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RESEARCH ARTICLE

INTEGRATING SHORTEST-PATH ANALYSIS and MULTI-AGENT SIMULATION for CAMPUS ACCESSIBILITY EVALUATION

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Abstract

Physical accessibility constitutes a fundamental dimension of spatial justice, ensuring that all individuals can equally benefit from the built environment. This study aims to evaluate and quantify the accessibility challenges faced by wheelchair users within the Sivas Cumhuriyet University campus and to propose a model that objectively identifies spatial inequalities. For this purpose, the intra-campus pedestrian network was modelled using Python, and shortest-path analyses were conducted via Dijkstra's algorithm for 1,000 randomly selected origin–destination pairs. These routes were further simulated within a multi-agent system (MAS) environment to estimate travel times and compare mobility performance between wheelchair users and able-bodied individuals. This study provides one of the first quantitative frameworks to integrate Dijkstra-based shortest-path computation and MAS-driven simulation for assessing wheelchair accessibility in outdoor environments. The resulting data were used to develop a numerical accessibility scoring system that expresses spatial disadvantage as an accessibility coefficient. The findings revealed that 85.8% of the routes were completely inaccessible for wheelchair users and that, where access was possible, travel distances were on average 8.5 times longer than those of non-disabled individuals. By establishing a reproducible and data-driven framework, the study connects the aim of promoting spatial equity with quantifiable outcomes, thereby providing a decision-support tool for campus redesign and urban accessibility planning. These findings provide a scalable analytical framework for promoting spatial equity, offering practical guidance for policymakers and urban planners seeking to improve accessibility in built environments.

Keywords

Accessibility,
Dijkstra algorithm,
Multi-agent systems,
Wheelchair users,
Campus planning

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1. INTRODUCTION

Accessibility is recognized as a fundamental human right that enables individuals to lead independent lives and participate equally in social life [1]. Pineda [2] emphasizes that accessibility serves not only as the key to physical access but also as the gateway to social participation. Within the framework of the social model—which regards disability as a societal rather than an individual issue—Oliver [3] asserts that spatial justice is intrinsically linked to physical accessibility.

University campuses, as settings in which academic and social life intersect, bear particular significance with respect to accessibility. Sönmez and Aydın [4] report that accessibility standards at many Turkish university campuses are inadequate, highlighting a multitude of physical barriers that constrain the independent mobility of wheelchair users. Ezme Gürlek and Ezme [5] conducted a comparative

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assessment of inter-campus accessibility levels and uncovered marked inequalities in this area. In a city-scale study, Kesik et al. [6] determined that the majority of sidewalks are narrow, lack ramps, and are obstructed by various impediments, with only a limited number meeting accessibility requirements.

In this regard, a variety of legal and technical regulations exist at both national and international levels in the field of accessibility. Among these, the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) [1], the World Health Organization's World Report on Disability [7], the Americans with Disabilities Act (ADA) [8], and the Turkish Standards Institution's TS 12576 standard [9] are particularly notable. Nevertheless, despite the existence of all these standards, physical accessibility on university campuses remains a subject in need of further improvement [4, 5].

In the extant literature concentrating on accessibility within university campuses, map production [10], geographic information systems (GIS)-based static analyses [11], and user opinion–based evaluation methods [5] are predominantly employed. For instance, Botsis and Panagiotopoulos [10] modeled on-campus pathways using graph theory to compare the Dijkstra and Bellman–Ford algorithms; Le Pira et al. [11] examined student mobility by assessing the physical characteristics of routes through GIS-based analyses. Fortu et al. [12], meanwhile, utilized multi-agent systems (MAS) for mobility modeling, yet did not quantitatively reveal the spatial disadvantage faced by individuals with disabilities.

PATH-U, developed to analyze the uncertainties arising from inadequate wayfinding and erroneous decision-making in enclosed environments, represents another model employing the MAS approach [13]. Similarly, SimArch is a MAS-based model devised to simulate human movement trajectories within architectural design processes [14].

Although numerous studies have examined the accessibility challenges encountered by individuals with disabilities in daily life, the majority of these efforts have focused on map production and the analysis of physical accessibility barriers. Research on expansive open environments, such as university campuses, has investigated in detail the physical obstacles faced by wheelchair users, as well as route lengths and travel times [15-16]; however, simulation-based approaches that dynamically model access difficulties remain insufficiently developed. Furthermore, while these studies emphasize the identification of physical barriers [5, 11, 17], dynamic analyses that directly measure the impact of these obstacles on individual mobility are limited. In this context, more comprehensive research is required to optimize simulation-based models for individuals with disabilities.

Accessibility has emerged as a critical dimension of spatial justice, emphasizing the need for environments that enable equitable mobility for all individuals, including those with physical disabilities. Recent studies have increasingly focused on quantifying accessibility challenges using spatial network models and computational simulation techniques.

For instance, Arai et al. (2022) proposed a spatial network–based evaluation framework to analyze wheelchair accessibility in train stations, emphasizing the relationship between spatial configuration and travel efficiency [18]. Their approach introduced measurable accessibility indices such as reachable time and path independence, highlighting how spatial structure influences mobility constraints. Complementing this, Koritsoglou et al. (2022) developed a penalty-based shortest-path algorithm specifically tailored for pedestrian navigation systems, integrating accessibility parameters (e.g., ramps, surface quality, and width) into the edge-weighting process to identify optimal and alternative routes in urban pedestrian networks [19].

Recent advances in geospatial analytics have emphasized the integration of network-based optimization and agent-based simulation to capture both macroscopic and microscopic mobility dynamics. For instance, Ullrich et al. (2024) presented a hybrid workflow combining network analysis and agent-based modelling to predict pedestrian movement patterns and evaluate accessibility at multiple spatial scales [20]. Similarly, Zhou et al. (2024) proposed a data-driven agent-based modelling framework linking

urban mobility behaviors with accessibility indices, thereby establishing a methodological foundation for dynamic accessibility assessment [21]. In a more applied context, Alqahtani et al. (2025) demonstrated how simulation-based optimization techniques can enhance wheelchair accessibility evaluations in built environments [22]. Building on these methodological developments, the present study couples Dijkstra-based network computation with multi-agent simulation to quantify spatial disadvantage and accessibility disparities in outdoor campus settings.

To operationalize this framework, the study introduces a hybrid accessibility assessment model that merges Dijkstra-based shortest-path computation with MAS to quantify the degree of spatial disadvantage experienced by wheelchair users within the Sivas Cumhuriyet University (SCU) campus. By coupling graph-theoretical network analysis with dynamic agent-based modelling, this research aims to provide a reproducible, data-driven methodology for evaluating accessibility inequalities in large-scale open environments such as university campuses.

Unlike conventional GIS-based accessibility studies that rely solely on static spatial metrics, this research introduces a hybrid modeling framework combining graph-theoretical network analysis with agent-based dynamic simulation. This approach quantifies spatial disadvantage and is adaptable to diverse urban environments, supporting local governments in enhancing service quality as well.

Accessibility research has increasingly emphasized the importance of ensuring equitable mobility for individuals with disabilities in both indoor and outdoor environments. Recent systematic mapping studies have revealed that despite the growing number of digital and assistive technologies, research addressing accessible wayfinding and navigation remains fragmented and technologically uneven across different user groups and environments [23]. Particularly, the limited integration of dynamic simulation models and user-oriented accessibility assessments highlights a persistent methodological gap.

In parallel, advancements in ABM have offered new opportunities to simulate pedestrian movement and spatial decision-making through rule-based agents that interact with their environment. Ma, Brandt, Seipel, and Ma (2024) demonstrated that simple agents governed by visual and spatial cognition parameters—such as vision angle and depth—can generate complex, emergent pedestrian path systems [24]. This approach bridges the gap between graph-theoretical and behavioral modelling, providing valuable insights into pedestrian flow and spatial affordances.

Within the specific context of wheelchair users, recent GIS-based analyses have underscored the significance of barrier-free path planning for assessing healthcare and service accessibility. Chen et. al., (2024) developed a method to quantify accessibility inequalities between wheelchair users and the general population by integrating public transport data with network-based travel time estimation [25]. Their findings emphasize that spatial disadvantage persists even in highly urbanized areas, reinforcing the need for accessibility frameworks that integrate both topological analysis and agent-based simulation.

Drawing on these perspectives, the present study contributes to the literature by proposing a hybrid modelling framework that integrates Dijkstra-based shortest-path analysis with MAS simulations, thereby quantifying spatial disadvantage for wheelchair users at the intra-campus scale. This integration enables a more dynamic representation of accessibility inequality and supports data-driven campus redesign strategies aimed at promoting spatial justice and inclusive mobility.

Recent advances in spatial simulation show that ABM complements graph-theoretical optimization by translating static route costs into time-dependent mobility performance for heterogeneous users. Within this study, agents serve as micro-scale entities that traverse pre-computed shortest paths, enabling a dynamic estimation of accessibility disadvantage over realistic campus networks. This integration motivates the use of a deterministic, path-following agent layer atop Dijkstra-based routing to reveal spatiotemporal inequities that remain hidden in purely static analyses.

In this study, the analysis extends beyond merely mapping physical obstacles to also examine the movement dynamics and access constraints experienced by individuals with disabilities. Utilizing a Python-based model, shortest-path analyses were performed for 1,000 randomly selected samples—both non-disabled and disabled—using the Dijkstra algorithm, and the resulting route distances were compared. An accessibility coefficient was then defined based on these differences, and an objective, comparative scoring system was developed for the entire campus. Consequently, this work contributes to the numerically, dynamically, and spatially oriented accessibility assessments that are currently lacking in the literature, and it proposes a model that is applicable not only to the SCU campus but also to other campuses with similar configurations.

2. STUDY AREA and METHODOLOGY

This study was designed to analyze the intra-campus spatial mobility of individuals with disabilities at the SCU campus. As shown in Figure 1, an 86-hectare area within the campus was selected as the study site, situated approximately 6 km south of the city center of Sivas, the second largest city of Türkiye. The SCU currently hosts 47,155 students and comprises 18 faculties, 4 institutes, 1 state conservatory, 4 schools, and 14 vocational schools [26]. The physical development of the campus has taken place gradually over a long period. As a result, many buildings were constructed at different times and added to the campus system incrementally rather than within a single comprehensive master plan [27]. Consequently, this fragmented spatial structure creates additional challenges for accessible mobility within the campus, particularly for individuals with disabilities.

To investigate these accessibility challenges, a detailed documentation of the campus mobility infrastructure was conducted. Within the campus, physical features such as pedestrian pathways, staircases, ramps, and sidewalks were documented (via photographs and videos) using both existing and orthophoto maps. As depicted in Figure 1, routes for both non-disabled and disabled individuals were subsequently generated.

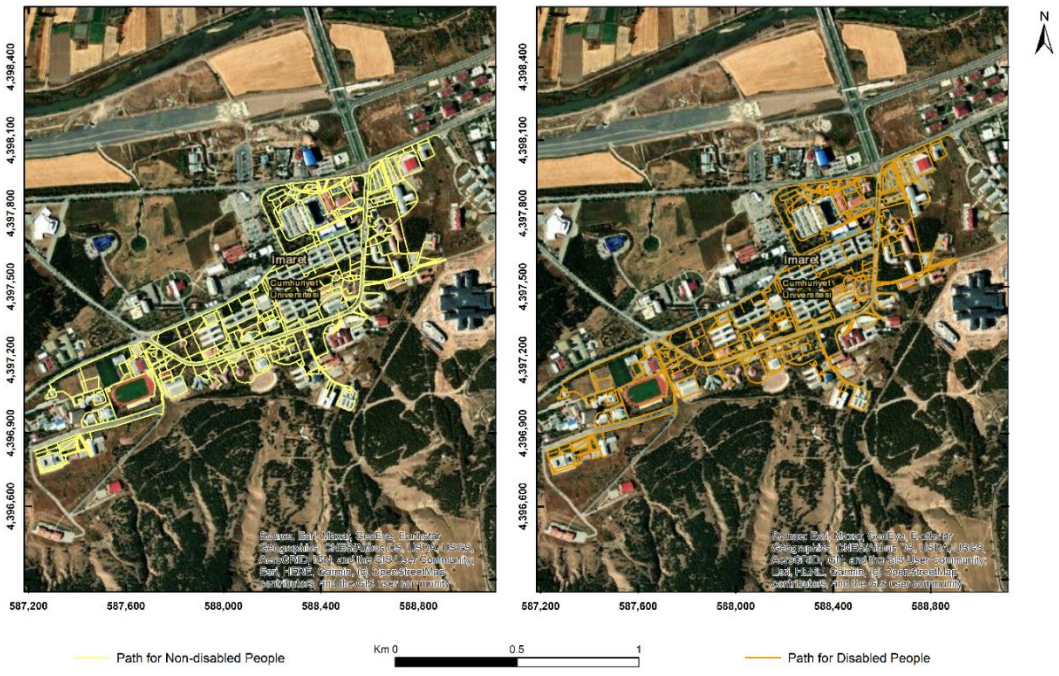


Figure 1. Study area and routes for non-disabled and disabled people in Sivas Cumhuriyet University.

2.1. Data Collecting and Processing

The data collection process for this study was initiated to compile the existing geospatial information of the SCU campus and to model its internal transportation network. In this context, the as-built maps obtained from the SCU Construction Affairs Technical Department and the orthophoto maps provided by the Sivas Municipality were used as the primary data sources. However, certain areas were identified as incomplete or incorrectly annotated. To rectify these deficiencies, field surveys were conducted, and the campus roads, sidewalks, and parking areas were updated. Furthermore, within the study area, features such as level surfaces accessible to wheelchair users, accessible ramps, and impassable elements (e.g., staircases, curbs, and curb breaks) were recorded through photographic and video documentation and digitized using Netcad and ArcGIS software. ArcGIS software was used for spatial data preparation, digitization, and validation of the network topology, while all algorithmic computations and simulations were conducted in Python using open-source libraries (NetworkX and Mesa) to ensure full transparency and reproducibility. During map production, separate routes for wheelchair users and non-disabled individuals were delineated and differentiated by color. This annotation process yielded two distinct transportation networks, on which shortest-path analyses were subsequently performed.

Shortest-path analyses for non-disabled individuals were conducted under the assumption that all walkways and sidewalks within the campus are accessible. In this procedure, the shortest routes between two predefined points (A and B) that cover the entire study area, as well as between two randomly selected points chosen by the Python script, were calculated and subsequently visualized.

As for wheelchair users, it was conducted by accounting for the inaccessibility of certain pathways and sidewalks within the campus. Routes suitable for individuals with disabilities were determined based on information obtained during the data-collection process, and shortest-path analyses were performed along these routes. The predefined and randomly selected points employed for non-disabled individuals were applied identically for wheelchair users. For both the predefined and randomly selected origin–destination (O-D) pairs, the shortest paths were computed using Dijkstra's algorithm, and all analyses were implemented in Python.

In the data analysis phase, the routes of non-disabled individuals and those of wheelchair users were assessed independently. Two separate directed network models—one representing non-disabled users and the other representing wheelchair users—were constructed. Within each network structure, 1,000 random (O-D) pairs were defined, and the shortest paths between these points were computed in Python using the Dijkstra algorithm, as illustrated in Figure 2.

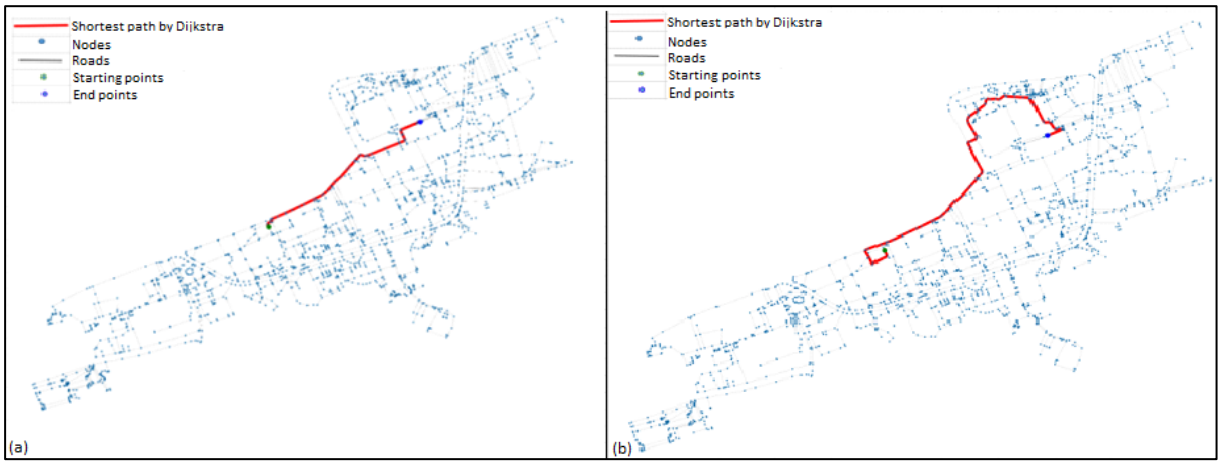


Figure 2. (a) Shortest path for non-disabled people (b) Shortest path for disabled people.

For each route, the distance difference between non-disabled and wheelchair-using individuals was calculated; based on these differences, an accessibility coefficient was derived for each (O-D) pair. This coefficient enabled the quantitative expression of the spatial disadvantage encountered by individuals with disabilities and allowed the overall accessibility level of the campus to be objectively defined. Moreover, situations in which access was impossible were represented with a value of zero. This approach facilitated the comparative identification of accessibility-advantaged and -disadvantaged areas within the campus and produced spatially based, measurable planning data for local authorities.

A scoring system was developed to numerically represent the level of accessibility using the collected data. In this system, the difference between the route lengths traversed by individuals with disabilities and those traversed by non-disabled individuals serves as the basis; by computing the average of the scoring values for 1,000 routes, an overall intra-campus accessibility score is obtained.
Equation (1) presents the scoring calculated for each sample. In this equation, $Range_{non\text{-}disabled(i)}$ denotes the shortest-path distance computed for non-disabled individuals, and $Range_{disabled(i)}$ denotes the shortest-path distance computed for individuals with disabilities. The average of the scores calculated for all samples is then shown in Equation (2):

$$Score_{(i)} = \frac{Range_{non-disabled(i)}}{Range_{disabled(i)}} \tag{1}$$

$$Average\ Score = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Range_{non-disabled(i)}}{Range_{disabled(i)}}\right) \tag{2}$$

These ratios, which can be defined as accessibility coefficients, have enabled the quantitative representation of spatial disadvantage across the campus. Routes that proved inaccessible were assigned a value of zero and integrated into the scoring system. These data not only expose the limitations on the mobility freedom of individuals with disabilities within the campus but also contribute to identifying areas that should be prioritized in spatial planning.

2.2. Dijkstra Algorithm

Shortest-path analysis is a method that aims to identify the least-cost route between two points within a network structure [28-29]. This cost typically represents distance, time, energy consumption, or a weighting function [30-31]. Widely employed in GIS, this technique finds application across a variety of domains, including transportation planning, logistics optimization, and network analysis [32].

In network analysis, methods for computing the shortest path typically draw upon graph theory [33]. A network comprises nodes and edges, with each edge assigned a specific cost value used to calculate the shortest path [34]. One of the most widely employed algorithms in the literature for this purpose is Dijkstra's algorithm, which operates on weighted directed graph structures [35].

In this study, Dijkstra's algorithm—a classical graph-theoretical method developed by Edsger W. Dijkstra—was employed to compute the shortest paths within the pedestrian network. The algorithm was implemented in Python using the NetworkX library, where each network segment was represented as a weighted edge based on travel cost values. These costs differed for wheelchair and non-disabled users depending on slope, surface type, and accessibility attributes, thereby quantifying the spatial disadvantage between user groups.

Its simplicity, efficiency, and broad applicability are cited among its principal advantages. Owing to its computational efficacy, wide application scope, guarantee of an optimal solution, and ease of adaptation, Dijkstra's algorithm was utilized in this study to determine shortest paths. Additional benefits of Dijkstra's algorithm include its accuracy and reliability, suitability for dynamic networks, capacity to provide partial solutions, and seamless integration with GIS [36-38].

2.3. Estimating Shortest Paths

In this study, the travel routes between two randomly selected points for wheelchair users and non-disabled individuals within the SCU campus were computed using the Python programming language. For this purpose, road network datasets prepared in the ArcGIS environment for both user groups were employed. Geographic data—comprising campus roads, sidewalks, and other pathways—were stored and processed using the Geopandas library; network analyses were carried out with NetworkX; and the computational results were visualized using Matplotlib. The workflow involved first converting the geographic datasets into graph representations, and subsequently calculating the routes between the randomly selected O-D pairs. Additionally, to validate the calculated values, the shortest paths were computed and compared using the Network Analyst module of the ArcGIS software.

2.4. Simulating Transportation Costs by MAS

Wooldridge (2009) defines an agent as a computer system that can perceive its environment through sensors and act upon that environment via actuators. A MAS, in turn, is characterized as a system in which independent agents work together or interact with one another to accomplish specific tasks [39]. Agents in our model represent individual pedestrians (wheelchair or non-disabled) assigned to O-D pairs drawn from the set of pre-computed shortest paths. Each agent holds a polyline path and advances deterministically along its geometry at each simulation tick.

Segment speeds are parameterized to reflect group-specific mobility and environmental attributes (e.g., slope/surface), and global ratios can be applied for wheelchair vs. non-disabled profiles. The simulation engine updates agents in discrete steps, records arrival events, and yields distributions of travel times across 1,000 O–D samples, thereby converting static path costs into temporal accessibility metrics.

In MAS, the specification of agents' behavioral rules constitutes a fundamental component of the modeling process. The ways in which agents interact with their environment, their decision-making processes, and their relationships with other agents are factors that directly influence the system's functioning [39]. These rules are typically shaped by the system's objectives, the types of agents involved, and the simulation context, and can be addressed through different modeling approaches [40].

ABM is a modeling approach in which individual agents, by operating under predefined rules, give rise to the emergent behavior of the overall system. The Python programming language is a widely employed tool for implementing agent-based models. In this study, a MAS was employed to simulate the movements of wheelchair users and non-disabled individuals within the campus. The Mesa library was used to simulate agents' movement and travel times, and the Tkinter library was utilized to develop the simulation's graphical user interface.

The MAS simulation incorporates two agent model types: non-disabled individuals and wheelchair users. These agents traverse designated routes within the campus to compute intra-campus travel times through simulation. For non-disabled agents, all pathways are assumed accessible, whereas for wheelchair users, only selected routes (e.g., accessible ramps) are modeled as accessible. Both agent groups move between randomly chosen points and calculate the travel durations along their respective shortest-path routes.

The methodological contribution of this study lies in its hybrid integration of graph-theoretical optimization, geospatial network analysis, and agent-based simulation within a unified Python-based modeling environment. While previous research has primarily employed either static GIS analyses or isolated simulation frameworks, the present study establishes a dynamic workflow that sequentially couples Dijkstra's algorithm, network-based accessibility modeling, and multi-agent systems (MAS) to quantify spatial disadvantage with high computational precision.

In the first stage, Dijkstra's algorithm was applied to compute the least-cost routes between 1,000 randomly selected origin–destination pairs within the campus pedestrian network, producing a reproducible and objective topological representation of accessibility. This process transforms the physical layout of the campus into a weighted, directed graph, where edge costs are defined based on slope, surface type, and accessibility attributes specific to wheelchair users.

In the second stage, these pre-computed routes are embedded into a multi-agent simulation environment developed using Python's Mesa framework. Each agent—representing either a wheelchair user or an able-bodied individual—moves autonomously along its assigned shortest path, generating time-dependent travel data that translate static network metrics into dynamic mobility performance indicators. This two-layer architecture converts distance-based costs into spatiotemporal accessibility coefficients, thereby revealing hidden inequalities that conventional GIS analyses cannot detect.

Unlike prior accessibility studies that rely solely on static distance or connectivity measures, the proposed approach combines the deterministic optimality of Dijkstra's algorithm with the emergent behavioral realism of MAS. This hybrid methodology provides a reproducible, data-driven framework capable of quantifying accessibility disparities at both micro (individual path) and macro (campus-wide) scales. By embedding graph-theoretical precision within a simulation-based context, the model advances accessibility research toward a more dynamic, scalable, and policy-relevant analytical paradigm.

The movement speed of each agent in the simulation is based on specific assumptions. Mohler et al. (2007) determined that individuals' average preferred walking speed is 1.3 m/s [41]; accordingly, this value was applied to non-disabled agents in the simulation. To enable an accurate comparative analysis of travel time ratios between non-disabled individuals and wheelchair users, the same speed parameter was assigned to wheelchair-using agents. Under these assumptions, agents traversed the designated routes, and their travel times were subsequently computed.

The autonomous agents employed in the simulation are defined by the "RouteAgent" class, which models each agent's fundamental attributes and behaviors. Agents are classified into two types—"Disabled" and "Non-disabled"—and are designed to traverse the network in accordance with the simulation's objectives. The "path" attribute specifies the geometrical route that an agent follows, while the "agent_type" attribute indicates whether the agent is "Disabled" or "Non-disabled." The "distance" and "pos" variables are used to track the agent's current movement status.

3. RESULTS and DISCUSSIONS

This study employed shortest-path analyses on 1,000 randomly selected sample pairs within the Sivas Cumhuriyet University campus and determined that individuals with disabilities face significant accessibility disadvantages. The analyses revealed marked disparities between the network model constructed for non-disabled users and the accessibility-oriented network model specifically designed for wheelchair users.

The results show that for 858 O–D pairs, non-disabled individuals were able to reach their destinations whereas individuals with disabilities could not access the target via any route. This situation reveals the presence of certain campus areas where access is entirely restricted. Of the 142 samples for which access

was possible, wheelchair users and non-disabled individuals followed the same route in 45 cases; in the remaining 97 cases, wheelchair users were forced to take longer routes than non-disabled individuals. The average accessibility score across all 1,000 routes was calculated as 11.75%, indicating that individuals with disabilities experience approximately 8.5 times greater difficulty compared to non-disabled users.

To further visualize and quantify the spatial distribution of accessibility inequalities, a geo-spatial distribution analysis was conducted using the route difference data obtained from the non-disabled and disabled user networks. The difference between the two networks—representing the relative accessibility gap—was first computed for each segment of the campus pedestrian network.

Subsequently, a buffer analysis was applied to cluster these difference values and identify zones where accessibility disparities were most concentrated. The results were visualized as a geo-spatial distribution map to highlight of accessibility challenges, as illustrated in Figure 3.

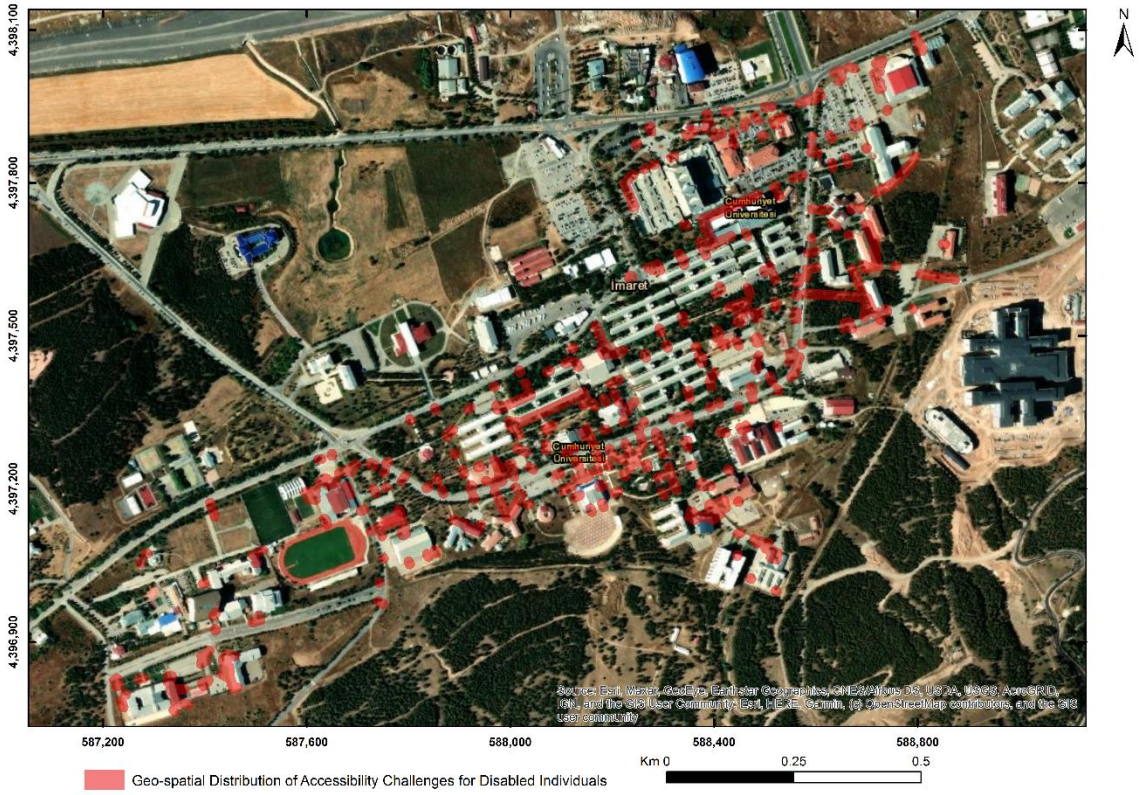


Figure 3. Geo-spatial distribution of accessibility challenges for disabled individuals

This visualization enables a clear understanding of the spatial concentration of obstacles, showing that most accessibility challenges are located along high-traffic pedestrian corridors, such as the main academic spine and the areas connecting social facilities and faculty buildings.

The findings of this study provide a more comprehensive assessment than comparable analyses in the literature by accounting not only for route lengths but also for the presence or absence of accessibility. In this regard, the developed scoring system functions as an objective and comparative tool for conducting accessibility analyses on university campuses. Furthermore, this work serves as a foundational resource for potential future improvement and urban renewal initiatives by local authorities.

The computed shortest and accessible routes will optimize the intra-campus mobility of wheelchair users, thereby facilitating their daily lives. These individuals will be able to navigate the campus more efficiently, gain easier access to social events and academic activities, and participate more actively. The results of the transportation analysis conducted for non-disabled individuals contribute to more rapid and efficient movement within the campus. By enhancing overall campus mobility and delivering time and energy savings, this approach also enables both individuals and institutions to utilize their resources more effectively.

The primary objective of the MAS-based simulation is to compare intra-campus travel times for able-bodied individuals and wheelchair users. During the simulation, the shortest path between two randomly selected points was identified for each agent type, and the travel durations along these paths were computed.

Simulation outcomes indicated that wheelchair users required substantially longer time to traverse the same distances as non-disabled individuals. This finding is attributable to wheelchair users' inability to utilize inaccessible pathways, necessitating the adoption of longer alternative routes. Moreover, the data derived from the simulation facilitate the graphical depiction of the campus's prevailing accessibility barriers.

The optimization strategies developed in this study have the potential to serve as a significant guide for future projects concerning on-campus transportation infrastructure and planning. These findings demonstrate that the challenges encountered by individuals with disabilities must be taken into account by local authorities and university administrations in their planning processes.

Among the fundamental causes of the challenges encountered by individuals with disabilities are the lack of physical accessibility of certain roads and sidewalks, insufficient provision of ramps, and the presence of physical barriers in specific areas. In particular, access to high-traffic campus facilities—such as social amenities, faculties, and sports halls—is restricted for these individuals. This clearly underscores the need for a comprehensive redesign of university campuses to ensure improved accessibility.

For the SCU campus specifically, ensuring that wheelchair users can navigate independently and safely requires the widening of sidewalks, the enhancement of accessible ramps, the removal of physical barriers, and the strengthening of accessibility inspections.

4. CONCLUSIONS

This study was undertaken to identify the spatial access challenges faced by wheelchair users on the SCU campus, to develop concrete remedial proposals for these challenges, and to objectively evaluate the resulting findings using a numerical scoring system. In the Python-based model, the Dijkstra algorithm was employed to perform shortest-path analyses for 1,000 randomly selected samples—both non-disabled and disabled—and the resulting route distances were compared.

The data indicate that individuals with disabilities were completely unable to access certain areas and, where access was possible, were required to traverse distances on average approximately 8.5 times greater than those of non-disabled individuals. These discrepancies were quantified using an accessibility coefficient, resulting in an overall campus accessibility score of 11.75 %.

In prior studies, accessibility has typically been assessed through map production, GIS-based analyses, or survey-driven approaches; however, scoring systems that quantify, compare, and directly measure the actual route experiences of individuals with disabilities have not been implemented. This study fills a critical gap in the literature by moving beyond the mere identification of inaccessible areas via surveys,

measurements, observations, or geospatial analyses, and by proposing a scoring methodology based on an adequate sample size.

This study focused exclusively on the physical accessibility conditions of outdoor spaces. As a result, indoor access features (e.g., building entrances, elevators, interior corridor configurations) were excluded. Moreover, the accessibility assessment considered only the presence of ramps; technical criteria such as slope, width, and maneuvering space specified in the TS 12576:2012 standard were not integrated into the model. Consequently, some ramps may have been classified as accessible in the analysis despite being inaccessible under real-world conditions.

The geo-spatial distribution map also provides a decision-support layer for campus planners, indicating where physical interventions such as ramp adjustments, surface improvements, or redesigns should be prioritized. In future studies, it is recommended to enhance the model by integrating all technical criteria specified in the Turkish Standards Institution (TSE) accessibility standards. Furthermore, a significant limitation of this study is its exclusive focus on wheelchair users. Since the accessibility requirements of individuals with visual impairments, hearing impairments, or cognitive disabilities differ, adapting the model to accommodate various disability types will render accessibility analyses more inclusive.

Ultimately, the developed method offers a flexible and generalizable framework that can be applied not only to the SCU campus but also to other university campuses or public spaces with similar physical configurations. Although the model was tested on the SCU campus, its structure is fully parametric and adaptable to other universities, public institutions, or city-scale pedestrian networks that share comparable topological characteristics. In the context of local authorities' planning and urban renewal efforts, this model provides a foundational guide for the quantitative assessment and prioritization of accessibility inequalities.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

CRediT AUTHOR STATEMENT

Onur Ferdi Güzel: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – Original Draft, Visualization. **İsmail Ercüment Ayazlı:** Conceptualization, Methodology, Formal analysis, Writing – Review & Editing, Visualization, Supervision, Project administration. **Hüseyin Duman:** Methodology, Formal analysis.

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