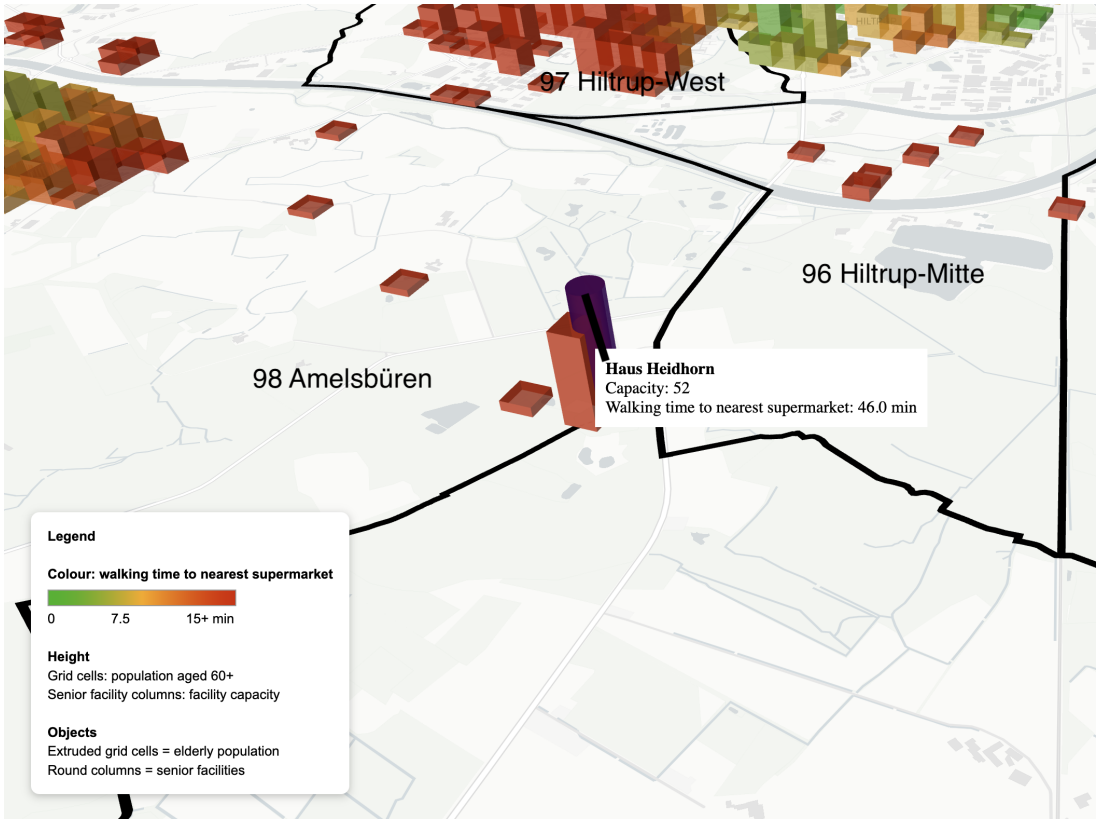

Figure 9 Selected perspective of the 3D visualisation: Haus Heidhorn

In Amelsbüren, two critical areas could be identified. Figure 8 shows a high concentration of elderly residents in the western part of the district. Two senior facilities are located here: Haus Thomas, with a capacity of 54, and Haus Augustinus, with a capacity of 18. The immediate surroundings are also populated, comprising eight grid cells with around 100 residents aged 60 and above. The walking time to the nearest supermarket amounts to approximately one hour. Figure 9 shows the facility Haus Heidhorn on the south-eastern edge of Amelsbüren, which has a capacity of 52 and is surrounded by two grid cells with a total population of around 40. Here, the walking time reaches roughly three quarters of an hour. In both cases, these walking times are effectively unfeasible on foot, particularly for elderly residents.

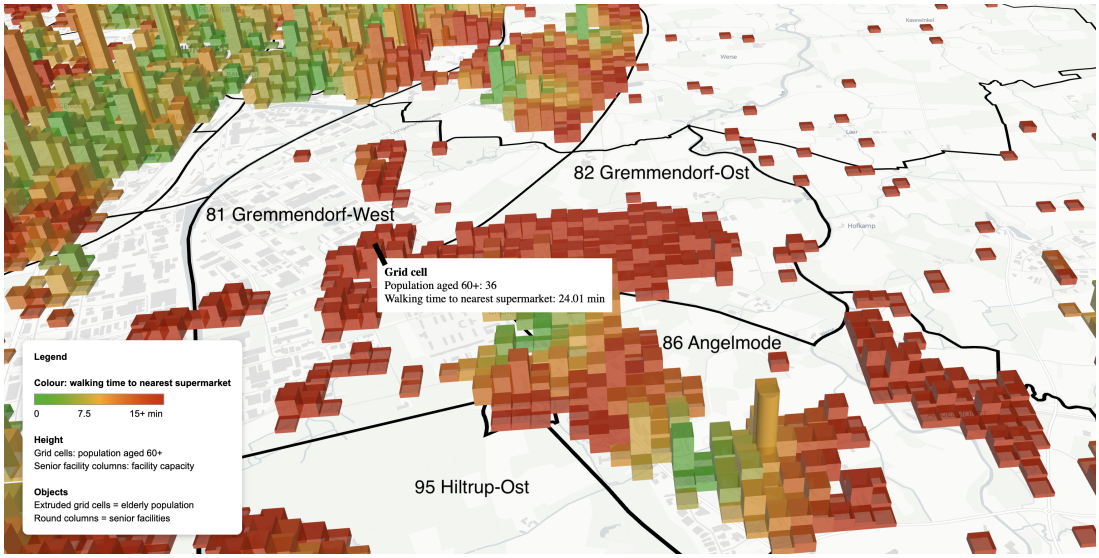

Figure 10 Selected perspective of the 3D visualisation: Gremmendorf

Figure 10 reveals two main critical hotspots in Gremmendorf. The first extends from Gremmendorf-West across into Gremmendorf-Ost, with walking times ranging between 15 and 30 minutes. In this area, an estimated total of more than 1,000 elderly residents are affected by limited walking accessibility to supermarkets. Two smaller critical hotspots can be observed in the north of Gremmendorf-West and in the west of Gremmendorf-West, close to the border with Berg Fidel. In addition, the neighbouring district of Angelmodde shows a critical hotspot in its north-eastern part, where the walking time to the nearest supermarket ranges from 17 to 38 minutes and affects approximately 300 to 400 elderly residents.

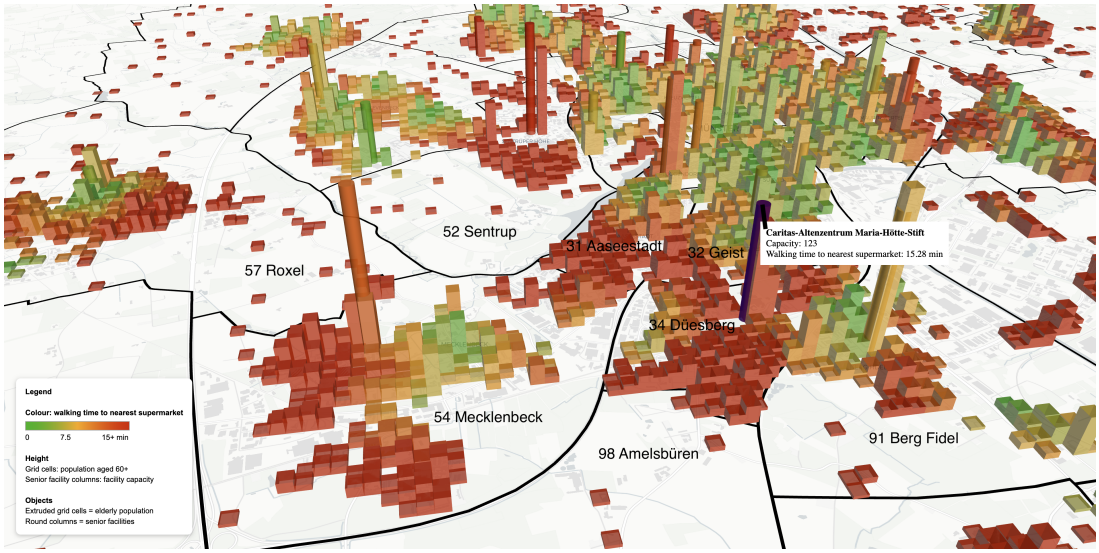

Figure 11 Selected perspective of the 3D visualisation: Mecklenbeck, Aaseestadt, Düesberg

Figure 11 highlights several areas of limited accessibility across Mecklenbeck, Aaseestadt, and Düesberg. In Mecklenbeck, poor accessibility is concentrated in the south-west, affecting around 800 elderly residents with walking times between 16 and 30 minutes. Similar walking times of 20 to 26 minutes occur along the border between Aaseestadt and Mecklenbeck, as well as in the south-west of the neighbouring district of Geist. In Düesberg, the Caritas-Altenzentrum Maria-Hötte-Stift, with a capacity of 123, has a walking time of approximately 15 minutes. Limited accessibility is also evident in the southern part of Düesberg, where walking times reach around 25 minutes.

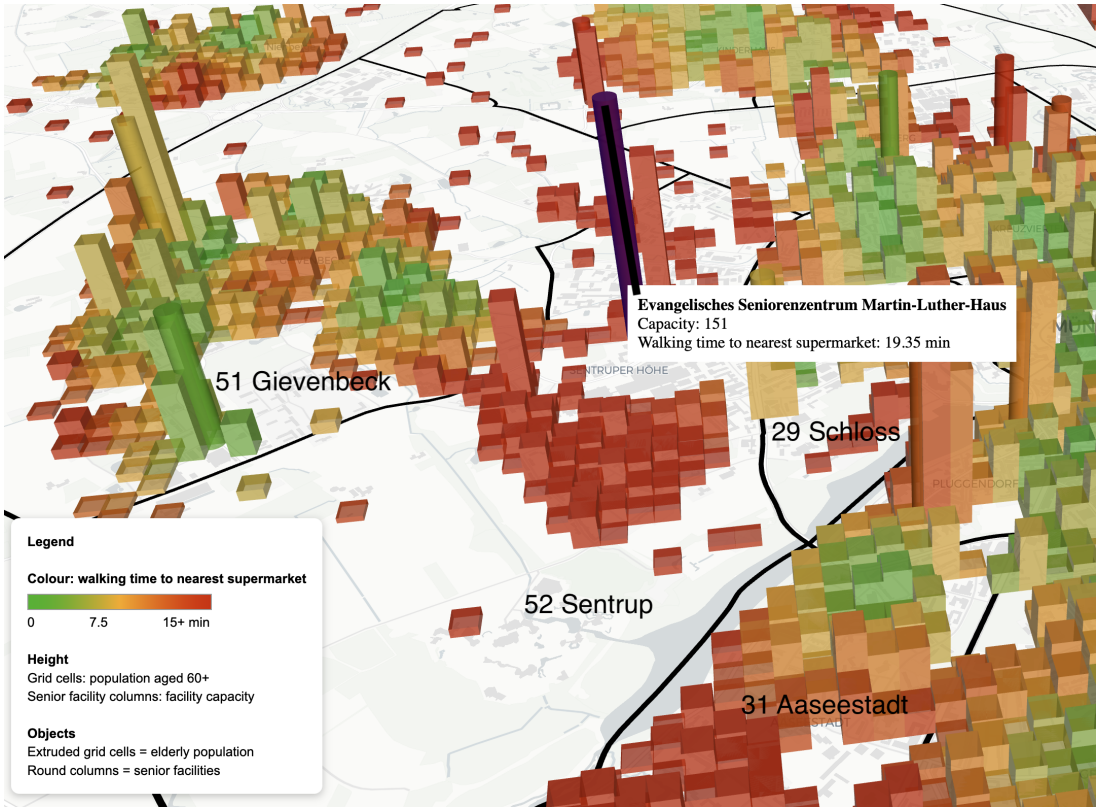

Figure 12 Selected perspective of the 3D visualisation: Martin-Luther-Haus



Figure 13 Selected perspective of the 3D visualisation: Sentrup

Sentrup is one of the most conspicuous districts, having already stood out in the previous analyses as a non-peripheral district with poor accessibility. Figure 12 confirms the very poor accessibility in this area: the Evangelisches Seniorenzentrum Martin-Luther-Haus, with a capacity of 151, requires nearly 20 minutes to reach the nearest supermarket. Figure 13 shows a critical area slightly to the south of the facility, with walking times of 20 to 27 minutes. The northern part of Sentrup is also characterised by limited accessibility, with walking times of 15 to 20 minutes.

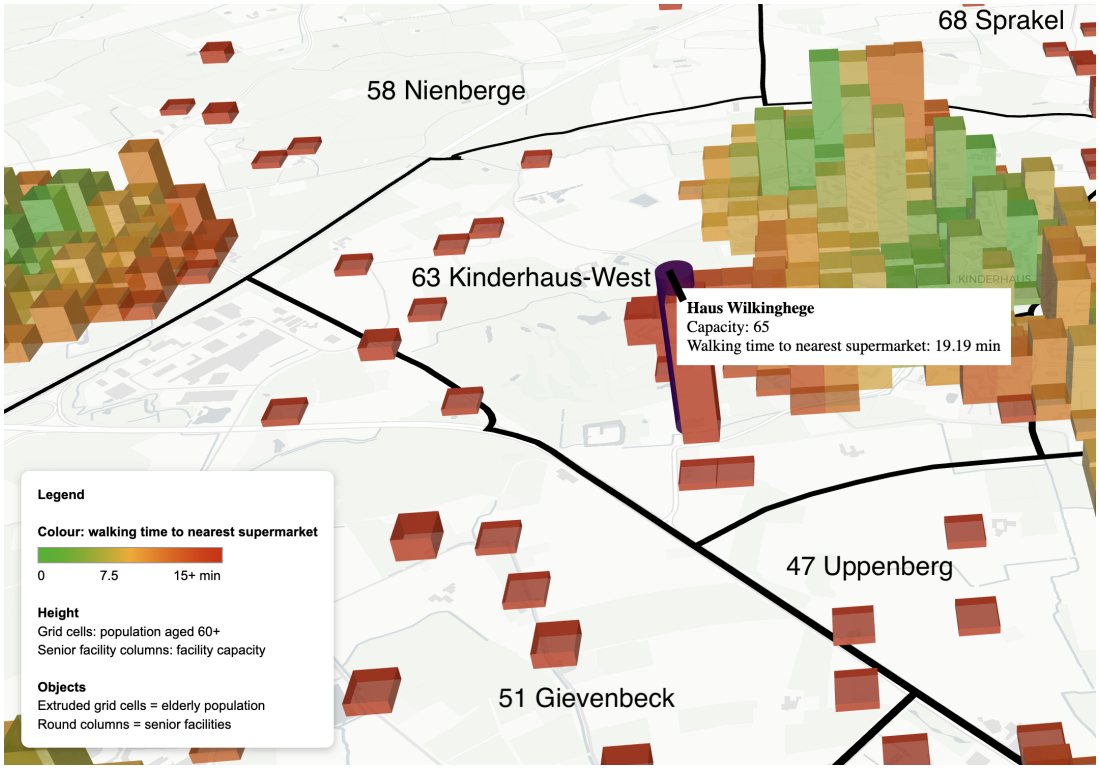

Figure 14 Selected perspective of the 3D visualisation: Haus Wilkinghege

Figure 14 shows the facility Haus Wilkinghege in Kinderhaus-West, which has a capacity of 65 and a walking time of nearly 20 minutes to the nearest supermarket.

These excerpts indicate that limited supermarket accessibility for elderly residents is not evenly distributed, but concentrated in a small number of critical areas. Two recurring patterns emerge. First, several senior facilities, such as Haus Thomas, Haus Heidhorn, the Martin-Luther-Haus, and Haus Wilkinghege are located in areas with walking times of 20 minutes or more, meaning that a large number of residents share the same limited access due to the facilities' high capacities. Second, extensive residential critical hotspots, most notably in Gremmendorf and around Mecklenbeck, affect several hundred to more than a thousand elderly residents living in private households. In the most extreme cases, particularly in Amelsbüren, walking times of up to one hour make walking to the nearest supermarket effectively impractical. Taken together, these findings confirm that elderly accessibility vulnerability is driven less by age itself than by the combination of peripheral or poorly served locations with high concentrations of elderly residents or large senior facilities. These results, along with the broader accessibility patterns identified across Münster, are discussed and interpreted in the following chapter.

5 Discussion

Both accessibility indicators, at the cell level as well as at the aggregated district level, confirm that more rural districts farther away from the city centre exhibit larger areas with longer walking times. Walking accessibility in these outer areas is more fragmented and often limited to smaller clusters around individual supermarkets. This pattern is in line with previous research about supermarket accessibility (Apparicio et al., 2007). However, it is important to note, that centrality does not improve accessibility on its own, but rather through the factors associated with it. Münster's inner city is characterised not only by higher population density, but also by higher levels of human activity generated by students, visitors from other parts of the city, and shopping-related trips (Stadt Münster, 2025; Universität Münster, 2026). This concentration of activity generates greater turnover and demand for supermarkets, which in turn supports a denser and more diverse retail supply. In addition, the more fine-grained street network in central areas contributes to shorter walking times by enabling more direct routes to supermarket locations.

At the same time, the district-level results show that supermarket accessibility does not always follow a simple centre–periphery pattern. Several districts perform better than their location would suggest, including especially Berg Fidel, Hiltrup-Ost, Hiltrup-Mitte, Gievenbeck, and Kinderhaus-West, which show comparatively short average walking times despite being located farther from the centre. By contrast, some more centrally located districts, such as Sentrup, Düesberg, Gremmendorf-West, and Gremmendorf-Ost, perform worse than expected. Population density explains these deviations only partially: it offers a plausible explanation for districts such as Hiltrup-Mitte, Gievenbeck, Kinderhaus-West, Berg Fidel, and Gremmendorf-West, but the poor accessibility values of Sentrup, Gremmendorf-Ost, and Düesberg, as well as the surprisingly good values of Hiltrup-Ost, can be explained neither by centrality nor by population density alone.

A closer look at Figure 1 provides an explanation for Hiltrup-Ost, as it shows a striking concentration of residents around its supermarkets. In hardly any other district is the population clustered so strongly around retail locations, reflecting a successful realisation of the 15-minute city concept in the context of supermarket access (Moreno et al., 2021). For Sentrup, the main reason for the poor accessibility is the absence of any supermarket within the district itself, as can be seen in Figure 1. This is compounded by the fact that a large share of the district's area is occupied by non-residential uses, including the University Hospital (UKM), further university buildings, the Münster Zoo, and a large undeveloped area in the south-west of the

district. As a result, residents often have to rely on other modes of transport for their grocery shopping.

Another notable result is the difference in aggregated supermarket choice between Gremmendorf-West and its neighbouring district Hafen. This contrast can be explained by two factors: the internal distribution of residents within the districts and the specific characteristics of Hafen. First, the population of Hafen is strongly concentrated in the north of the district, close to several supermarkets and the city centre, whereas the population of Gremmendorf-West is concentrated in the south (see Figure 2). As a result, the dense supermarket landscape of the city centre benefits the northern residents of Hafen far more than the southern residents of Gremmendorf-West. Second, Hafen differs considerably from other districts in terms of its function: it is characterised by numerous restaurants, company locations, and a generally activity-oriented profile, yet, unlike central districts, it has a comparatively low population density (see Figure 6). This suggests that district-specific characteristics, such as those of a harbour district or similar functional areas, also play a role in shaping supermarket accessibility, which aligns with Christofa et al. (2023), who highlight the influence of community characteristics on food access.

Regarding elderly accessibility, the group comparison provides mixed results. Average walking times to the nearest supermarket are similar for older residents and the general population, but older age groups can reach slightly fewer supermarkets within 15 minutes. The results therefore indicate comparable proximity but somewhat less choice for older residents. This partly aligns with Hosford et al. (2022), who found inequalities in grocery store accessibility across age groups in Vancouver. Residents of senior facilities also recorded less favourable average values for both indicators than the general population. The 3D visualisation further made it possible to identify six senior facilities with particularly poor accessibility: Haus Thomas, Haus Augustinus, Haus Heidhorn, the Caritas-Altenzentrum Maria-Hötte-Stift, the Martin-Luther-Haus, and Haus Wilkinghege. Several factors may contribute to this pattern. As shown in the correlation analysis, accessibility tends to be better in densely populated areas. Senior facilities may tend to be located in less densely populated surroundings: elderly people often prefer quieter surroundings, and senior facilities require considerable space, which is rarely available in densely built-up areas that generally offer good supermarket accessibility. In addition, residents often move into senior facilities in order to receive care, meaning that independent grocery shopping may be infrequent or no longer necessary for many of them. These considerations suggest that the poorer accessibility of senior facilities does not necessarily translate into an equivalent everyday burden for all of their residents. Moreover, the 3D visualisation revealed critical areas for elderly residents in Gremmendorf-

West, Gremmendorf-Ost, Angelmodde, Mecklenbeck, Düesberg, Aaseestadt, Geist, and Sentrup. These critical areas partly coincide with the underserved districts identified in the district-level analysis, most notably Sentrup, Gremmendorf-Ost, and Düesberg, which shows that limited walking accessibility to supermarkets for elderly residents is concentrated in a small number of critical areas.

6 Conclusion

This paper examined walking accessibility to supermarkets in Münster at both the census grid-cell and statistical district levels, with a particular focus on elderly residents. The results show that Münster generally provides good walking accessibility to supermarkets, especially in central and inner-city districts. However, the results demonstrate that supermarket accessibility does not always follow a simple centre-periphery pattern. Some peripheral districts perform comparatively well, while several more centrally located districts showed weaker accessibility than expected. The analysis further showed that population density is strongly associated with both accessibility indicators, but does not fully explain the observed spatial differences. Additionally, internal distribution of residents and supermarkets within districts plays an important role. Regarding elderly accessibility, older age groups showed similar walking times to the general population but could reach slightly fewer supermarkets within 15 minutes. However, senior facilities showed poorer accessibility in both indicators. Finally, the 3D visualisation identified several critical areas where high concentrations of elderly residents or large senior facilities coincide with comparatively poor walking accessibility to supermarkets.

Several limitations need to be considered when interpreting these findings. First, the Census population data are affected by the anonymisation procedure of the German Census 2022. Individual cell values may be slightly modified and age-specific values do not necessarily add up exactly to the reported total population. This limitation is unlikely to substantially affect the main results, as most conclusions are based on aggregated patterns rather than one individual grid cell. Nevertheless, very small cell-level values should not be interpreted too precisely.

Second, the analysis focuses only on walking accessibility from residential locations. It therefore does not capture actual shopping behaviour, alternative transport modes, or daily mobility patterns. People may shop by bicycle, public transport or car, combine grocery shopping with other trips, or use supermarkets outside their residential neighbourhood. This relates to the neighbourhood effect averaging problem, as residential accessibility does not necessarily reflect the full set of places people use in everyday life (Kwan, 2018).

Third, district-level results are affected by the modifiable areal unit problem (Fotheringham & Wong, 1991). Aggregated accessibility values may vary depending on the chosen spatial units and boundaries. Nevertheless, district-level results remain useful because they correspond to established administrative units and provide an inter-

pretable basis for comparing accessibility patterns across Münster. To account for this limitation, the discussion related district-level findings back to cell-level patterns.

Fourth, walking speed was assumed to be constant, although actual walking speeds can vary between population groups, especially between younger and older residents. As a result, accessibility for elderly residents may be overestimated in some cases. Finally, the analysis captures proximity to supermarkets, but not the full quality of the walking environment. Factors such as pavement quality, safety, crossings, lighting or perceived comfort were not included.

Future research could address these limitations by combining objective accessibility measures with survey data on shopping behaviour, perceived accessibility and transport mode choice. This would make it possible to assess whether poor residential walking accessibility actually translates into everyday disadvantages. Further research could also evaluate the potential value of building new supermarkets in critical areas, for example in terms of time savings, reduced car use, lower emissions or improved quality of life for elderly residents.

Overall, the study shows how combining network-based accessibility modelling, high-resolution population data, district-level aggregation, and a focused analysis of elderly residents can reveal local inequalities that remain hidden in broader averages. The identified critical areas provide a basis for retail and mobility planning in Münster, while the methodological framework can be transferred to other cities and everyday destinations.

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