Performance Analysis of 15-Minute City Zones Through Spatial and Machine Learning Techniques

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Abstract
This study presents a methodology for evaluating pedestrian accessibility within the 15-minute city framework, focusing on Istanbul's Küçükçekmece district. By integrating spatial clustering, slope-adjusted walking speeds, and categorized point-of-interest (POI) data, the study assesses accessibility across 15-, 20-, and 25-minute intervals. The Mean Shift algorithm identified 42 urban clusters based on building density. The findings show that while 71.5% of the district is accessible within 15 minutes, significant spatial inequalities remain, especially in cultural facility access in peripheral neighborhoods. High-density areas with irregular urban forms exhibit limited internal connectivity, which reduces walkability. The study highlights the need for inclusive planning in underserved areas and provides a framework for promoting equitable, resilient, and pedestrian-friendly urban development.

Keywords: 15-Minute Cities; Accessibility; GIS; Machine Learning; Performance Metrics

1. Introduction

Modern cities have faced a multitude of complex challenges, ranging from growing social inequalities and economic instability to pressing environmental concerns such as climate change and resource depletion. To address social, economic, and environmental challenges, various planning principles have been adopted, including livable, inclusive, sustainable, and walkable designs that prioritize accessibility and active mobility (Akrami, Sliwa, and Rynning, 2024). In recent times, the world has faced two significant challanges: the COVID-19 pandemic and the growing climate crisis. These events have significantly reshaped urban priorities, prompting cities to reevaluate how space, mobility, and public health are intertwined. As a result, urban areas are increasingly committed to fostering healthy, resilient, and equitable environments (Liu, Kwan, and Wang, 2023). Amid this backdrop, Professor Carlos Moreno introduced the concept of the "15-minute city" in 2016. This innovative concept seeks to establish self-sufficient areas that encompass essential functions for humans, including living, working, commerce, healthcare, education, and entertainment (Khavarian-Garmsir, Sharifi and Sadeghi, 2022).

This approach is designed to create mixed-use, densely populated, and pedestrian-friendly neighborhoods, allowing residents to access all essential amenities within a 15-minute walk. Additionally, the concept of the 15-minute city is grounded in chrono-urbanism, which posits that the quality of urban life diminishes as the time spent on transportation increases (Moreno et al., 2021). The novel concept aims to enhance transportation efficiency, reduce automobile-related pollution, and transform urban environments so that residents can access essential services and facilities within a designated time frame (Olivari et al., 2023). Additionally, the concept of the 15-minute city is built on four pillars that address various issues, resulting in improvements to both human well-being and urban resilience: proximity, density, diversity, and digitalization (Moreno et al., 2021).

The 15-minute city concept seeks to create urban environments that are mixed-use, livable, sustainable, and pedestrian-friendly (Allam et al., 2024). Since its introduction in 2016, this innovative urban model has sparked ongoing studies and debates, resulting in a continually evolving definition and scope. The effective implementation of the 15-minute city largely depends on the spatial characteristics, as well as the social, environmental, and economic dimensions of each specific urban area. As a result, various adaptations have emerged, leading to the development of cities centered around different time thresholds, collectively referred to as the "x-minute city" concept (Logan et al., 2022). For instance, there have been numerous implementations and studies related to time-based urban models across different cities: the 1-minute city in Stockholm (Schwimmer and Schaufler, 2023), the 5-minute city in Copenhagen (State of Green, 2016), the 10-minute city in Stavanger (Kesarovski and Hernández-Palacio, 2022), the 15-minute city in Milan (Abdelfattah, Deponte, and Fossa, 2022a), the 20-minute city in Tempe, Arizona (Da Silva, King, and Lemar, 2019), and the 30-minute city in Montreal (Birkenfeld et al., 2023).

The literature presents a range of approaches to evaluating accessibility in time-based urban areas. For instance, Staricco (2022) conducted a study in Turin that measured pedestrian accessibility within 5-, 10-, and 15-minute intervals. However, this study focused solely on the number of accessible facilities and did not implement a categorical classification of services. In contrast, another study introduced a categorical framework, grouping facilities into six categories: groceries, healthcare, education, recreation, services, and public transport. This systematic approach aimed to assess accessibility and identify spatial inequalities. Furthermore, this research proposed an innovative index to evaluate the 15-minute city concept, emphasizing the importance of considering a broader spectrum of urban opportunities and addressing the varied needs of populations with different social identities (Guzman, Oviedo, and Cantillo-Garcia, 2024). Additionally, Pour and Partanen (2024) conducted a two-level spatial analysis to examine Tallinn's alignment with the principles of a 15-minute city. The first level focused on population distribution, transport infrastructure, and access to essential services, while the second level identified suitable areas for urban expansion using land use/land cover data, a digital elevation model (DEM), and proximity analysis. Similarly, Ferrer-Ortiz et al. (2022) carried out a network-based accessibility analysis using cadastral parcels, classifying urban social functions into five main categories: care, education, provisioning, entertainment, and public/non-motorized transportation.

Numerous studies have examined accessibility analysis within the context of the 15-minute city concept. Nevertheless, there remains a notable gap in comprehensive and realistic assessments of pedestrian accessibility that account for topographical conditions. Furthermore, defining the spatial structure and layout of the 15-minute city poses a significant challenge for its practical implementation in varying urban contexts. This research aims to address two fundamental questions: a) how to develop appropriate 15-minute zones within already constructed areas, and b) how accessibility varies under different topographical conditions across various time intervals. To accomplish this, the study will evaluate the performance of 15-minute city zones through the application of spatial and machine learning techniques. In the first stage, points of interest (POI) data for various facilities were gathered using the Google Maps Platform Places API and categorized into ten groups to address daily needs. The second stage assessed accessibility based on topographical conditions by utilizing a Digital Elevation Model (DEM) and road network data from OpenStreetMap (OSM) through zonal analysis. The third stage involved obtaining building footprint data from the Humanitarian OpenStreetMap Team (HOT) and applying the Mean Shift clustering algorithm to identify potential 15-minute accessibility zones, with hyperparameter tuning to ensure accuracy. Finally, the fourth stage conducted accessibility analyses over three-time intervals—15, 20, and 25 minutes—and compared the results.

2. Data and Methodology

This study consisted of four steps: a) pre-processing input data, b) clustering of buildings, c) accessibility analysis for three different time intervals, and d) evaluation of accessibility results.

2.1. Study Area

This study examines the Küçükçekmece district of Istanbul to assess the 15-minute city concept, taking into account the district's active participation in related projects. Küçükçekmece is situated in the southwestern part of Istanbul, on the European side, and is approximately 15 km from the city's historical center. The district spans an area of 37.75 km² and is home to a population of 792,030, resulting in a population density of about 17,600 people per square kilometer (Endeksa, 2025). This high density is evident from land cover analysis. Based on land cover data from Esri (ESRI, 2025) for 2023, the land use in Küçükçekmece is diverse, but predominantly urban. Residential areas account for 93% of the district's total land use, highlighting its highly urbanized and densely populated character. Agricultural land comprises 3%, while forested areas make up only 2%, indicating a significant reduction in rural and natural spaces. Furthermore, green spaces constitute just 1% of the total land area, underscoring the limited amount of public open space and the relatively low share of greenery per capita. Bare ground is virtually nonexistent at 0%, with other land uses representing the remaining 1%. This suggests that nearly all available land has been developed, primarily for residential and urban purposes.

2.2. System Architecture

The system architecture is shown in Figure 1 and consists of four essential steps: pre-processing, clustering, accessibility analysis, and evaluating results. Each step is briefly explained below.

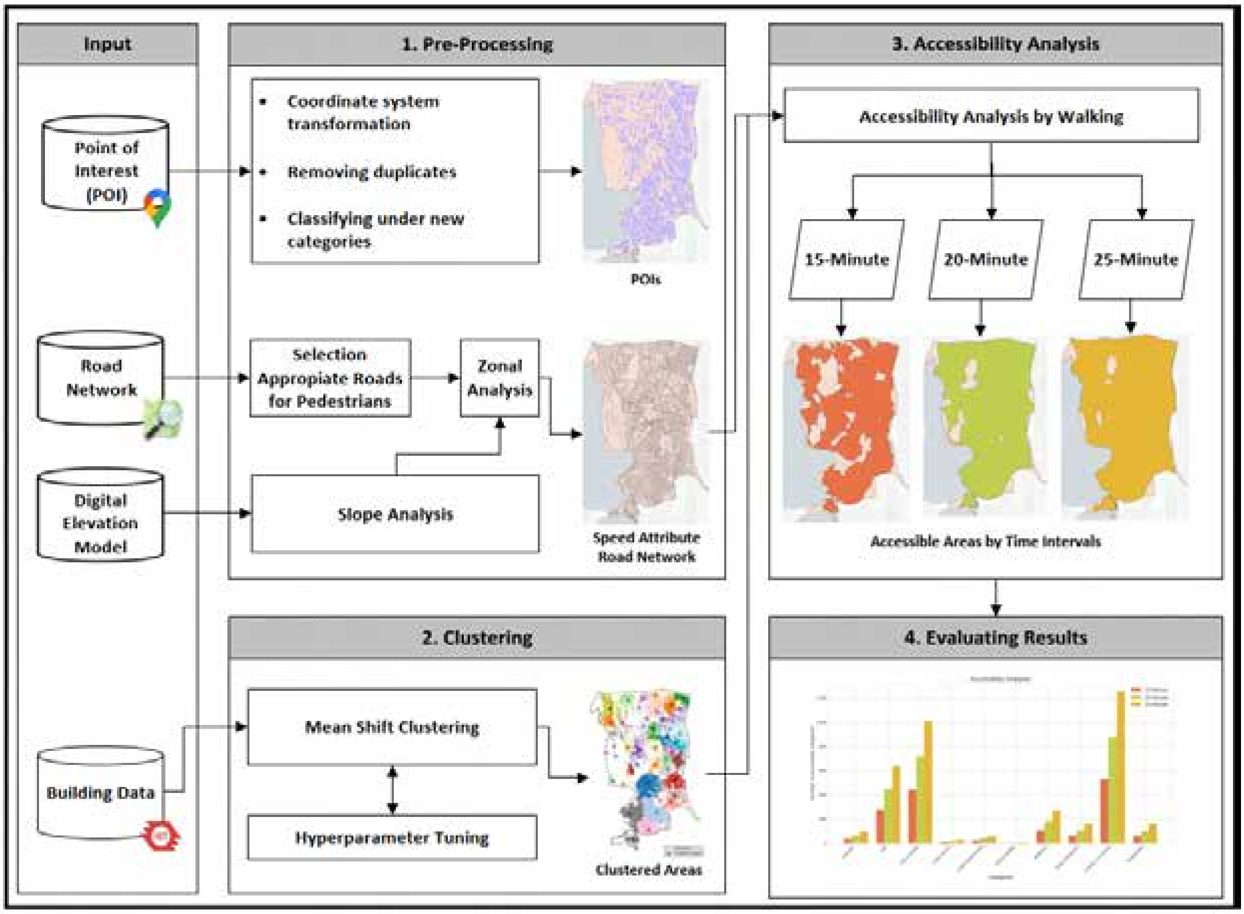


Figure 1. The proposed framework for evaluating 15-minute city concept.

To initiate the analysis, data is gathered from a diverse range of sources, including both open-source repositories and commercial mapping service. Initially, POI data, which covers various types of facilities, is sourced from the Google Maps Platform Places API, a commercial repository. This API offers detailed location information, and for this study, it is utilized within the constraints of its free data request allowance (Google Maps Platform, 2025). For the accessibility analysis, the road network constitutes another crucial dataset. In this research, road data is obtained from the well-regarded open-data platform, OSM (Geofabrik, 2025). To assess variations in walking speed in sloped areas, a Digital Elevation Model (DEM) is employed. The specific model utilized is the Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data from the United States Geological Survey (USGS, 2025). Lastly, to develop clustered areas within the district for evaluating the 15-minute city concept, building data is incorporated. This data is sourced from the HOT, which updates building footprints on a monthly basis (Humanitarian Data Exchange, 2025).

2.2.1. Pre-Processing

The essential initial phase in interpreting spatial data is pre-processing. This stage involves several key steps: transforming the coordinate system, removing duplicate POIs, and classifying the retrieved data based on predefined categories. In the proposed framework, the coordinate system of the POI dataset was converted to a projected coordinate reference system, which supports metric-based calculations and is essential for accurate accessibility analysis. Due to limitations associated with the Google Maps Platform Places API, duplicate POIs may appear within the dataset. To prevent misleading results, these duplicates must be identified and removed prior to analysis. Also, there are various approaches to assess accessibility based on categories. One of these was developed by Prof. Dr. Carlos Moreno in 2021, encompassing six categories: living, working, commerce, healthcare, education, and entertainment (Moreno et al., 2021). In another study, nine categories were determined namely food/grocery stores, commercial stores, cultural venues, educational facilities, parks and green spaces, restaurants, health facilities, sports facilities and other (Abdelfattah, Deponte and Fossa, 2022b). Moreover, according to Regulation on the Preparation of Spatial Plans of Türkiye (Official Gazette, No. 29030), some spatial areas are defined such as small industrial areas, cultural areas, social infrastructure areas, and social facility areas. Hence, within this study, in order to cover all relevant aspects of daily urban life and align with both international and national frameworks, a customized categorization scheme was developed. This classification integrates widely accepted categories from the literature with those defined in national planning regulations.

Moreover, slope is an important factor on pedestrian accessibility. Sloping walkways tend to diminish pedestrian flow performance compared to level surfaces (Wei et al., 2023). Considering DEM in accessibility analysis is essential. However, there is a notable gap in the literature regarding the use of DEM for assessing accessibility within the 15-minute city concept. To address this shortcoming, the present study incorporates slope information derived from a DEM to adjust walking speeds throughout the road network. This adjustment enables the analysis to account for the effects of terrain variations on walking accessibility, resulting in a more accurate representation of areas that can be reached within designated time thresholds. This approach not only enhances the methodological rigor of evaluations related to the 15-minute city but also introduces topographic realism into pedestrian accessibility modelling.

2.2.2. Clustering

The study employs the Mean Shift clustering algorithm, a popular machine learning technique that is also used in spatial clustering applications (Chen et al., 2018; Peng et al., 2024). This clustering algorithm is introduced by Fukunaga and Hostetler in 1975 (Fukunaga and Hostetler, 1975). Mean Shift clustering is an unsupervised learning algorithm that organizes data according to its natural distribution. One of its most notable characteristics is that it does not require any prior knowledge of the number or positions of the cluster centers. Furthermore, Mean Shift imposes no assumptions about the shape of the clusters and places no restrictions on their size (Tehreem et al., 2017). The study clusters building data using the Mean Shift algorithm and applies hyperparameter tuning to optimally identify clustered areas based on building density.

2.2.3. Accessibility Analysis

The concept of the 15-minute city encompasses several time-based proximity approaches. Initially proposed by Prof. Dr. Carlos Moreno in 2016, this framework seeks to enhance walkability and develop pedestrian-friendly neighborhoods. Since its introduction, various time-oriented strategies such as 15, 20, and 30 minutes have been implemented across different regions to further this objective (Giuffrida et al., 2024). Overall, the policy directions related to this concept are inconsistent across thematic areas and geographic regions (Lu and Diab, 2022).

The built-up surface per capita is 13 m^2/capita in Küçükçekmece resulting high density and compact city (OECD Local Data Portal, 2020). This study analyzes pedestrian accessibility by examining three walking time intervals for clustered areas with varying building densities: 15, 20, and 25 minutes. These intervals are utilized to define the spatial reach of services and amenities from the centers of clusters identified through the Mean Shift algorithm. The cluster centers represent the most densely developed areas within the study region and serve as potential focal points for urban activity. By creating service areas around these centers for each time threshold, the study seeks to quantify how far individuals can walk within the specified time frames and to assess the distribution and coverage of accessible urban functions in relation to population density.

2.2.4. Evaluation of Results

In this step, pedestrian accessibility results for various time intervals, 15, 20, and 25 minutes, are assessed and compared to provide insights into how accessibility levels shift with walking time. The analysis aims to highlight differences in the spatial extent of reachable areas from each cluster center and examines how these variations correspond to the distribution of urban amenities. In addition to this comparative evaluation, special emphasis is placed on outlier areas—locations that significantly fall outside the primary clustered accessibility zones.

These outliers are analyzed to identify spatial mismatches, underserved regions, or peripheral zones with limited access to urban functions. The recognition of such areas is essential for uncovering potential gaps in service provision and informing equitable urban planning strategies.

3. Results and Discussion

3.1. Pre-Processing

In this step, walking accessibility is evaluated by pre-processing the collected spatial data from various perspectives. Initially, the coordinate system of POI dataset is transformed to a projected coordinate reference system (EPSG:5254) to ensure necessary metric-based spatial accuracy for accessibility analyses. Subsequently, duplicate POIs are removed to eliminate any potential skewing or misleading outcomes in the accessibility results. The POI dataset, which originally contained a range of labels such as "bank," "police," "food," and "supermarket," is reclassified according to a system developed for assessing 15-minute cities. A refined classification system comprising ten thematic categories is utilized, reflecting essential components of daily urban life: education, food, daily essentials, public services, small industrial areas, cultural facilities, healthcare services, social infrastructure, commerce & economy, and transportation. Each category is considered crucial for fostering a well-rounded and accessible urban environment. In the Table 1, POI labels for defined categories are given.

Table 1. Defined categories and belonging POI labels.

Categories	POI Labels
Education	primary_school, school, secondary_school, university
Food	supermarket, bakery, convenience_store, food, grocery_or_supermarket, liquor_store
Daily essentials	shoe_store, restaurant, parking, meal_takeaway, meal_delivery, laundry, hair_care, atm, beauty_salon, clothing_store, gas_station
Public services	post_office, police, local_government_office, city_hall, courthouse, fire_station, lawyer
Small industrial areas	*These category is evaluated manually from POI data.*
Cultural facilities	library, movie_theater, museum
Healthcare services	veterinary_care, physiotherapist, dentist, doctor, drugstore, health, hospital, pharmacy
Social infrastructure	stadium, spa, premise, place_of_worship, park, night_club, mosque, amusement_park, aquarium, gym, lodging
Commerce & Economy	store, shopping_mall, roofing_contractor, real_estate_agency, plumber, pet_store, painter, locksmith, jewelry_store, insurance_agency, home_goods, hardware, general_contractor, furniture_store, finance, electronics_store, electrician, department_store, accounting, bank, bar, bicycle_store, book_store, cafe
Transportation	taxi_stand, train_station, transit_station

In the second step, a DEM was used to improve the accuracy of accessibility measurements by incorporating topographic features. Firstly, the appropriate roads for pedestrians were selected from road dataset. Specifically, slope values for the Küçükçekmece district were extracted from the DEM. These slope values were then integrated with the road network through zonal analysis, creating a slope-attributed road dataset where each segment reflects its corresponding gradient. According to Giannoulaki and Christoforou (2024), the average walking speeds for males and females in Türkiye are 1.34 m/s and 1.27 m/s, respectively. For this study, an average walking speed of 1.31 m/s was utilized to represent the general population.

By combining this standardized walking speed with the slope information for each road segment, adjusted walking speeds were calculated, allowing for a more accurate modelling of pedestrian accessibility across varying terrain conditions.

3.2. Clustering

In the proposed assessment system for a 15-minute city, the Mean Shift clustering algorithm is used to categorize buildings based on their densities and analyse potential areas for the 15-minute city. To do that, building footprint dataset is utilized in Mean Shift clustering algorithm. In the Mean Shift clustering algorithm, the bandwidth parameter is essential for determining the results of clustering. It defines the kernel radius used to estimate data density, which influences the number, size, and shape of the clusters formed. A larger bandwidth results in fewer, broader clusters, while a smaller bandwidth creates more, smaller clusters that capture local variations in the data. To determine the appropriate bandwidth value for the Mean Shift algorithm, hyperparameter tuning was conducted by evaluating both quantitative metrics and visual interpretations of the resulting clusters. Although slightly higher Silhouette scores were observed with alternative bandwidth settings, a bandwidth defined by a quantile value of 0.02 and 300 samples was ultimately selected, yielding a Silhouette score of 0.38. This configuration was preferred because it provided a good balance between cluster compactness and spatial interpretability, ensuring that the identified clusters aligned well with the underlying built environment and urban density patterns. As a result of this hyperparameter selection, a total of 42 clusters were generated. In the Figure 2, the clustered buildings and cluster centers are presented.

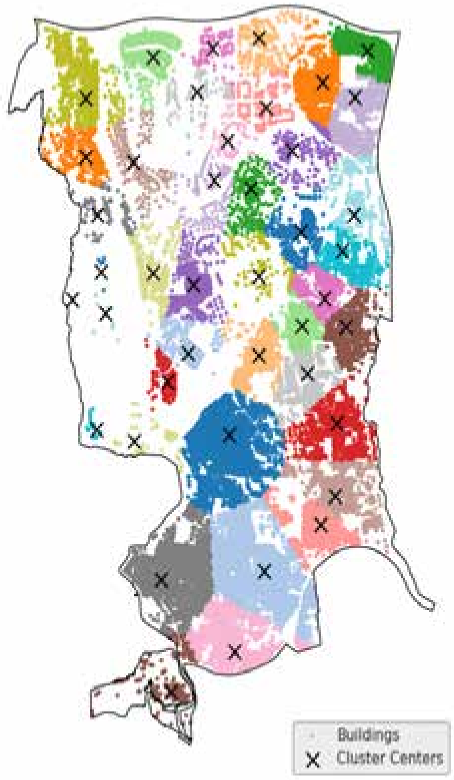


Figure 2. Clustered buildings and cluster centers.

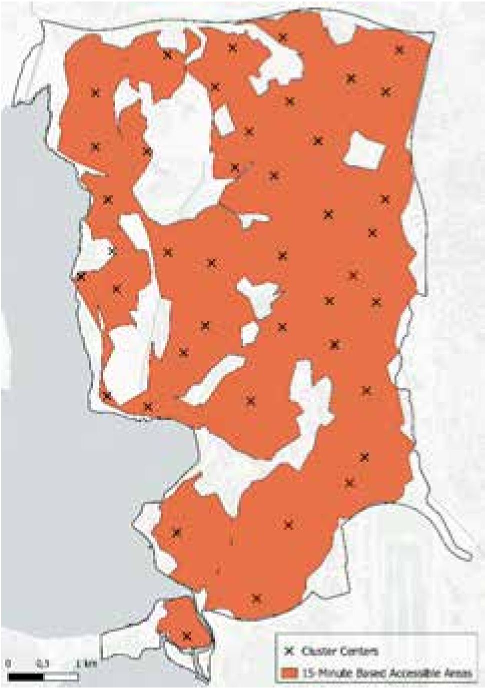
It has been noted that the southern part of the study area has developed through unplanned and irregular urbanization. In this region, residential density has increased in a fragmented and uncontrolled manner, resulting in a significant decline in the continuity and accessibility of green spaces. Conversely, the north-western part of the study area displays a more organized urban layout, where the balance between green spaces and built-up areas has been preserved through careful planning. This spatial contrast is clearly reflected in the Mean Shift clustering results. As illustrated in Figure 2, clusters in the planned areas are smaller and more compact, while those in regions affected by irregular urbanization are larger and more dispersed. This observation underscores a strong correlation between unplanned urban sprawl and building density, a relationship further confirmed by the Mean Shift clustering analysis. Figure 3 presents a comparative example of high- and low-density urban zones within the study area. Moreover, it has been observed that the data sourced from the HOT does not entirely capture ground realities. When compared to actual field conditions, certain areas lack complete building footprints or contain outdated information.

a) Southern side of the study area. **b)** North-western side of the study area.

Figure 3. Clustering results from urban layout: (a) urban area with high building density, (b) urban area with low building density (yellow crosses indicates cluster centers).

3.3. Accessibility Analysis

This study examines accessibility in the Küçükçekmece district by analyzing designated cluster centers and utilizing a modified road network that reflects variations in walking speed due to slope data. The objective of the analysis is to determine the spatial reach of areas accessible on foot within specific timeframes. The findings reveal that approximately 71.5% of the district can be accessed within a 15-minute walking distance, 85.5% within 20 minutes, and 91.6% within 25 minutes. These results indicate that a significant portion of Küçükçekmece lies within walking distance of the identified urban clusters, reinforcing the viability of the 15-minute city concept in certain areas of the district. These results are shown in Figure 4.



a) 15-minute based accessible areas.

b) 20-minute based accessible areas.

c) 25-minute based accessible areas.

Figure 4. 15-,20- and 25-minute based accessible areas.

When examining accessibility from a comprehensive perspective, it becomes clear that the north-western portion of the study area—comprised of planned residential neighborhoods with a balanced distribution of green spaces and buildings—remains partially inaccessible, despite its proximity to major arterial roads. This inaccessibility can be attributed to the design of these areas as enclosed systems surrounded by major thoroughfares, which results in a lack of pedestrian-friendly internal connectivity. In the southern parts of the district, characterized by significantly higher building density, the algorithm encounters difficulties in identifying an adequate number of cluster centers. As a result, despite the high residential density and substantial pedestrian potential, these areas cannot be reached within a 15-minute walking threshold. The 20-minute analysis reveals an expansion in overall accessibility, owing to the extended walking time. However, certain regions—particularly newly developed neighborhoods and high-density residential zones—remain unreachable because of their distance from the identified cluster centers and the limited pedestrian infrastructure available. The 25-minute analysis demonstrates that a considerable portion of the district becomes accessible. Nevertheless, areas without any development, especially in the north-eastern part, continue to lack pedestrian access and remain unreachable in all time-based scenarios. Moreover, across all analyses, it is observed that accessibility improves in regions with steep terrain as the time threshold increases. However, during the 15-minute interval, these high-slope areas remain notably less accessible. Overall, the findings underscore that construction sites and enclosed residential complexes in the north-western part of the study area face significant challenges regarding pedestrian accessibility, highlighting their unfavorable position within the urban landscape.

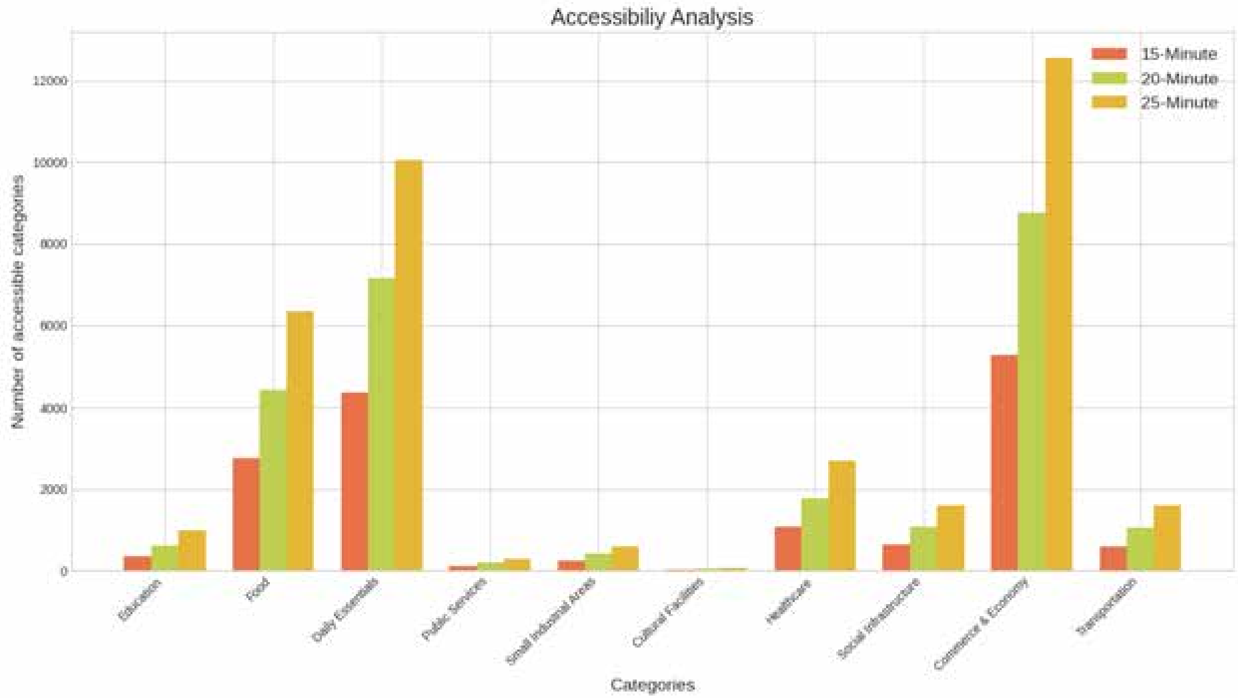


Figure 5. Number of accessible categories regarding to different time-based intervals.

As depicted in Figure 5, the number of accessible facilities increases considerably as walking time expands. This trend is particularly evident in categories such as daily essentials, food, and commerce and economy. For instance, there are 4,368 facilities reachable within 15 minutes, which escalates to 10,047 within 25 minutes, indicating a relatively well-distributed supply of these services across the district. In contrast, categories like public services and, more notably, cultural facilities demonstrate low levels of accessibility. Cultural facilities consistently rank the lowest in accessibility across all time intervals, with only 27 facilities reachable within 15 minutes and just 80 within 25 minutes. This observation highlights not only the scarcity of such facilities but also their concentration in specific areas of the district. Moderate and relatively balanced accessibility patterns are found in education, healthcare, social infrastructure, and transportation. This suggests a more deliberate spatial distribution for these services. However, some deficiencies are still apparent, particularly in newly developed neighborhoods and peripheral zones of the district. Additionally, the findings reveal that accessibility levels are closely tied to both functional distribution and urban form and morphology. While the planned and orderly developments in the north-western part of the district exhibit high pedestrian accessibility, the irregularly developed areas in the south show more limited and uneven access. This is particularly noticeable in gated communities or unplanned residential areas, which, despite having a high building density, suffer from poor internal connectivity, significantly impeding walkability within a 15-minute range.

4. Conclusion

This study offers a comprehensive methodology for assessing pedestrian accessibility within the framework of the 15-minute city concept, using the Küçükçekmece district of Istanbul as a case study. By integrating spatial clustering, elevation-based speed adjustments, and categorized POI data, the analysis effectively captures both the physical and functional aspects of accessibility in a densely populated urban environment. The findings indicate that while over 70% of the district is reachable within a 15-minute walking distance, notable spatial disparities persist across various areas and functional categories. Though services related to daily needs, food, and economic activities are fairly well-distributed, essential public services and cultural facilities remain limited in both quantity and spatial coverage. This imbalance highlights the necessity for more inclusive spatial planning to ensure equitable access to all urban functions, especially those linked to cultural participation and civic engagement. Furthermore, the study emphasizes the influence of urban form on accessibility outcomes. Well-planned and integrated areas in the north-western part of the district generally facilitate walkability, whereas fragmented and irregular developments—particularly in the southern and peripheral areas—encounter structural barriers to pedestrian movement, such as disconnected street networks and gated communities. Incorporating slope data into the accessibility model further refines the analysis by illustrating how terrain variation can significantly impact walkability, especially within shorter time thresholds. In conclusion, this research demonstrates that the 15-minute city framework is partially attainable in a high-density context like Küçükçekmece. However, to fully capitalize on its potential, Geomatics Engineers, Urban Planners and decision-makers must advocate for a more equitable distribution of public and cultural services and prioritize pedestrian-oriented urban design, particularly in high-density and newly developed areas. The methodology presented in this study can also be adapted for use in other urban settings seeking to enhance proximity-based accessibility and cultivate more resilient, inclusive, and livable cities.

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