Public Transit and Health Access in Utrecht's 10-Minute City Vision

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Abstract

This thesis examines the relationship between public transit accessibility and health amenities within the framework of Utrecht's '10-minute city' vision. The study focuses on five neighborhoods: Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord. The research aims to determine how effectively the current public transportation system supports the 10-minute city goals, specifically in terms of access to health amenities and public transport. Using a combination of distance-based and gravity-based measures, the study maps accessibility via public transit and walking, providing a comprehensive analysis of the transit network's effectiveness.

The findings reveal significant variability in accessibility across different neighborhoods, with Wittevrouwen and Leidsche Rijn-Centrum showing higher accessibility scores due to more frequent and reliable public transit services. In contrast, Vechtzoom-Zuid exhibits considerable internal variability, with some areas showing high accessibility and others much lower, indicating a dependence on specific locations within the neighborhood. Kanaleneiland-Noord generally exhibits lower accessibility, highlighting the need for targeted improvements in these areas. Achieving the vision of a 10-minute city is highly dependent on which indicators, amenities, and services fall under this term. The variability in definitions and categories used in different studies underscores the importance of context-specific criteria and priorities set by each municipality.

Overall, the study provides valuable insights into the spatial distribution of healthcare services and underscores the importance of public transport in achieving the 10-minute city vision. It highlights areas where improvements in public transport infrastructure and service quality can significantly enhance healthcare accessibility, supporting Utrecht's goal of creating a more inclusive, sustainable, and connected urban environment.

Keywords: 10-minute city, public transit accessibility, healthcare access, spatial analysis

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1. Introduction

'Utrecht must be a 'ten-minute city' by 2040: sports, work and school are around the corner for everyone'
- *Algemeen Dagblad (Hoving, 2021)*

In July 2021, the municipality of Utrecht unveiled a new spatial vision, outlining its strategic plan for the city's development and urban landscape. Within this plan, a concept arose: the ten-minute city. The ten-minute city is a version of the original 15-minute city attributed to Carlos Moreno (2021). This innovative approach envisions every day, or frequently needed amenities conveniently located within approximately 10 minutes from one's residence or workplace, transforming Utrecht into a more accessible and interconnected urban environment (Ruimtelijke Strategie Utrecht, 2021, p.27).

Given the essential roles of health and medical care in our daily lives, ensuring sufficient access to healthcare facilities across different regions and demographic groups is imperative (Zhang, Deng & Li, 2020, p.1). Unlike general services, healthcare facilities, ranging from community-level healthcare centers to hospitals, vary significantly in the nature and urgency of their services. For instance, the expectation for a general practitioner to be within a 15-minute reach aligns with the goal of a '15- minute city,' acknowledging the immediate and routine nature of primary care. On the other hand, the efficiency of a hospital, offering comprehensive and specialized services, within a 15-minute radius is questioned (Song, Kong, Li, Zhai & Luo, 2022, p.3).

Papadopoulos, Sdoukopoulos & Politis (2023, p.16) showed that in terms of the means of transport used to access urban amenities within the 15-minute city concept, the existing literature focuses mostly on walking or cycling. This is because the distances that could be covered by traveling on foot are systematically smaller than those using other modes of transport, within the same time range. The importance of cycling and public transport decreases when measuring accessibility to local amenities, these modes of transport are important extensions that allow city dwellers to reach their destinations beyond the 15-minute walking isochrone (Papadopoulos et al, 2023, p.16).

According to Zhang, Deng & Li (2020, p.1) individuals facing physical limitations, such as the elderly, people with disabilities, post-surgery patients, and pregnant women, who often need to visit health amenities, may confront challenges in walking, cycling, or driving themselves to these facilities. This is particularly noteworthy for those without personal vehicles, as dependence on public transportation becomes crucial, especially for hospital visits. Recognizing this interplay between transportation modes and accessibility to health amenities, there is a need to assess how effectively public transport facilitates access to healthcare facilities (Zhang, Deng & Li, 2020, p.1).

Public transport plays a relevant role in bridging these accessibility gaps. The "wheel with spokes" model, emphasized in Utrecht's urban planning, supports high-frequency transit routes and strategically placed hubs, facilitating better connectivity and reducing travel times. By aligning the 10-minute city goals with this model, Utrecht plans to enhance public transit reliability, making healthcare services more accessible to all residents (Ruimtelijke Strategie Utrecht, 2021, pp 113-115).

This study addresses the gap by examining the challenges and opportunities of public transportation for health amenity accessibility in Utrecht's 'ten-minute city.' Unlike the predominant focus on walking and cycling, it acknowledges the unique needs of those depending on public transport for healthcare. It responds to the municipality's vision and aligns with broader goals of fostering an inclusive, sustainable, and health-conscious urban landscape. The research provides insights into the effective integration of public transportation into the 'ten-minute city' model, aiming to ensure equitable access to health amenities for all residents in Utrecht.

1.1 Aim and Research Question

Building upon the identified challenges in healthcare accessibility highlighted by Zhang, Deng & Li (2020, p.1), this study aims to assess how well the current public transportation system in Utrecht aligns with the principles and objectives of the 'ten-minute city' concept. The unique needs and challenges of individuals relying on public transport for healthcare access will be examined. The neighbourhoods selected for investigation are Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Kanaleneiland-Noord and Vechtzoom-Zuid. The central research question is:

To what extent does the current public transportation system align with the objectives of the 'ten-minute city' concept regarding the accessibility of healthcare facilities in Utrecht?

The sub-questions are:

1. To what extent are general practitioners accessible from residential homes in the study areas?
2. To what extent are the bus or tram stops accessible from residential homes in the study areas?
3. To what extent are the Hospitals located in Utrecht accessible using public transportation from the study areas?
4. How does accessibility vary when using different criteria or definitions of what services should be reachable within ten minutes?

1.2 Delimitations

The scope of this investigation is thematically bounded to scrutinize the alignment of the current public transportation system in the Utrecht neighbourhoods of Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Kanaleneiland-Noord and Vechtzoom-Zuid with the objectives of the 'ten-minute city' concept. Specifically, the research will delve into the accessibility of healthcare facilities within these neighbourhoods in relation to the 'ten-minute city' model. It is important to note that this study offers a snapshot of the existing situation and does not aim to provide a definitive assessment of the overall effectiveness of the 'ten-minute city' concept. Instead, the primary goal is to assess the current state, strengths, risks, and challenges in the context of public transportation and healthcare accessibility within these specific Utrecht neighbourhoods. This research seeks to contribute valuable insights to the ongoing discussion on the 'ten-minute city' concept, providing practical information for urban planning and healthcare accessibility considerations in the studied areas.

1.3 Disposition

This thesis is structured into seven chapters. The introductory chapter provides an overview of the research, followed by a background section that explores the current urban trends in Utrecht, as well as specific details about the study areas. The third chapter establishes a theoretical framework, encompassing a literature review and focusing on three key theoretical terms: (1) Accessibility, (2) The 15-minute city and (3) the total travel time. The fourth chapter details the methodology employed in the investigation, outlining the materials collected and utilized during the research process. Subsequently, the fifth chapter presents a thorough analysis of the empirical material gathered. Moving forward, chapter six serves as the conclusion, summarizing findings and offering recommendations based on the research outcomes. Finally, chapter seven engages in a discussion of the results obtained from the analysis.

2. Background

The background section aims to contextualize the city of Utrecht by delving into its future urban and regional planning policies. Additionally, it will introduce the five specific study areas within Utrecht.

2.1 Urban and Regional Planning

Utrecht ranks as the fourth-largest city in terms of population. It is projected to grow from over 350,000 to approximately 455,000 residents in the next twenty years (Ruimtelijke Strategie Utrecht, 2021, p.9). The city is centrally situated in the province of Utrecht (see figure 1 for reference).

Figure 1. A map of the Netherlands with the municipality of Utrecht in red.

Source: Centraal Bureau van Statistiek (n.d.) Wijk- en buurtkaart 2022.

Utrecht is relatively the fastest-growing city in the Netherlands. With this growth comes an increasing demand for housing, green spaces, amenities, jobs, mobility, and sustainable energy. Embracing this growth, Utrecht aims to leverage it to enhance healthy urban living for everyone. The city currently has approximately 157,000 dwellings. However, with the population set to increase, there is a need for over 60,000 additional homes, accompanied by a proportional growth in social amenities and green spaces within the city for recreation and climate adaptation. Additionally, around 70,000 extra job opportunities will be required (Ruimtelijke Strategie Utrecht, 2021, p.87).

By 2050, Utrecht also aims to achieve climate neutrality, necessitating investments in energy transition. Further urban densification requires a reimagining of available space. There will be less room for both moving and parked cars; thus, promoting walking, cycling, public transportation, and shared mobility is imperative, demanding significant investments in mobility infrastructure. Utrecht's current and future strength lies in its relatively short distances for daily urban and peri-urban interactions: also know as the human scale of Utrecht. Consequently, the city council, as delineated in the Principles Document for the Regional Structural Vision 2040 (Ruimtelijke Strategie Utrecht, 2021, p28), has placed emphasis on urban development through the following priorities:

1. Increasing density around urban hubs.
2. Enhancing density in peripheral urban hubs and within urban areas, while preserving green spaces (including small-scale greenery) and public spaces (especially squares) whenever feasible, independent of full utilization of priority (1).
3. Extending development beyond the city boundaries.

To improve access and ease congestion in the city centre, the municipality plans to create new urban hubs in various parts of Utrecht. These hubs will include housing, shops, amenities, and green spaces, turning Utrecht into a city with multiple focal points. Following the 10-minute city model, residents living near these hubs should be able to reach one within a 10-minute travel time. Connected to a reliable transportation network and green-blue areas, these hubs are needed for the city's growth. Their development aligns with Utrecht's goal for healthy city living, ensuring balanced expansion and maintaining the city's quality (Ruimtelijke Strategie Utrecht, 2021, p28).

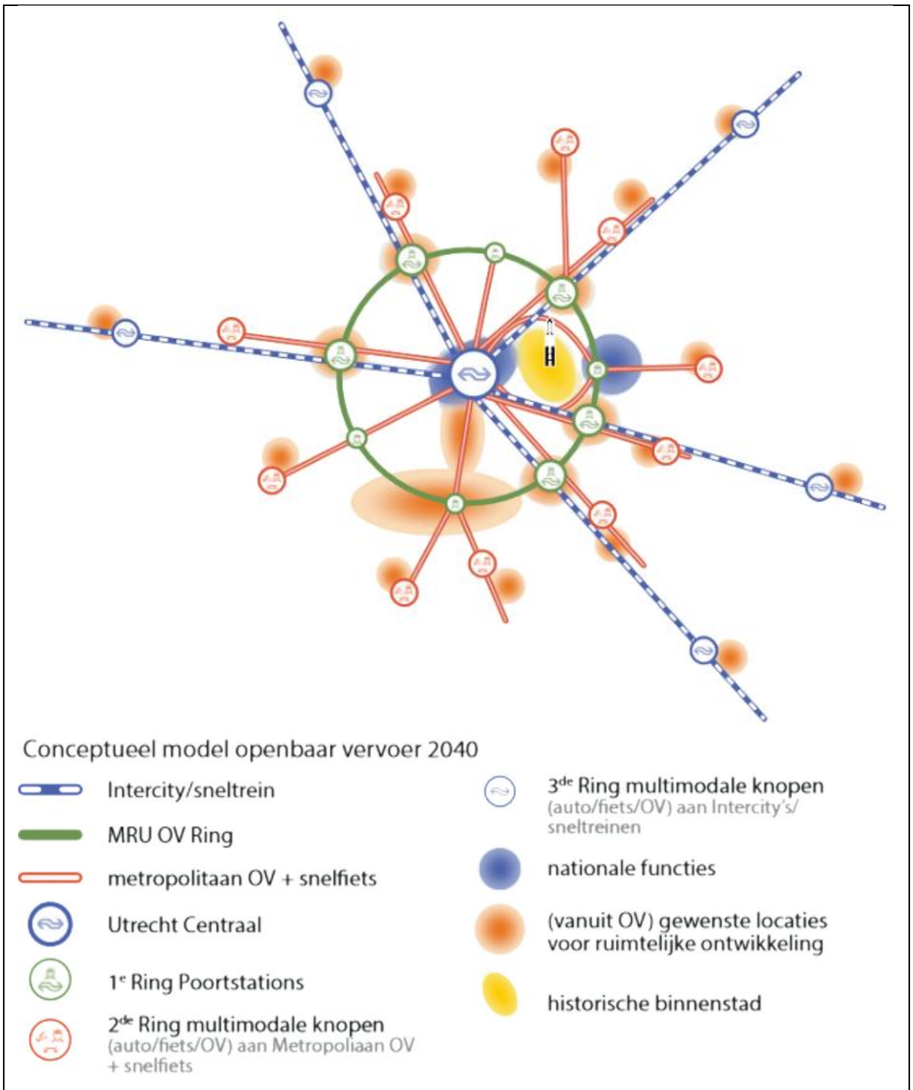
2.2.1 Utrecht Mobility Approach

According to the spatial plan of Utrecht, the city is grappling with an existing traffic overload, compounded by forecasts indicating a 35% surge in journeys by 2040 compared to 2015. Congestion plagues Utrecht, manifesting in queues of cars, congested bike lanes, and crowded public transport services including buses, trams, and trains. Addressing these challenges necessitates substantial investments in diverse mobility strategies, prioritizing sustainable transportation modes like walking, cycling, public transit, and shared mobility options (Ruimtelijke Strategie Utrecht, 2021, pp 113-115).

Therefore, the municipality suggests a new mobility plan, also known as the Utrecht mobility approach (Ruimtelijke Strategie Utrecht, 2021, pp 113-115). The Utrecht mobility approach consists of five key components. Firstly, it emphasizes (1) Smart Allocation of Destinations, integrating city growth with an expanded public transport network to shorten travel distances between residences, workplaces, and amenities. Secondly, (2) Alternative Travel methods are promoted through collaboration with employers and educational institutions, encouraging telecommuting, schedule adjustments, and sustainable transport usage to alleviate congestion and reduce reliance on personal vehicles. Thirdly, (3) Networks in Order focuses on adapting pedestrian, cyclist, and public transport networks to accommodate increased mobility, dispersing traffic to ease congestion and improve safety. Fourthly, (4) Smart Parking initiatives repurpose street spaces for pedestrian zones, green areas, and recreational activities, while encouraging off-site parking solutions and reducing on-site parking in new developments. Finally, (5) Intelligent Management involves proactive management of the entire transportation network to prioritize sustainable modes of transport, optimize traffic flow, and accommodate other functions like leisure and green spaces, with considerations for pedestrian and cyclist safety in recreational areas (Ruimtelijke Strategie Utrecht, 2021, pp 113-115).

The Utrecht region is focusing on the mobility concept of the "wheel with spokes" as the backbone for the mobility transition and as the foundation for urban development (see figure 2). This concept involves a network of high-quality bus, tram, and train connections, with spokes providing connections from the region and beyond to the national hub at Utrecht Central and the city centre, and wheel connections forming direct, frequent links between the region, a network of Park and Ride locations, and economic core areas. Intersection points between spokes and wheel connections create nodes where travellers can conveniently transfer between different modes of transportation (intermodal mobility) and are attractive for urban development. By 2040, trains will run at least every 10 minutes on all major rail connections, reducing the need for travel via Utrecht Central. The wheel and hub connections are designed to be fast and attractive, encouraging fewer people to travel via Utrecht Central (Ruimtelijke Strategie Utrecht, 2021, pp 113-115).

Figure 2: The wheel with spokes as backbone of the public transport network in Utrecht (in Dutch).

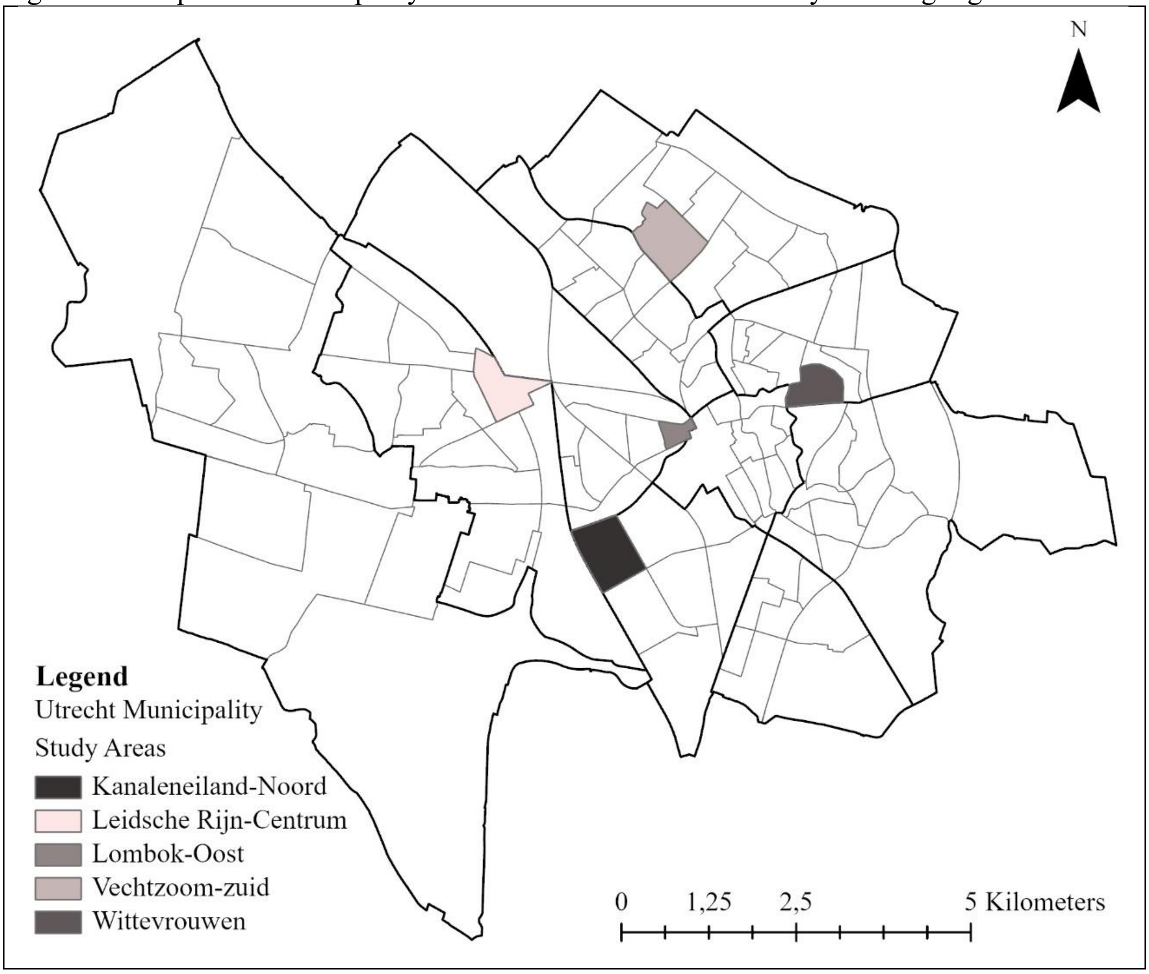


Source: Ruimtelijke Strategie Utrecht 2040, Gemeente Utrecht (2021, p.114).

2.2 Study Areas

The study areas selected encompass Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord (See Figure 3). Each subsequent section will offer a comprehensive overview of these neighbourhoods. The choice of these neighbourhoods is based on their diverse residential demographics, construction periods, housing types, and locations. Figure 3 illustrates the location of each study area, aligning with Utrecht's mobility approach resembling a wheel of spokes. Through an examination of these neighbourhoods, a current assessment of the mobility plan is conducted. This information will inform the development of strategies to enhance mobility in specific areas as part of the overall mobility approach.

Figure 3. A map of the municipality of Utrecht with the selected study areas highlighted.



Source: Centraal Bureau van Statistiek (n.d.) Wijk- en Buurtregister 2022.

2.2.1 Wittevrouwen

Wittevrouwen is a neighbourhood located in the North-East district of Utrecht. Many houses in Wittevrouwen were constructed in the late nineteenth-century eclectic style, characterized by elaborately decorated facades with decorative elements (see figure 4). The neighbourhood has a rich history, originating from the Wittevrouwenklooster (Wittevrouwen Convent) dating back to the Middle Ages. Wittevrouwen borders the city centre and other neighbourhoods such as Buiten Wittevrouwen, the Zeeheldenbuurt, and the Vogelenbuurt (Gemeente Utrecht, n.d.-b). The neighbourhood is primarily accessible by public transport via the bus, with the following lines serving the area: bus 28, bus 50, bus 73, bus 74, and bus 77 (Nederlandsche Spoorwegen, n.d.).

In 2023, Wittevrouwen had a population of 6,605 inhabitants, marking a decrease of 100 residents since 2013, representing a decline of 1.49%. Covering a total area of 37 hectares, the neighbourhood maintains an average density of 5,333 addresses per square kilometre. Notably, the largest age group among Wittevrouwen's residents falls between 25 and 45 years old, constituting over a third of the total population. The area is primarily inhabited by families or dual-income households with higher earnings. Approximately 63% of the houses are privately owned, while 24% are rented out by individuals. Housing associations manage 11% of the properties, focusing on providing affordable housing. The average property value, as assessed by the WOZ in 2023, is €559,446, exceeding the municipality average of €463,228 (Gemeente Utrecht, Onderzoek & Advies en Volksgezondheid, n.d.).

Figure 4. Wittevrouwen, Utrecht (Utrecht by Inge, 2024)

2.2.2 Leidsche Rijn-Centrum

Leidsche Rijn-Centrum is a relatively new neighbourhood that is still under construction. The architecture in Leidsche Rijn-Centrum is modern and varied, featuring both apartment complexes and single-family homes. The heart of the neighbourhood is the Leidsche Rijn Shopping Centre, which offers a diverse range of shops, supermarkets, and specialty stores (see figure 5). Nearby, Maximapark is a popular spot for recreation and relaxation. Leidsche Rijn-Centrum has its own train- and bus station (Gemeente Utrecht, n.d.-a). This station is located directly at Brusselplein and is only about a 5-minute walk from the city centre of Leidsche Rijn. By train, you can reach the shopping centre in just 4 minutes from Utrecht Central. By bus, you can reach Leidsche Rijn with the following lines: 5, 73, 28, and 11 (Nederlandsche Spoorwegen, n.d.).

The first residents were registered in 2016, numbering 88. By 2019, the population had grown to 2,206 people, and in 2023, it reached an impressive 5,715. In the Leidsche Rijn-Centrum area of Utrecht, there are 2,397 addresses per square kilometre, covering a total area of 52 hectares of land. The majority of residents fall within the age categories of 20-29 years and 30-39 years. Apartments are particularly popular among young professionals, while the single-family homes are ideal for families. Of all the residences, the largest share is privately rented, accounting for 74%. The percentage of owner-occupied homes is 22%, while 5% are owned by housing corporations. The most common type of dwelling is the apartment building (50% of residences), followed by gallery flats (23%). The average WOZ value for homes in Leidsche Rijn-Centrum is €382.384, which is below the municipality 's average (Gemeente Utrecht, Onderzoek & Advies en Volksgezondheid, n.d.).

Figure 5. Brusselplein in Leidsche Rijn-Centrum, Utrecht (by Baljon Landscape Architects, n.d.).

2.2.3 Lombok-Oost

Lombok is the multicultural heart of Utrecht. Its vibrant streets, like Kanaalstraat and its side alleys, are packed with shops offering exotic specialties, trinkets, and gourmet delights. Once a traditional working-class neighborhood with early 20th-century architecture, Lombok now boasts trendy coffee shops, eateries, and cozy cafes alongside its characteristic narrow streets and quaint workers' cottages (see figure 6) (Gemeente Utrecht, n.d.-d). It is situated within a walking distance (10-20 min) of the Central Station. It has two bus stops around the edges of the neighbourhood, with one being only a stop towards the station and not the opposite destination. The busses that pass these stops are bus 28, bus 73, bus 38 and 120 (Nederlandsche Spoorwegen, n.d.).

In 2013, Lombok-Oost was home to 2,179 residents. By 2023, the population did not change much: it consists of 2,220 residents. Spanning an area of 13 hectares, the neighbourhood boasts a density of 4.856 addresses per square kilometre. The majority of its inhabitants are between the ages of 20 and 29. Regarding housing tenure, 38% of the residences are owner-occupied, while 29% are owned by housing associations, and 32% are privately rented. The average WOZ value in Lombok is €390.0.63 (Gemeente Utrecht, Onderzoek & Advies en Volksgezondheid, n.d.).

Figure 6. Kanaalstraat in Lombok-Oost, Utrecht (Utrecht by Inge, 2024).

2.2.4 Vechtzoom-Zuid

The neighborhood of Vechtzoom-Zuid is in the Overvecht district and is part of the northern section of the municipality. This part of the district largely dates to the second half of the 1960s and comprises several large residential areas within a green framework (see figure 7). In the north, the primary shopping center with neighborhood-level amenities is situated. Additionally, there are several neighborhood shopping centers. Key green spaces include Gagel Park and its extensions, Vechtzoom Park, and Shanghai Park. New construction has been implemented in various locations, such as the former Overvecht hospital site, where a neighborhood of owner-occupied homes has been built. Adjacent to the shopping center, a large new residential complex is being constructed, featuring student and starter homes. The industrial park was established in the 1960s/70s with an expansion in the 1990s, consisting predominantly of industrial warehouses with showrooms and office space (Gemeente Utrecht, n.d.-c). Public transportation to Vechtzoom-Zuid is accessible from Utrecht Central Station via bus lines 1, 6, and 9. In Overvecht, there is a train station called Overvecht Station, which provides convenient access to the area. Each day, around 145 trains go to the station from the Central Station in Utrecht. (Nederlandsche Spoorwegen, n.d.).

Vechtzoom-Zuid features a relatively high proportion of mid-rise buildings, with high-rise buildings mainly situated along major infrastructure routes. Much of the mid-rise and high-rise buildings are designated for social housing (Gemeente Utrecht, n.d.-c). In 2013, Vechtzoom-Zuid was home to 4.111 residents, a number that swelled to 5.207 by 2023. Spanning 68 hectares, this neighborhood boasts an average density of 4.175 addresses per square kilometre. It is characterized by a vibrant community, with a significant portion of families calling it home. The largest age categories include individuals aged 30-39 and 20-29, with the younger demographic of 0-9 years also prominently represented. De average WOZ value of housing in Vechtzoom-Zuid is €300.743 (Gemeente Utrecht, Onderzoek & Advies en Volksgezondheid, n.d.).

Figure 7: Vechtzoom-Zuid, Utrecht (Gemeente Utrecht, n.d.-c).

2.2.5 Kanaleneiland-Noord

Dating back to the latter half of the 1950s, the Kanaleneiland district boasts a cohesive urban design (see figure 8). Kanaleneiland North and South both feature the distinctive layout characterized by what are known as "stamps." These stamps consist of a blend of high-rise and low-rise buildings, with communal open spaces interspersed between them. There's a noticeable contrast between Kanaleneiland North and South: in the North, the stamps are arranged side by side, while in the South, they extend linearly, allowing for additional features such as neighborhood parks like the Marco Polo Park. Greenery plays a pivotal role in the neighbourhood’s ambiance, with expansive stretches of green spaces including the recreational zone along the Amsterdam-Rijn Canal, the water corridor, and the Marco Polo Park.

Moreover, green spaces within the stamps and streets further enhance the character of the neighborhoods. Situated on the border between North and South lies the large shopping center, serving the entire district (Gemeente Utrecht, n.d.-e). Kanaleneiland-Noord is served by several bus and tram lines, including bus lines 34, 50, 65, 74, 77, 85, 7, 295, 195, 48, 90, 285, and tram line 21 (Nederlandsche Spoorwegen, n.d.).

In Kanaleneiland-Noord, the population grew from 7,550 in 2013 to 8,677 in 2023. It covers 67 hectares with an average of 3,334 addresses per square kilometre. Most residents are aged between 20 and 39 or are children below the age of 18. 15% of homes are owned, 38% are managed by housing associations, and 46% are privately rented. This differs from the wider trend in Utrecht, where most homes are owned. De average WOZ value of housing in Kanaleneiland-Noord is €293.789, making it the lowest WOZ value of the five study areas (Gemeente Utrecht, Onderzoek & Advies en Volksgezondheid, n.d.). A significant portion of the residential housing, particularly the high-rise buildings in the residential areas, is dedicated to social housing provided by housing associations. However, in 2016, several housing association flats were sold to investors, marking a notable change in ownership dynamics within the community (Gemeente Utrecht, n.d.-e).

Figure 8: Kanaleneiland, Utrecht (Vanschagen Architecten, 2024)

3. Theoretical Framework

In this chapter the theoretical framework is discussed, which later will be utilised as support in the analysis of the empirical material. This framework is focusing on three key theoretical terms: (1) accessibility, (2) The 15-minute city and (3) the total travel time.

3.1 Theoretical foundations of Accessibility

In the field of urban and economic geography, accessibility is defined by Handy and Niemeier (1997, p. 1) as 'the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality, and character of the activities found there.' The more evenly the potential destinations are spread out within a given area, the more accessible they are likely to be for the residents of that area. An area with a high density of destinations within a short distance is considered to have good spatial distribution. Factors influencing the ease of reaching each destination include transportation infrastructure (roads, public transit, walking and biking paths), travel time, cost, and the physical and cognitive effort required. For example, an area with a well-connected public transit system and safe pedestrian routes offers greater ease of access. The magnitude refers to the number or volume of activities available. Quality encompasses the standard or excellence of the services or activities. Character refers to the specific nature of these activities. A place that offers a wide range of high-quality activities, which meet the diverse needs and preferences of the population, is considered more accessible (Handy and Niemeier, 1997).

Saif, Zefreh, and Torok (2019) describe accessibility as one of the most important results of the transportation system, characterized as a facility to reach a specific area or location. Accessibility quantifies the advantage of a zone or area's location relative to other locations. The primary objective of assessing public transport accessibility is to enhance connectivity between people and locations (Saif, Zefreh & Torok, 2019, p.1).

3.1.1 Measuring Accessibility

According to Zhang, Ma, Fan, Xie, Jiang & Wang (2023, p.2), the methodology employed in measuring accessibility can significantly influence outcomes related to spatial inequities. Accessibility analyses, in this context, involve evaluating residents' ability to overcome obstacles like distance and travel time for accessing public service facilities (Zhang et al., 2023, p.2). According to Páez, Scott & Morency (2012, pp. 9-11), accessibility metrics typically encompass two key components: the travel time/cost, influenced by the spatial arrangement of both travellers and opportunities, and the quality/quantity of available opportunities. The less time and money spent on travel, the greater the number of places that can be reached within a certain budget, resulting in higher accessibility (Pozoukidou and Chatziyiannaki 2021, p.21). Destination choice also plays a crucial role as shown by Handy and Niemeier (1997): 'The more destinations available, and the greater the variety among them, the higher the level of accessibility'.

Additionally, travel options are equally significant: the wider the range of transportation modes available to reach a particular destination, the greater the choice and accessibility. Accessibility is thus influenced by both land use patterns and the transportation system's nature. However, two individuals in the same location may perceive their accessibility differently, as preferences and needs vary (Handy & Niemeier, 1997, p.1). In the normative accessibility indicator of Páez, Scott & Morency (2012), the emphasis is on evaluating the reasonable distance one can travel, emphasizing a shift away from specifying the distance individuals ought to travel. This approach is based on a thorough examination of demographics, encompassing factors such as household size, age distribution, presence of children, income levels, and occupation. Analyzing demographics is important because it helps us understand how individuals have different capacities and needs when accessing public services and amenities (Páez, Scott & Morency, 2012, p. 9).

Various methods exist for measuring accessibility via active transportation, categorized into four groups by Vale, Saraiva & Pereira (2016, pp. 9-20): distance-based, gravity-based, infrastructure-based, and composite measures like Walk Score types. Distance-based measures consider travel time or distance to destinations within a certain threshold like the closest destination(s), or the mean distance or travel time to the closest opportunities. Gravity-based measures assign weights to opportunities based on their distance from the origin, considering factors like floor space or number of employees. Infrastructure-based measures assess network characteristics like cycle path type and safety. Composite measures like Bike Score integrate network qualities and travel time to opportunities (Vale, Saraiva & Pereira, 2016).

3.1.2 Distance-based accessibility measures

Distance-based measures, according to Vale, Saravia & Pereira (2016, p.9-10) differ from other types of accessibility measures, in that they primarily focus on the physical proximity between locations without considering factors like the attractiveness of opportunities, travel impedance functions, or individual preferences. Distance-based measures are therefore straightforward and easy to understand. They are relatively simple to calculate, making them particularly useful in scenarios where opportunities are seen as perfect substitutes, like accessing the closest supermarket or bus stop. However, these measures have several disadvantages. They offer a limited perspective by only considering physical distance, ignoring other factors like transportation modes, travel time, and the quality of the built environment. Additionally, they assume that all opportunities are equal, which may not reflect the diverse characteristics and qualities of different destinations. Furthermore, the accuracy of distance-based measures is sensitive to how travel impedance is measured, which can vary depending on the chosen metric: Euclidean, Manhattan, network distance, etc. (Vale, Saraiva & Pereira, 2016, p.9-10).

3.1.3 Gravity-based accessibility measures

Gravity-based measures differ from distance-based measures in that they consider both the size of opportunities and the cost of traveling to them, providing a more holistic view of accessibility. Unlike distance-based measures that focus solely on proximity, gravity-based measures use an impedance function to weigh opportunities based on their spatial separation and importance. However, gravity-based measures come with their challenges. They are more complex to calculate due to the need to define an impedance function that quantifies travel costs between locations, which adds a layer of complexity beyond simple distance calculations. Additionally, implementing gravity-based measures may require more detailed data on travel costs and opportunity sizes, potentially making them more resource-intensive. Furthermore, these measures assume a trade-off between opportunity benefits and travel costs, which may not always align perfectly with real-world scenarios (Vale, Saraiva & Pereira, 2016, p.12).

3.1.4 Infrastructure-based & Composite accessibility measures

Infrastructure-based measures focus primarily on how the physical design and layout of built environments influence accessibility. These measures analyse network connectivity and design to evaluate how well transportation infrastructure facilitates movement and connectivity between different locations within a specific area. In contrast, composite measures take a broader approach by integrating a wide range of variables. These include not only network connectivity but also factors like land use patterns, the location of key facilities (such as schools and workplaces), population density, socio-economic characteristics, and other relevant variables affecting accessibility. By combining multiple factors into a unified framework, composite measures offer a more comprehensive understanding of accessibility dynamics in urban environments. The key difference lies in their scope: infrastructure-based measures focus on physical elements, while composite measures explore the complex interrelationships between various factors that shape how people interact with their surroundings (Vale, Saraiva & Pereira, 2016, p.19).

3.2 The 15-Minute City

In a 15-minute city, all citizens are able to meet most or all their everyday needs within a short walk or bike ride from home. Those everyday needs include living, working, commerce, healthcare, education, and entertainment (Moreno et al., p.8). It is intended to function as a model of reconnecting people to their neighborhoods and localize city life. Moreno et al. (2021, p.1) show that the 15-minute city is built upon the idea of "chrono-urbanism," which suggests that the betterment of urban life decreases as the time spent on transportation, particularly by car, increases. One notable distinction of 15-minute cities compared to other neighborhood-centered approaches is their aim to bring activities directly to neighborhoods rather than drawing people to centralized locations. This approach seeks to revive the urban planning principle of proximity, emphasizing the importance of geographic closeness between individuals, services, and activities (Pozoukidou & Chatziyiannaki, 2021, pp. 3-4). Moreno et al. (2021, p.9) showcase a framework to achieve the 15-minute city. The framework consists of four essential pillars: density, proximity, diversity, and digitalisation (see figure 9).

Figure 9. Framework of the 15-minute city by Moreno et al. (2021, p.10).

3.2.1 Density

Density, viewed in the context of the 15-minute city, focuses on ‘determining the optimal number of people per square kilometre to sustainably support urban service delivery and resource consumption’. (Moreno et al. 2021, p.10) Unlike traditional approaches that prioritize ultra-high-rise buildings, this perspective emphasizes achieving an optimal density that promotes economic, social, and environmental sustainability. By achieving this optimal density, it becomes feasible to plan available space effectively, ensuring accessibility to essentials without relying on automobiles.

3.2.2 Proximity

Proximity entails having people, services, and activities situated near one another, thereby offering residents convenient access to a variety of opportunities within their urban environment (Pozoukidou & Chatziyiannaki, 2021, pp. 3-4). Within the 15-minute concept, this means that every basic need you have is within 15 minutes walking or biking. The emphasis is on both temporal and spatial accessibility to basic services within quickly accessible radial nodes. Proximity not only reduces commuting time but also minimizes the environmental and economic impacts of transportation (Moreno et al., 2021, p.11).

3.2.3 Diversity

Diversity within the framework of the 15-Minute City concept is twofold: 'the need for mixed-use neighborhoods that offer a healthy blend of residential, commercial, and entertainment components, and secondly, diversity in culture and people' (Moreno et al, 2021, p.11). According to Moreno et al. (2021, p.11), mixed-use neighborhoods are important for maintaining economically vibrant urban fabrics, ensuring sufficient housing for all city residents, promoting inclusivity, and sustainable practices.

3.2.4 Digitalisation

The fourth pillar, digitalisation, was originally not part of the framework. Moreno et al. (2021, p.12). added this dimension because it is essential for realizing the concept of a 15-minute city. Digitalization closely aligns with the Smart City concept, drawing inspiration from factors such as inclusivity, resident participation, and real-time service delivery. By effectively deploying various technologies, similar far-reaching impacts can be achieved within the framework of the 15-Minute City. Digital tools and solutions play a significant role in enhancing biking experiences, ensuring safety and security for cyclists, and promoting services like online shopping, cashless transactions, and virtual communications. Particularly during the COVID-19 pandemic, digitalization has facilitated remote work and virtual communication, thereby reducing the necessity for physical commuting (Moreno et al., 2021, p.12).

3.2.5 Benefits of a 15-minute city

Since the onset of the COVID-19 pandemic, the 10-, 15- or 20-minute city concept has gained significant popularity as a planning strategy, becoming a focal point in numerous research studies and discussions (Pozoukidou & Chatziyiannaki, 2021, p.1; Khavarian-Garmsir, Sharifi, & Sadeghi, 2023, p.1; Papadopoulos, Sdoukopoulos & Politis, 2023, p.1). According to Pozoukidou & Chatziyiannaki (2021, p.1), the concept is not a newly created idea but has its roots in older planning strategies. After the pandemic, it became evident that cities need to consider ways in which people can live healthier, reducing the car use within cities. The large car-dependency our cities are displaying are making the streets busy and congested, negatively impacting both biodiversity and quality of life. Time lost in traffic jams, fuel and vehicle maintenance are some of the unavoidable costs of having a car (Moreno Allam, Chabaud, Gall & Pratlong, 2021, p.8.). According to Allam, Nieuwenhuijsen, Chabaud & Moreno (2022, p.2), the 15-minute city increased density (of population and services) and diversity result in shorter travel distances. Motorized traffic is replaced with active travel, leading to lower CO2 and air pollution emissions, thereby improving air quality. The resulting freed public space can be repurposed for green spaces, contributing to some extent to carbon sequestration, and reducing urban heat island effects (Allem et al., 2022; Moreno et al., 2021).

3.2.6 Criticism on the 15-Minute City

The 15-minute city concept has faced criticism for its emphasis on physical determinism (Khavarian-Garmsir, Sharifi, Sadeghi 2023, p.10-12). This approach prioritizes solving complex societal issues like public health, climate change, economic prosperity, and social inclusion primarily through the physical design and modification of urban structures, neglecting social, cultural, and economic dimensions. Additionally, critiques highlight the concept's disregard for certain neighborhood sustainability criteria, including environmental protection, biodiversity, energy efficiency at the building scale, and preservation of local culture, heritage, and identity. Energy strategies under the 15-minute city primarily target city and district levels, often overlooking smaller scales like individual buildings, which is seen as a limitation (Khavarian-Garmsir, Sharifi, Sadeghi 2023, p.10-12).

The concept of a 15-minute city may appear arbitrary to some, questioning why precisely 15 minutes and not another duration, like 17 or 20 minutes. Moreno et al. (2021, p. 14) acknowledge this criticism, noting concerns that flexibility in defining proximity could lead to inconsistencies in planning and implementation across different urban contexts. Moreover, alternative concepts such as 20-minute or 30-minute cities have been proposed, suggesting that rigid adherence to a 15-minute radius may not universally meet the diverse needs of all city residents or address varying urban morphologies effectively. However, the 15-minute city concept is designed to be adaptable, tailored to fit the unique characteristics and needs of each city. It acknowledges the varying speeds and distances of different modes of transportation and encourages the integration of infrastructure such as walking and biking lanes (Moreno et al., 2021, p.14).

3.2.7 Health Amenity Accessibility in the 15-Minute City Framework

While Moreno et al. (2021) highlight the six main aspects that should be within reach in a 15-minute city—living, working, commerce, healthcare, education, and entertainment—they do not provide specific details regarding the types of amenities involved. To address this gap, this research draws inspiration from the report: Netherlands: Health System Review by Kroneman, M., Boerma, W., van den Berg, M., Groenewegen, P., de Jong, J., van Ginneken, E., & World Health Organization (2016).

General practitioners (GPs) play a pivotal role in primary care and in the healthcare system in general, because they function as gatekeepers. The gatekeeping concept restricts access to hospital and specialty care, requiring referrals from general practitioners, except in cases of emergency care. Every person has a GP, usually in their own neighborhood. Patients register with the GP of their choice, and they are free to move to another one. Patients may be turned away from the practice for a variety of reasons, such as living too far away or the GP having an excessive number of patients on their list. Nearly all people can get to a GP from their house in less than 15 minutes in the Netherlands. Getting to a GP quickly and easily is widely regarded as crucial, given their essential position in the healthcare system (Kroneman et al., 2016, p. 167).

Hospitals and mental health facilities are the main providers of secondary care, which is referred by primary care physicians like general practitioners. Comprehensive inpatient and outpatient services, including round-the-clock emergency treatment, are provided by these institutions. Except for emergencies, patients receive recommendations to specialists from their general practitioner (GP) or from other medical professionals. In 2012, there were 257 hospital admissions per 1000 population, with about 54% of these admissions lasting only one day. On average, clinical admissions in 2014 lasted 5.2 days. These statistics indicate that hospital visits are less frequent and often involve shorter stays compared to routine visits to GPs or other primary care providers. In an emergency, patients or others can call the emergency call centre and ask for an ambulance. An ambulance should not take longer than 15 minutes to reach an emergency site. Apart from isolated islands, emergency rooms are dispersed strategically throughout the nation to ensure that they are reachable in 45 minutes or less from most regions (Kroneman et al., 2016, p. 176).

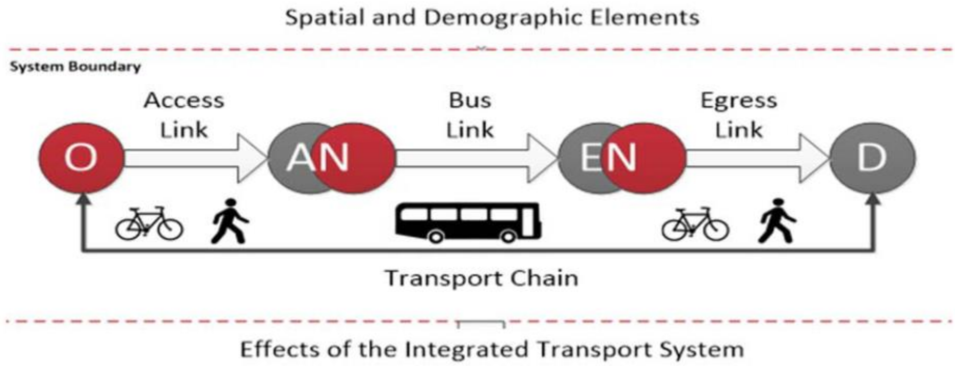
Ensuring GPs are within a 10-minute radius aligns with their pivotal role in primary care and supports the overarching goals of the 10-minute city concept, which aims to provide swift and convenient access to essential services. Unlike GPs, hospitals provide specialized care that is less frequently needed for everyday purposes such as routine medical visits. While quick access to emergency services is crucial and addressed by ambulance response times, routine hospital visits are not typically included within the 10-minute city framework due to their less frequent nature (Kroneman et al., 2016).

3.3 Total Travel Time

This study investigates the range of destinations accessible exclusively via public transit and walking within the conceptual framework of a 10-minute city. Therefore, it delves into factors such as total travel time to discern the feasibility of reaching essential services and amenities. Travel time estimation is based on a transportation network. A transportation network consists of a set of nodes (or vertices) and a set of arcs (or edges or links) that connect the nodes. The total travel time is an important resistance factor of transport and is calculated taking the sum of the access time, the waiting time, the in-vehicle time, the egress time, and the hidden waiting time at the origin (Brand, Hoogendoorn, Van Oort, Schalkwijk, 2017, p.2).

In the research of Brand et al. (2017, p.1), an integrated bus system is presented in Figure 10 and consists of: (1) The Transport Chain: The transport chain is the entire trip from origin (O) through the access node (AN) and egress node (EN), using the bus link, to the destination (D). (2) The Spatial and Demographic Elements: These are outside of the system boundary, and thus are elements from the environment of the system that influence the system. (3) The Effects of the Integrated Transport System: This is the 'outcome' of the system, the effects of the system on travellers (e.g. total travel time) and society (e.g. emissions).

Figure 10: Integrated bus system by Brand et al. (2017, p.2)



Mavoa, Witten, McCreanor and O'sullivan (2012, p.2) have also addressed this by creating a measure of public transit and walking access to a range of health destinations that people travel to in everyday life. Their research categorizes existing accessibility measures into three categories: (1) access to transit stops, (2) duration of public transit journey, and (3) access to destinations via public transit.

3.3.1 Access to transit stops

According to El-Geneidy, Grimsrud, Wasfi, Tétreault, and Surprenant-Legault (2014, p. 2), the standard walking distances of 400 meters to bus stops and 800 meters to rail stations are frequently inaccurate. Walking distances vary based on route and trip qualities (such as type of transit service, transfers and wait time), as well as personal, household, and neighbourhood characteristics. Accordingly, service areas around transit stations should vary based on the service offered and attributes of the people and places served. Public transport accessibility is determined by the overall availability and quality of public transport services within a reasonable walking distance. Thus, access time (1) is calculated as the sum of walking time and average waiting time (Wu & Hine, 2003, p.2).

(1) Access Time = walking time + average waiting time

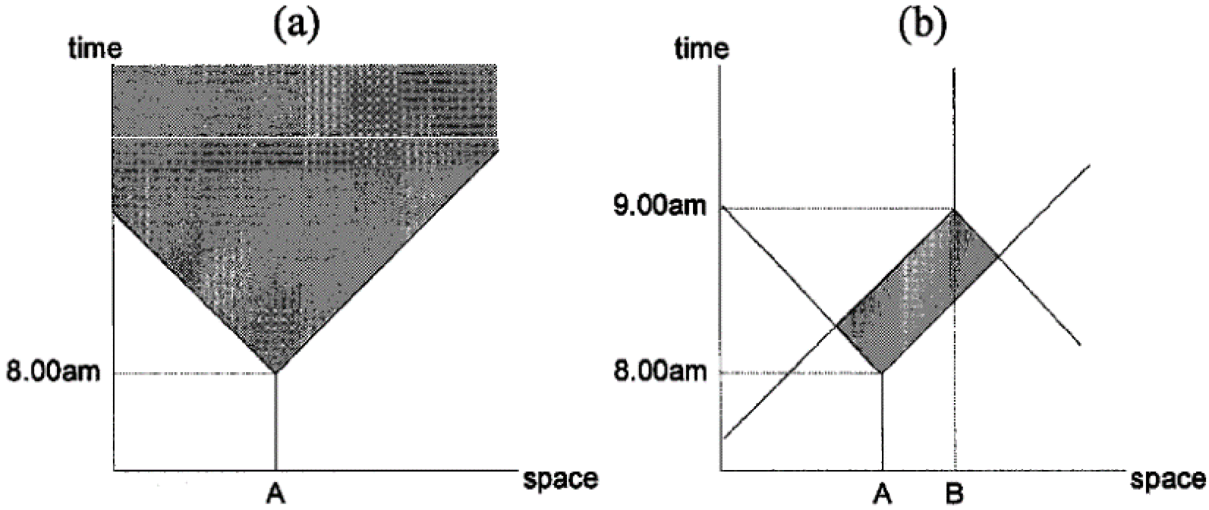
Platform Ruimte voor Lopen is a collaboration of organizations and professionals (including the municipality of Utrecht) aiming to create more space for walking in the Netherlands. They commissioned CROW-kpVV to conduct a study titled "Insight into Acceptable Walking Distances" (2021). This research reveals that in the Netherlands, the vast majority of bus passengers (just under 90%) almost always walk to the bus stop from home. Most bus passengers are willing to walk 5 to 10 minutes to reach a bus stop (48%), and in most cases, they find a bus stop within this range (Ruimte voor Lopen, 2021, pp.11-12).

However, pedestrians are more satisfied when the walk to the bus stop is only 0 to 5 minutes (27%). Pedestrians living in highly urbanized areas accept shorter walking times to a bus stop compared to other pedestrians. Conversely, those in moderately urban areas accept longer walking times than other respondents. The study compares the willingness to walk with the physical condition of the respondents. It distinguishes between those who need assistance when walking and those who do not, noting that the former group has a slower walking speed. Consequently, for the same acceptable walking time, the acceptable walking distance is shorter for those who need assistance (Ruimte voor Lopen, 2021, pp.11-12).

3.3.2 Duration of public transit journey

The focus should not only be on physical access but also on the travel time between the origin and destination. Accessibility models address this by using public transit travel time to measure accessibility. O'Sullivan et al. (2000, p.3) utilized isochrone analysis to investigate public transport accessibility, generating maps of areas reachable by public transit travel. This type of analysis is based on space-time geography by Hägerstrand (1970), see figure 11. The two-dimensional diagrams represent space as a single dimension. When an individual residing at location A departs from home at 8:00 am, the shaded area in figure 11(a) delineates the range of accessible locations, unrestricted by movement constraints other than the transport system. The slope of the lines diverging from A varies according to the speed of the transport system. If this individual needs to be at work at location B by 9:00 am, movement becomes constrained, effectively restricting accessibility to the shaded area in figure 11(b). The parallelogram represents the intersection of all the points reachable from A starting at 8:00 am and all the points from which B can be reached by 9:00 am. This shaded area is commonly referred to as a space-time prism, as it exists in three dimensions—two of space and one of time (O'Sullivan, 2000, p.3).

Figure 11: Two-dimensional space-time diagrams by O'Sullivan (2000, p.4.)



Only the opportunities that can be reached from a specific location within a certain amount of time are included in the accessibility calculation. All locations that can be reached from a given point within the specified time can be identified. When these locations are connected on a map, the resulting line is an isochrone from that point (O'Sullivan, 2000, p.4).

3.3.3 Access to destination with public transit

In the definition mentioned earlier, having access to various activities and opportunities is a crucial aspect of overall accessibility. This goes further than simply evaluating the accessibility of the transportation system, such as the convenience of reaching a destination. For example, it includes an evaluation of bus service levels, such as the number of daily busses runs between the neighborhood and the opportunity. Service frequency, a critical aspect of accessibility, can vary markedly between peak and non-peak commuting times. When evaluating service frequency, one method considers all public transit journeys. For instance, one possibility is to assess the number of trips per stop per week, while another option is to classify transit service frequency based on the frequency of bus/train arrivals (e.g., at least every 15 minutes, at least every 30 minutes, and 30 minutes or more) (Mavoa, Witten, McCreanor and O'sullivan, 2012, p.2).

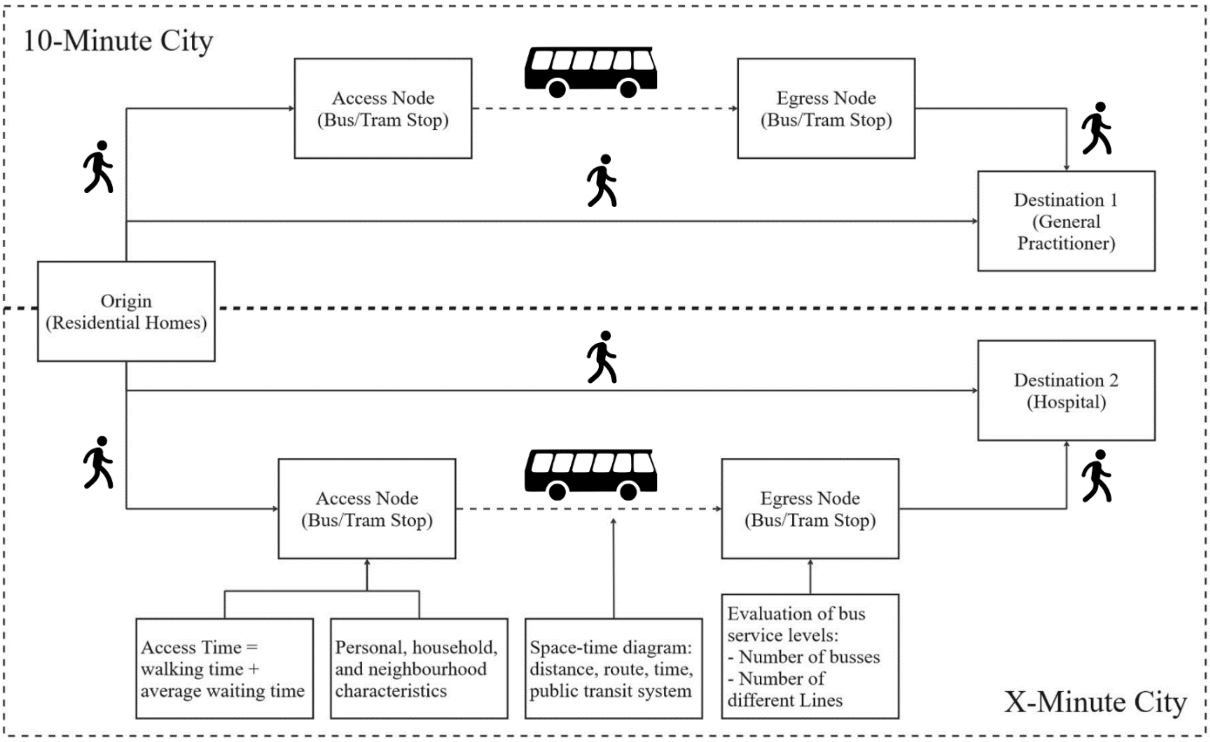
Additionally, it is important to consider the difference between weekday and weekend service frequencies. Typically, public transit services run more frequently on weekdays to accommodate commuters, while weekends may have reduced service frequencies due to lower demand. Moreover, some bus stops are served by multiple transit lines, which can significantly enhance the overall service frequency at these stops. This increased number of lines means that passengers have more options and shorter waiting times compared to stops served by fewer lines. This difference can significantly impact accessibility and travel planning for users (Mavoa, Witten, McCreanor and O'sullivan, 2012, p.2).

According to Rietveld, Bruinsma and Van Vuuren (2001, p.2), another critical factor influencing total travel time is the reliability of public transport. This reliability hinges on several crucial elements essential for operational efficiency and passenger experience. When constructing timetables, there is a delicate balance between prioritizing faster travel and minimizing stop times, which can affect scheduled travel times but jeopardize reliability due to potential deviations. Public transport reliability refers to the consistency between scheduled and actual travel times, often disrupted by external factors like congestion, weather conditions, or delays. Missed connections within complex transport chains exacerbate these challenges, as coordination issues between operators lead to delays, thereby extending passenger travel times (Rietveld, Bruinsma, Van Vuuren, 2001, p.2).

3.4 Conceptual Model

Figure 12 illustrates a conceptual model that visualizes the theoretical framework depicting the relationships between public transportation accessibility, healthcare facility accessibility, and the principles of the 10-minute city. This visual representation clarifies the interactions and influences among these elements. The first pathway emphasizes accessibility to general practitioners, ideally within a maximum walking distance or a short public transit ride from residential areas in the study zones, aligning with the 10-minute city concept. The second pathway delineates the routes residents can take using public transportation or walking to reach hospitals. Given the less frequent necessity of hospital visits, this aspect may fall outside the strict definition of the 10-minute city concept. Therefore, the total travel time from each study area to a hospital via public transportation or walking defines the variable "X" in the X-minute city model. It is preferable that "X" remains minimal to ensure the effective implementation of the 10-minute city concept. The factors influencing the use of public transportation also apply for reaching the general practitioner by bus or tram but are not shown a second time in the model.

Figure 12: Conceptual Model



4. Methodology

In this chapter, the methodology employed to investigate and analyse the research questions will be thoroughly outlined and justified, providing a comprehensive framework for the study's execution.

4.1 Type of Research

To answer the main question, a quantitative methodology will be used. This approach involves gathering numerical data related to the spatial distribution of health amenities and public transportation points in Utrecht, as well as the accessibility of bus or tram stops from residential homes in the selected study areas. Utilizing quantitative analysis techniques, such as spatial mapping, will allow for a systematic examination of the relationship between public transportation accessibility and the objectives of the 'ten-minute city' concept regarding healthcare facility accessibility. By employing a quantitative methodology, this research aims to provide robust and objective assessments of the current state of public transportation's alignment with the 'ten-minute city' model for healthcare accessibility in Utrecht.

4.2 The Data

This section outlines the data collection and the data preparation, including steps like cleaning, normalizing, and transforming the data for analysis.

4.2.1 The data collection

No open-source spatial dataset containing the locations of various health amenities in Utrecht was available. Therefore, Google Maps data will be utilized to generate a spatial dataset with point data for each health amenity, including general practitioners and hospitals. The search terms used to gather data from Google Maps include (Dutch): "huisarts", "huisartsenpraktijk", "gezondheidscentrum", "dokter", "ziekenhuis", "medisch centrum", and "huisartsenpost". To ensure accuracy, any uncertainties regarding the current status or operational status of general practitioners were further investigated online to verify active websites where appointments could still be made.

The Geo-point open-source platform from the municipality of Utrecht provides relevant datasets, including one covering the entire bus and tram network in the province. The General Transit Feed Specification (GTFS) data is essential for calculating average waiting times and other transit-related indicators, such as the number of services at each specific stop. This data includes detailed schedules, routes, and stop times, allowing for precise analysis of transit service availability and efficiency. The Wijk-Buurt Register 2022 from CBS provides comprehensive boundary data for all neighborhoods in the Netherlands. These delineated borders were utilized to define the study areas for this research (see table 1).

Table 1. Data Collection

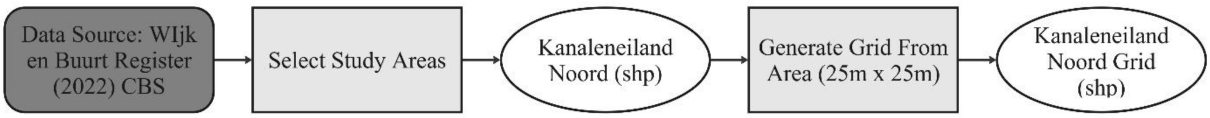
Name	Description	Source
Wijk-Buurt Register 2022 v2	Contains the digital geometry of the boundaries of neighborhoods, districts, and municipalities in two GIS formats. Key figures for neighborhoods, aggregated key figures for districts and municipalities, and statistics on the proximity of amenities are included on the map.	Centraal Bureau voor de Statistiek. (N.d.).
Health Amenities	Consists of point data representing the locations of various health facilities.	Google Maps

Bus-tram Stops	Consist of the bus and tram stops in the municipality of Utrecht. Each point in the dataset represents either a bus or tram stop.	Provincie Utrecht (2024) Openbaar vervoer. Bus- en tramhaltes
Bus-tram Lines	Consist of the bus and tram lines in and around the Province of Utrecht. Each line in the dataset represents either a bus or tram route.	Provincie Utrecht (2024) Openbaar vervoer. Bus- en tramlijnen.
GTFS	The General Transit Feed Specification (GTFS) data for the Netherlands provides comprehensive information on public transportation. This dataset includes details on schedules, routes, stops, and fares for various modes of transit, such as buses, trams, trains, and ferries.	Open Mobility Data (2024) Routes U-OV

4.2.3 Data Preparation

The initial step involved selecting the study areas from the Wijk-Buurt Register 2022, which provides comprehensive boundary data for all neighborhoods in the Netherlands (See figure 13). Using these delineated borders, we accurately defined our study areas. The Modifiable Areal Unit Problem (MAUP) occurs when the aggregation of spatial data is influenced by changes in the size, shape, or orientation of spatial categories or polygons. Such modifications can theoretically reallocate observations into new arrangements, altering the data interpretation (Buzzelli, 2020, p.2). To minimize the impact of MAUP, a grid with a resolution of 25x25 meters was chosen for this study (See figure 13). This fine-grained grid reduces the extent of data aggregation issues by maintaining consistent spatial units, thereby enhancing the precision and reliability of the spatial analysis. Using a grid can also better illustrate how all indicators are distributed within the neighborhood, as this can vary significantly within a neighborhood.

Figure 13: Data Preparation of the study areas (example: Kanaleneiland-Noord)



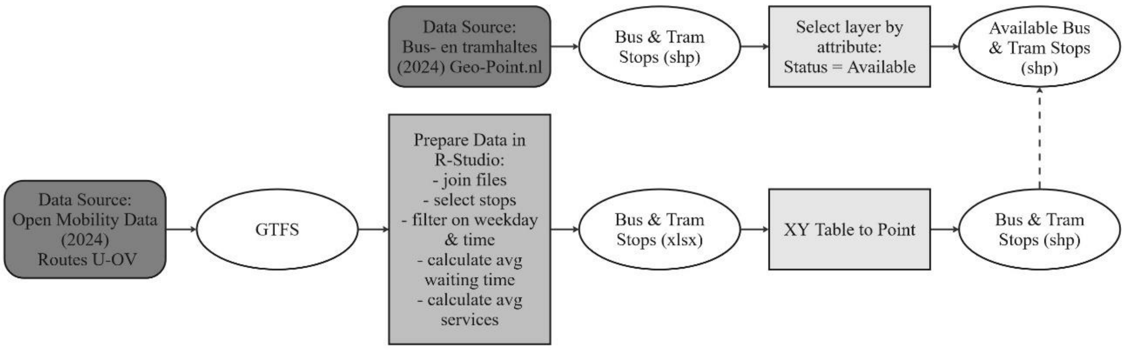
Data preparation for the bus and tram stops involved two data sources. First the data from Geo-Point was used to see the location of all available bus and tram stops within the municipality according to the municipality. In addition to using ArcGIS Pro 3.0 for mapping and analysis, R-studio was utilized for processing and calculating waiting times and number of services with the GTFS data.

This involved joining all the routes, trips, calendar dates and stop times from the GTFS data to one another based on their stop_id, route_id and trip_id. Next, a selection on specific bus stops that are reachable from the study areas was made. This was accomplished by examining the Geo-point dataset in ArcGIS Pro 3.0 and then selecting each stop located within a 5-minute walking distance from the study areas. To calculate average waiting times between services per stop and the average amount of services per week per stop, another selection on weekdays between 06:00 and 23:00 was made. During these selected hours on weekdays, bus services typically run more frequently and consistently. Including data from outside these hours, when buses may run less frequently or not at all, would result in artificially inflated average waiting times and fewer services per week. This selection ensures a more accurate and representative analysis of the regular bus service patterns.

Following categorization based on day type and stop, two primary datasets were generated from the filtered GTFS data. The first dataset aggregated counts of services per stop and day type, revealing the frequency of services at each stop. Additionally, to assess waiting times between consecutive services at each stop, a separate dataset was structured. This dataset computed waiting times as the differences in time between consecutive service arrivals, allowing for a detailed examination of service intervals. Subsequently, these intervals were summed and averaged to calculate the average waiting time per stop, providing valuable insights into passenger waiting experiences during weekdays in the study area.

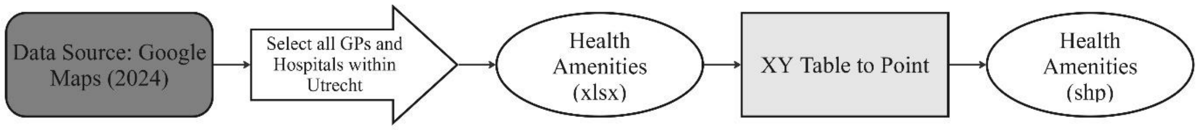
The resulting table was exported to ArcGIS Pro 3.0 and converted into point data using the latitude and longitude coordinates provided in the GTFS dataset. The accuracy of the GTFS-point data was validated by comparing it with a Geo-Point dataset. Instances where discrepancies in coordinates were identified in the GTFS-point data were addressed by spatially joining it with the municipal Geo-Point dataset to obtain precise location information verified by local authorities. This process ensured the reliability and accuracy of the spatial data used for further analysis and decision-making in the study.

Figure 14: Data Preparation of the bus and tram stops



For the health amenities, latitude and longitude coordinates for hospitals and general practitioners (GPs) were acquired using Google Maps. These coordinates were compiled into an Excel spreadsheet along with corresponding names of each GP or hospital. Subsequently, this dataset was imported into ArcGIS Pro 3.0. Using the latitude and longitude information, point features were generated in ArcGIS Pro to represent the locations of each health amenity (see figure 15). This spatial dataset was then utilized for further geospatial analyses and mapping exercises related to urban health infrastructure in the study area.

Figure 15: Data Preparation of the health amenities



4.3 ArcGIS Pro 3.0 and TravelTime

All analysis will be conducted using ArcGIS Pro 3.0. ArcGIS Pro 3.0 is a comprehensive mapping program that supports integration and visualization of data from multiple sources and formats. The Data from the Data Collection can be mapped and analysed using multiple tools that ArcGIS Pro 3.0 provides. Specific analyzing tools within ArcGIS will be discussed per sub-question. The TravelTime application is a way of searching and filtering data using time, not distance. It is a RESTful API, using HTTP request for access. In this research it is used to create the isochrone maps. By installing the TravelTime plugin in ArcGIS Pro 3.0, an analysing tool called 'Time Map' is added to the program. This tool allows the user to create travel time polygons that visualise what's reachable within a certain time limit. It gives the option to choose which type of transportation is used: 1) Public Transport; 2) Walking, 3) Cycling; 4) Driving (TravelTime, 2024).

Other input features involve a specific geographical point (longitude and latitude coordinates) or an address. From this location the isochrone will be drawn. The tools needs a specific date and time on which it will run and indicate whether this represents the departure time from the starting location or the arrival time at the destination. This distinction is particularly important when using public transportation because service availability and schedules can vary significantly depending on the day of the week and the time of day. The tool offers the option to draw isochrones for three different time journey durations (TravelTime, 2024).

The API relies on detailed street network data, which includes information about roads, paths, and walkways. This data is obtained from various sources, such as OpenStreetMap (OSM), commercial map providers, and government agencies. For public transport travel times, the API integrates data from transit agencies, schedules, and real-time updates. Using GTFS data where available, the API ensures accurate and comprehensive public transport routing. GTFS, or General Transit Feed Specification, is a standardized data format used by transit agencies to publish their schedule and route information. When GTFS data is not available, alternative timetable data is converted into the GTFS format to maintain consistency (TravelTime, 2024).

The integration of GTFS data allows the API to provide precise travel times and route options by leveraging both static schedules and dynamic updates. This capability is crucial for offering reliable public transport information, as it combines planned timetables with real-time changes such as delays or service disruptions. The continuous updating of data, at least biweekly, ensures that the API remains current, reflecting the latest available transit schedules and network modifications. This frequent updating, combined with the use of diverse data sources, guarantees that users have access to the most accurate and up-to-date information possible (TravelTime, 2024).

4.4 Data analysis methods

In this section, we will outline the data analysis methods for four sub-questions that are designed to address the central research inquiry. Each sub-question will be associated with a distinct approach to data analysis.

Maps will be generated per sub-question for all study areas to visualize and compare the results across different transport modes, providing insights into the spatial distribution and accessibility of GPs, transit stops and hospitals within the urban context of the study areas. For all maps generated in this study, the data were projected using the RD New coordinate system. This choice ensures uniformity in spatial representation across all study areas, facilitating accurate comparative analysis (Brewer, Pickle, 2002). To effectively communicate the spatial distribution and accessibility metrics of GPs, transit stops, and hospitals, graduated colors were selected as the symbology for visualization. Graduated colors symbology categorizes quantitative data into classes based on attribute values, assigning distinct colors or shades to each class. This method is particularly suitable for portraying average values or distributions across geographic areas, as it allows viewers to discern relative differences in data intensity at a glance (Brewer, Pickle, 2002).

4.4.1 General Practitioner Accessibility

To address sub-question 1 on the accessibility of general practitioners (GPs) from residential areas, the data analysis primarily employs a distance-based approach. Initially, isochrones are generated using the

Time Map tool to delineate areas accessible within a 10-minute walking radius from each general practitioner's location. These isochrones visualize the extent of accessibility from surrounding residential areas to each GP's office. To ensure reliability, any outlier or unexpected isochrones were verified using the route planner in Google Maps to confirm that the walking distance was indeed 10 minutes. Subsequently, a similar analysis is conducted using the Time Map tool to create isochrones representing a 10-minute travel time using public transport from the same GPs' locations. The isochrones were generated at multiple times (8:00, 12:00, 18:00) across several weekdays (Monday to Friday), for public transport, integrating operational schedules into the analysis.

Both sets of isochrones are overlaid onto a consistent 25x25 meter grid framework. Each grid cell displays the count of GPs reachable within the specified travel times for both walking and public transport modes. This approach combines a gravity-based methodology for public transport, accounting for varying network performances and schedules, with a straightforward distance-based analysis for walking distances.

4.4.2 Public Transportation Access

To comprehensively address sub-question 2 regarding the accessibility of bus or tram stops from residential areas, a structured data analysis process is employed. Firstly, isochrones are generated from each bus or tram stop using the Time Map tool, extending to a walking distance of 5 minutes. These isochrones outline the areas reachable within a brief walking duration from each public transportation point. The decision of 5 minutes comes from the research mentioned in the theoretical framework called Ruimte voor Lopen (2021), where they state that most people who live in highly urban places, the amount of time to walk to a bus stop is more around 5 min than 10 min. Within the concept of a 10-minute city, a 5-minute walking distance makes more sense because it accounts for the additional time needed to travel by bus. This ensures that the overall travel time remains efficient and within the desired 10-minute timeframe. The isochrones will again be merged onto the earlier created grids of 25x25 meters. Each grid cell will then show a count of Bus and Tram stops reachable within the given travel time. A map will be created for all study areas to show the differences.

Furthermore, the analysis will include calculating the average weekly services using GTFS data. These service frequencies will be integrated as indicators into the isochrone maps. This approach will visually demonstrate variations in accessibility, for example: while certain areas may have numerous buses or tram stops nearby, the actual frequency of services might be limited. Conversely, a single stop could provide higher service frequencies, highlighting disparities in public transport availability across different locations. the analysis will involve calculating the average waiting time between different services using GTFS data. This metric considers all services operating from 6:00 AM to 8:00 PM on weekdays (Monday till Friday), providing a comprehensive view of the waiting times passengers experience throughout the day. This combined approach of distance-based isochrone generation and gravity-based analysis with service frequencies and waiting times enhances the understanding of bus and tram stop accessibility in urban environments. It integrates spatial proximity with operational factors, providing nuanced insights into public transport accessibility across different study areas.

4.4.3 Hospital Amenities Access

The accessibility of hospitals in Utrecht was investigated through the creation of isochrones using the Time Map tool originating from three prominent hospitals: UMC Utrecht, Diakonessenhuis, and Antonius Ziekenhuis. Recognizing hospitals as secondary amenities, distinct from primary facilities, the analysis expanded beyond the conventional 10-minute accessibility criterion. Isochrones were generated at 30, 20, and 10-minute intervals using public transport routes to assess travel times to each hospital. Additionally, isochrones were constructed for 30, 20, and 10-minute walking distances to capture accessibility on foot.

To visualize cumulative hospital access within specified time frames, 30-minute isochrones from all three hospitals were merged onto a unified grid (250x250 meters). This mapping strategy enabled identification of areas where multiple hospitals could be accessed within 30 minutes for the whole of Utrecht, facilitating a spatial understanding of hospital distribution and accessibility. For the public transport analyses, isochrones were generated at multiple times (8:00-12:00-18:00) across several weekdays (Monday to Friday), utilizing GTFS data. Averages of these isochrones were computed to account for variations in the bus and tram network throughout different times of day and days of the week. The reason for averaging these isochrones is to provide a general representation of the accessible distance throughout the entire day, rather than reflecting accessibility at only one specific time, due to the significant variations in bus and tram schedules. This approach highlights a gravity-based analysis, considering operational factors such as schedules and network performance of public transport systems.

4.4.4 Multi-Criteria Analysis

For the final sub-question, the accessibility indicators were aggregated into a total score (range from 0-10) after undergoing min-max normalization (1) to ensure consistency across all study areas. For average waiting times in the context of this study, formula (2) was employed due to the nature of the indicator where lower values are considered more favourable for service accessibility. For cases where the average waiting time was observed to be zero (indicating no waiting time due to absence of a service or activity), the corresponding normalized score was specifically set to 0. This adjustment ensures that locations where there is no waiting time associated with bus stops or any service are appropriately reflected as having a score of 0, accurately indicating the absence of such facilities or services in the area.

$$(1)\ X' = \frac{X - Xmin}{Xmax - Xmin} * 10 \qquad (2)\ X' = 10 - \left(\frac{X - Xmin}{Xmax - Xmin} * 10\right)$$

Please refer to Table 1: All indicators for the multi-criteria analysis, in the appendix for a comprehensive list of these indicators. In both scenarios, equal weighting was applied to all indicators. The scenarios differ in terms of the specific indicators included in the multi-criteria analysis. The previously mapped hospital access isochrones, reflecting various travel times and transport modes for Utrecht, were integrated into the study area grids (25x25 meters) to comprehensively assess accessibility across Utrecht. Integrating previously mapped hospital access isochrones into the study area grids enhances the reliability and comprehensiveness of accessibility assessment in Utrecht by ensuring that all data are projected onto a consistent spatial grid. This approach minimizes spatial inaccuracies that may arise from different data sources or projection methods, allowing for a more precise comparison of accessibility metrics across the city.

4.4.4.1 Scenario 1

In Scenario 1(S1), a multi-criteria analysis is conducted based on various accessibility indicators essential for urban planning. These include the number of general practitioners (GPs) accessible within a 10-minute walking distance, GPs accessible within 10 minutes using public transport (PT), the number of bus or tram stops accessible within a 5-minute walking distance, average weekly bus or tram services within a 5-minute walking distance, average waiting time between services within a 5-minute walking distance, and the time required to access a hospital using PT or by walking. Each indicator is normalized to a consistent scale using min-max normalization to facilitate comparative analysis across study areas. The multi-criteria score (S1) is calculated as the average of these normalized indicators, assuming equal weighting for each criterion. This approach provides insights into overall accessibility to healthcare and transport services within each study area.

$$S1 = \frac{GP\_Walking + GP\_PublicTransport + BTStop\_Walking + TServices + BTWaitingT + HP\_PublicTransport + HP\_Walking}{7}$$

4.4.4.2 Scenario 2

In Scenario 2 (S2), a multi-criteria analysis is conducted based on accessibility indicators tailored to the objectives of a 10-minute city, keeping hospitals into the multi-criteria but only in a 10-minute radius. These indicators encompass the availability of general practitioners (GPs) within a 10-minute walking distance, GPs accessible within 10 minutes using public transport (PT), bus or tram stops accessible within 5-minute walking distance, average weekly bus or tram services within a 5-minute walking distance, average waiting time between services within a 5-minute walking distance, and the accessibility of hospitals within 10 minutes by walking or PT. Each indicator undergoes min-max normalization to ensure uniformity across study areas, facilitating a comparative assessment. The multi-criteria score (S2) is derived by averaging the normalized values of these indicators, with equal weight assigned to each criterion.

$$S2 = \frac{GP\_Walking + GP\_PublicTransport + BTStop\_Walking + TServices + BTWaitingT + MIN10\_PT + MIN10\_Walking}{7}$$

4.4.4.3 Scenario 3

In Scenario 3 (S3), a multi-criteria analysis is conducted based on accessibility indicators tailored to the objectives of a 10-minute city. These indicators encompass the availability of general practitioners (GPs) within a 10-minute walking distance, GPs accessible within 10 minutes using public transport (PT), bus or tram stops accessible within 5-minute walking distance, average weekly bus or tram services within a 5-minute walking distance, and average waiting time between services within a 5-minute walking distance. This selection of indicators reflects the focus on enhancing accessibility to essential services within a compact urban framework. The multi-criteria score (S3) is derived by averaging the normalized values of these indicators, with equal weight assigned to each criterion. The exclusion of hospital accessibility indicators in Scenario 3 is deliberate. Given that hospitals typically serve as primary amenities and are less feasible to locate within a 10-minute travel distance by walking or public transport in dense urban environments, they are not included in the evaluation criteria for S3.

$$S3 = \frac{GP\_Walking + GP\_PublicTransport + BTStop\_Walking + TServices + BTWaitingT}{5}$$

4.5 Viability and Reliability

This study ensures robust construct validity by accurately operationalizing public transit and healthcare accessibility. These constructs are grounded in established theoretical frameworks and extensive literature, with precise definitions and methods such as distance-based and gravity-based approaches, ensuring they reflect true accessibility (Kimberlin, Winterstein, 2008, p.6). Internal validity is strengthened through a meticulous study design that minimizes biases and confounding variables (Kimberlin, Winterstein, 2008, p.2). The data collection process includes comprehensive sources, such as Google Maps for health amenities and GTFS for public transportation schedules. By generating isochrones across various times and days, and including multiple transportation modes, the study effectively captures a wide range of scenarios, thus reducing the impact of extraneous factors. External validity is enhanced by analyzing five diverse neighborhoods in Utrecht, chosen for their varied demographics, housing types, and locations (Kimberlin, Winterstein, 2008, p.3). This selection provides a comprehensive representation of the varied urban landscape within Utrecht. While the specific characteristics of the 10-minute city concept may differ between cities, the methodology and findings of this study offer valuable insights and can be adapted to similar urban settings with diverse contexts.

Ecological validity is ensured by using real-world data and realistic travel scenarios (Schmuckler, 2001, p.1). The study incorporates actual public transit schedules and Google Maps data, making the results reflective of everyday experiences. The use of the TravelTime API, with its real-time updates and detailed street network data, further enhances the ecological relevance and ensures practical applicability. Reliability in data collection is maintained through reputable and consistent sources (Kimberlin, Winterstein, 2008, p.2). Google Maps and GTFS provide accurate and up-to-date information, ensuring dependable data across different conditions. The analysis process, using ArcGIS Pro 3.0 for spatial mapping, is designed to be replicable and consistent, allowing for systematic generation of isochrones, service frequency calculations, and waiting time assessments. To minimize subjectivity, the study employs clear operational definitions and standardized procedures. Walking distances are verified with Google Maps' route planner, ensuring that any manual adjustments are based on objective criteria.

4.6 Limitations and Considerations

While the methodology outlined above provides a structured approach to investigating the spatial distribution and accessibility of health amenities and public transportation in Utrecht, it is essential to consider potential limitations and challenges inherent in this type of research. One notable concern is the reliance on data from third-party sources such as Google Maps and GTFS datasets. While these sources provide comprehensive information, their accuracy and completeness can vary, potentially introducing biases or inaccuracies into the analysis. Furthermore, the methodology's focus on quantitative data may overlook qualitative aspects of accessibility, such as perceptions of safety, ease of navigation, or cultural barriers that could affect how individuals access healthcare and public transportation (Páez, Scott & Morency (2012, pp. 9-11). Additionally, the use of isochrone maps and grid-based analysis, while effective for visualizing spatial relationships, may oversimplify the complex dynamics of urban accessibility, especially in heterogeneous urban environments where socioeconomic disparities and infrastructural inequalities can significantly impact accessibility patterns.

5. Results

This chapter discusses the research findings, organized around the three sub-questions. The results are presented using analysis-generated maps.

5.1 Access to General Practitioners

The first sub-question examines the extent to which general practitioners are accessible from residential homes in the study areas. A distance analysis was used between the general practitioners and the study areas. This was done for both a walking distance of 10 minutes and a travel distance by public transport of 10 minutes.

5.1.1 Wittevrouwen

In Wittevrouwen, the accessibility of general practitioners (GPs) is evaluated based on walking and public transport (PT) accessibility (see Figure 16). In this neighborhood, all residents have access to at least 2 GPs by walking and 3 GPs by PT. Public transport enhances accessibility, allowing up to 8 GPs to be reachable within a 10-minute journey. The northeast side of Wittevrouwen has fewer nearby GPs, likely due to the barrier created by the Biltsche Grift. This waterway, running from the northwest to the southeast corner, encloses Wittevrouwen and, with limited crossing points like the Grift Bridge, affects maximum walking distances and travel routes. Compared to other study areas, Wittevrouwen offers superior GP access, resulting in a high density of healthcare services within a short walking distance.

5.1.2 Leidsche Rijn-Centrum

In Figure 17, the accessibility of general practitioners (GPs) in Leidsche Rijn-Centrum is illustrated. Within a 10-minute walking distance, most areas have access to 1 GP, with some areas having access to up to 2 GPs. The east side, however, has no access to GPs via either mode of transportation, requiring residents to travel longer distances to reach a GP. Utilizing public transport, accessibility slightly improves for the northwest side of Leidsche Rijn-Centrum. The most significant improvement is observed on the east side, where increased PT accessibility allows a larger portion of residents to reach GPs. Compared to other study areas, Leidsche Rijn-Centrum exhibits a relatively low access to GPs.

5.1.3 Lombok-Oost

In the Lombok-Oost area (as depicted in Figure 18), most areas have access to one GP, while some have access to two. The northern side of Lombok-Oost exhibits better accessibility than the southwestern side. Notably, the central station of Utrecht, situated just below the southwestern side, acts as a significant barrier, resulting in certain areas having no GP access within the 10-minute walking range. Public transport usage does not significantly alter GP accessibility in Lombok-Oost, except for a grid cell that gains access to a third GP. Compared to other study areas, Lombok-Oost generally exhibits moderate GP accessibility. However, it’s important to highlight that nearly all areas within Lombok-Oost have access to at least one GP within reach, which is not the case for other study areas like Leidsche Rijn-Centrum and Kanaleneiland-Noord.

Figure 16(A): Number of GPs accessible (walking) (B): Number of GPs accessible (public transport)

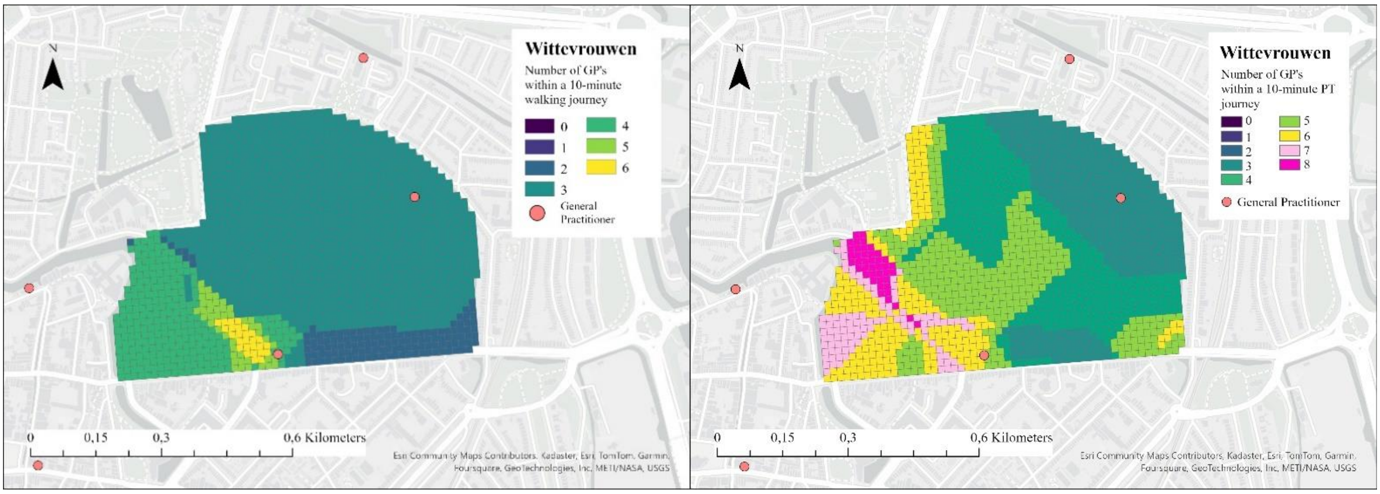


Figure 17(A): Number of GPs accessible (walking) (B): Number of GPs accessible (public transport)

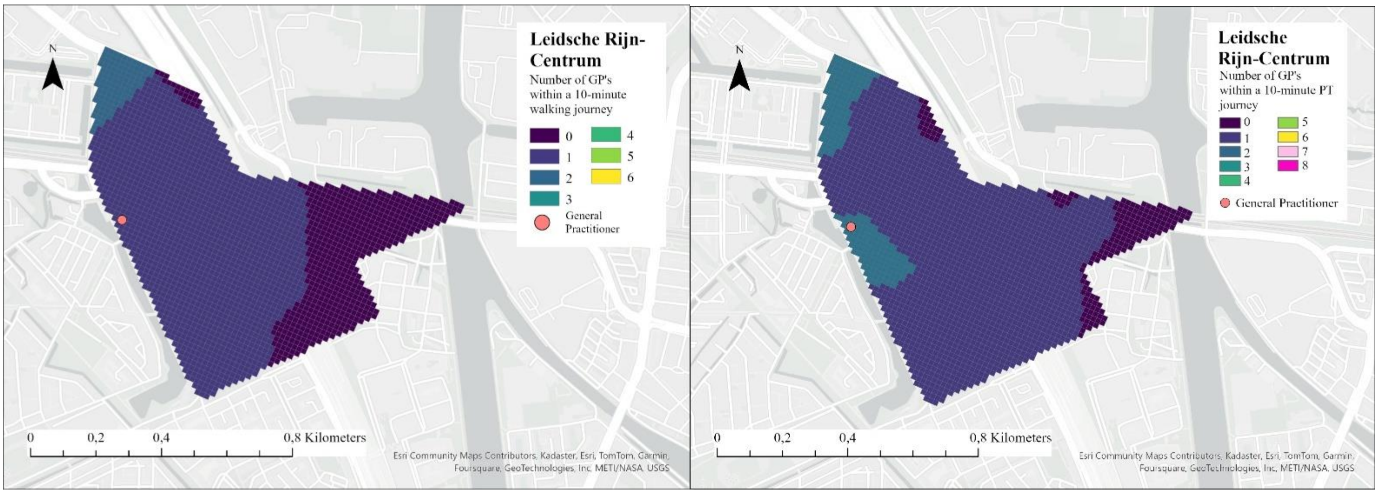


Figure 18(A): Number of GPs accessible (walking) (B): Number of GPs accessible (public transport)

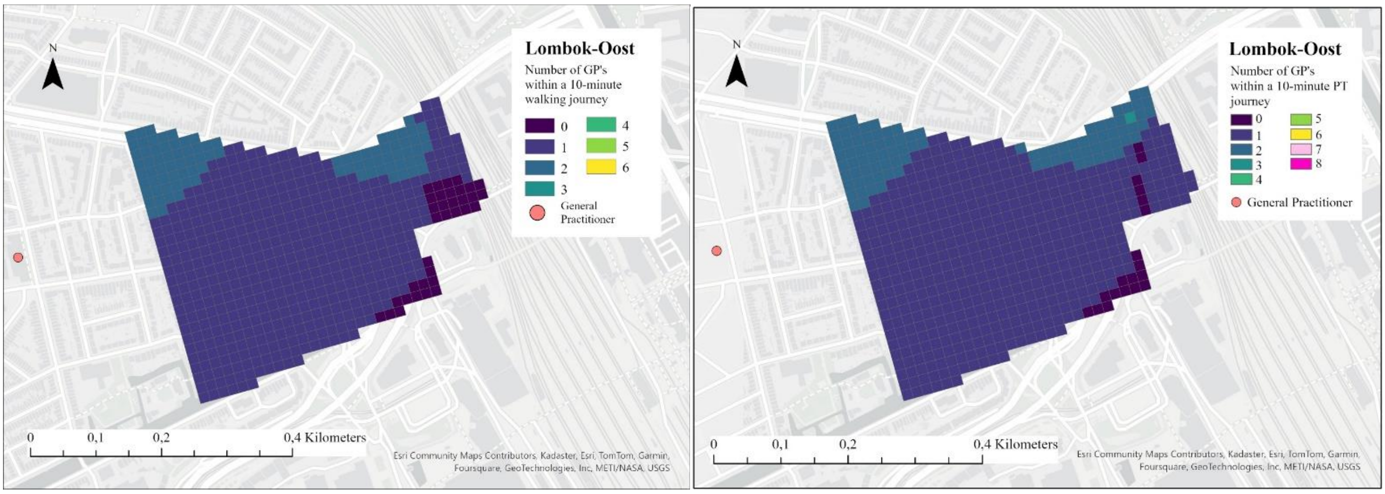


Figure 19(A): Number of GPs accessible (walking) (B): Number of GPs accessible (public transport)

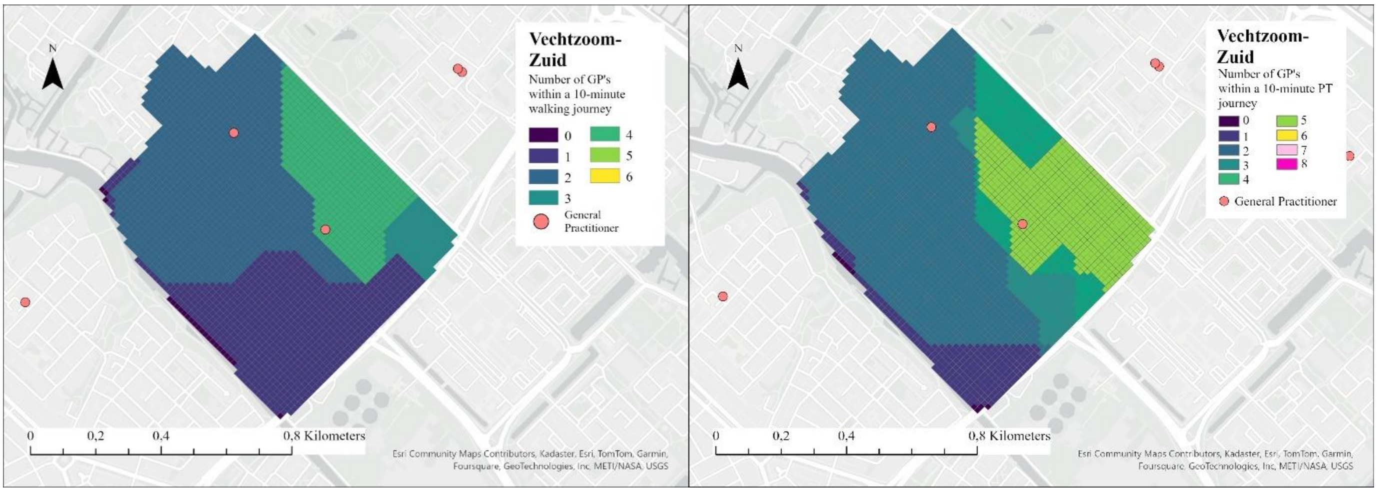
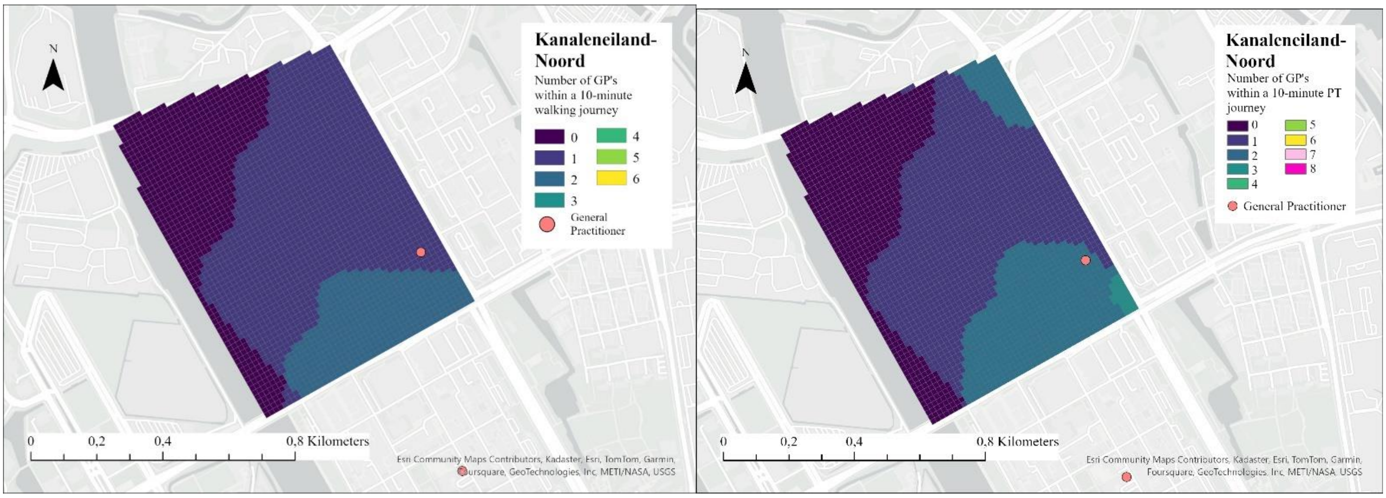


Figure 20(A): Number of GPs accessible (walking) (B): Number of GPs accessible (public transport)



5.1.4 Vechtzoom-Zuid

The results for Vechtzoom-Zuid (Figure 19) indicate that nearly all areas have access to at least 1 GP within a 10-minute walking distance. However, at the border near the Vecht, there are instances where 0 GPs are accessible, although these areas have no residents living there and thus less pertinent. The Vecht river acts as a barrier in accessing GPs located on the opposite bank. Moreover, a substantial portion of the area has access to between 2 and up to 4 GPs within a 10-minute walking radius. When considering a 10-minute public transport (PT) radius, there is a notable increase in accessibility, with nearly the entire neighborhood having access to at least 2 GPs. The western part shows a significant increase to 5 GPs within reach. Relative to other neighborhoods, Vechtzoom-Zuid exhibits relatively high accessibility to GPs. Public transport significantly enhances accessibility, ensuring most areas access to multiple GPs.

5.1.5 Kanaleneiland-Noord

For Kanaleneiland-Noord (Figure 20), most of the area exhibits access to 1 GP within a 10-minute walking distance, although notable exceptions exist. The northwestern part of the neighborhood lacks any GP accessibility within this radius, contrasting with the southern section where access extends to 2 GPs on foot. Analysis using public transport (PT) reveals significant enhancements: in the northeastern quadrant, where 1 GP was previously accessible by walking, PT now provides access to 2 GPs. Similarly, the southern area, initially served by 2 GPs on foot, expands its coverage northward with PT use. However, areas that lacked any GP access on foot continue to face this limitation. Notably, these areas are situated alongside the Amsterdam-Rijnkanaal, underscoring the barrier effect of this waterway on healthcare accessibility within Kanaleneiland-Noord. Kanaleneiland scores relatively low in GP accessibility because even with the use of public transport, a significant portion of the neighborhood still lacks access to a single GP.

Based on the comprehensive analysis of general practitioner (GP) accessibility across Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord, significant variations are observed in their alignment with the 10-minute city model for healthcare accessibility. Wittevrouwen stands out as a robust contender for fulfilling the 10-minute city criteria due to its extensive coverage of multiple GPs accessible via both walking and public transport, notwithstanding geographic constraints such as the Biltsche Grift. In contrast, Leidsche Rijn-Centrum and Kanaleneiland-Noord face substantial challenges, particularly in areas where no GPs are within a 10-minute reach, highlighting critical gaps in accessibility. Lombok-Oost demonstrates moderate GP access overall, albeit with localized deficiencies where no GPs are accessible by any transport mode. Vechtzoom-Zuid exhibits relatively high GP accessibility, particularly enhanced by public transport options, yet pockets with zero GP access highlight ongoing accessibility disparities. Overall, while certain neighborhoods exhibit promising aspects of a 10-minute city, achieving comprehensive healthcare accessibility across Utrecht will necessitate targeted infrastructure enhancements and strategic urban planning initiatives.

5.2 Access to Bus and Tram Stops

The second sub-question examines the extent to which bus or tram stops are accessible from residential homes in the study areas. A distance analysis was conducted between the bus or tram stops and the residential homes, considering a 5-minute walking distance. Additionally, the average number of services and the average waiting time between services for buses on weekdays between 06:00 and 23:00 were included to provide an overview of the relevance of each bus stop, employing a gravity-based approach.

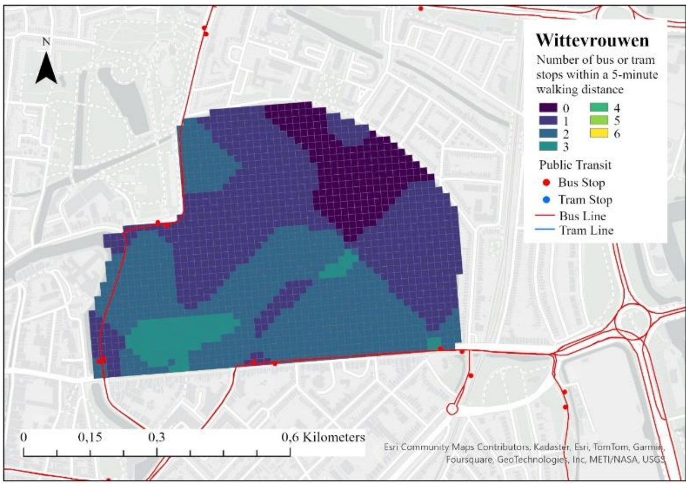
5.2.1 Wittevrouwen

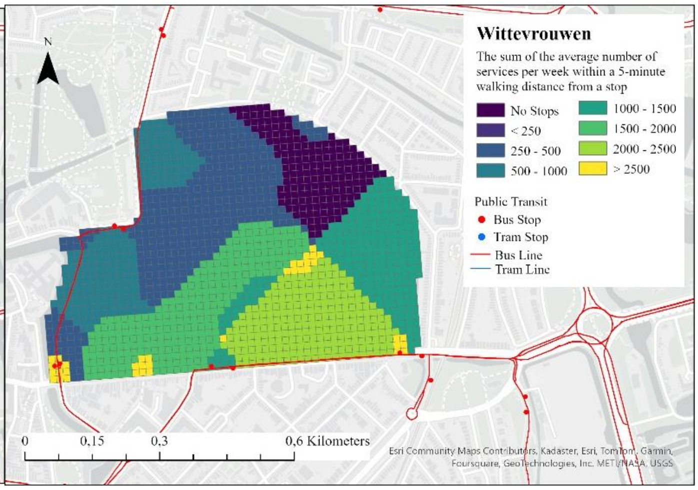
In Wittevrouwen, the accessibility and frequency of bus and tram services vary significantly across the neighborhood. Figure 21(A) indicates that the majority of Wittevrouwen residents have access to at least one bus or tram stop within a five-minute walking distance. However, a small northern section lacks any such access, while some southern areas benefit from proximity to two or even three stops within this range. Figure 21(B) demonstrates that areas without bus stops within five minutes also lack service options, marked as "No Stops." Notably, two bus stops in Wittevrouwen provide a high frequency of services, with 2000 to 2500 or more services per week, suggesting multiple bus service options in these areas. Conversely, stops on the western edge offer significantly fewer weekly services. Figure 21(C) shows that stops with higher service frequencies have shorter average waiting times, typically between 5 to 10 minutes. In contrast, the western part of Wittevrouwen has longer average waiting times, exceeding 30 minutes.

5.2.2 Leidsche Rijn-Centrum

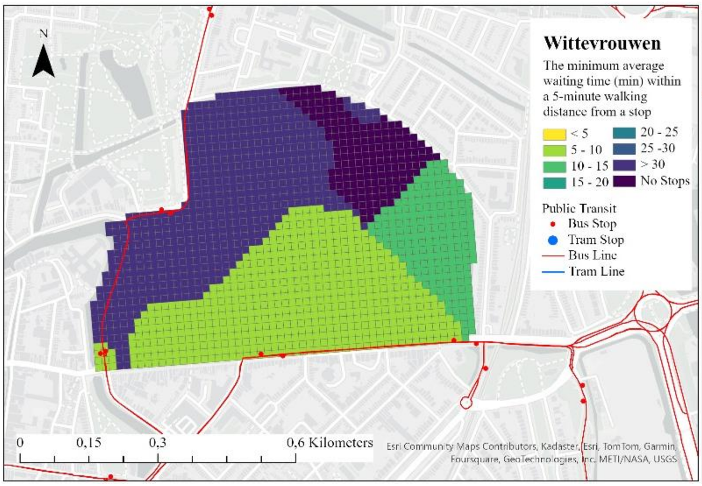
In Leidsche Rijn-Centrum, the distribution and frequency of bus services exhibit notable variations. Figure 22(A) indicates that the central area of Leidsche Rijn-Centrum, where the train and bus stations are located, boasts a high number of accessible stops, with up to four within a five-minute walking distance. However, as one moves further from this central hub, access declines. Notably, the upper part of Leidsche Rijn and the outer right corner have areas with no access to any bus stops. Figure 22(B) highlights that the bus station in the central part of Leidsche Rijn-Centrum has the highest number of service options. This is due to its role as a bus station rather than a mere bus stop, allowing multiple buses to pass through, thus increasing the frequency and variety of available services. In general, Leidsche Rijn-Centrum has good service options, with most of the neighborhood receiving between 500 to 1000 services weekly. Nevertheless, as mentioned, some areas lack access to any bus services. Figure 22(C) shows that the minimum average waiting time for a bus on weekdays is quite favourable, with most of Leidsche Rijn-Centrum experiencing a wait time of 15 to 20 minutes for the next bus to arrive.

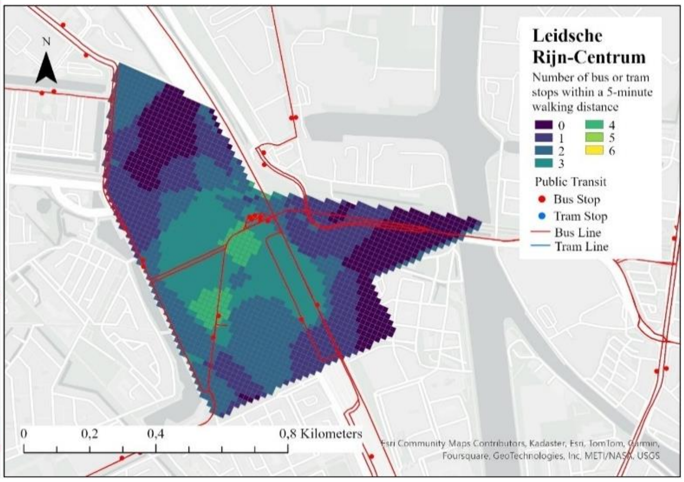
Figure 21 (A): Number of Bus or Tram Stops within 5M (B): Total Service Options within 5M



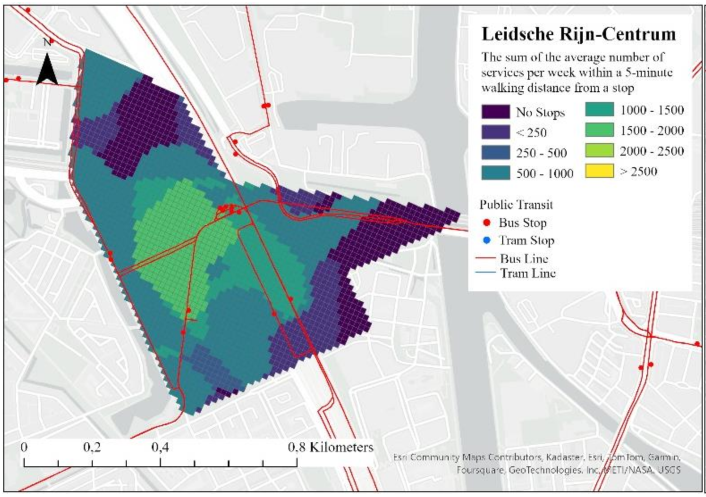


(C): Minimum waiting time between services within 5M Figure 22 (A): Number of Bus or Tram Stops within 5M





(B): Total Service Options within 5M



(C): Minimum waiting time between services within 5M

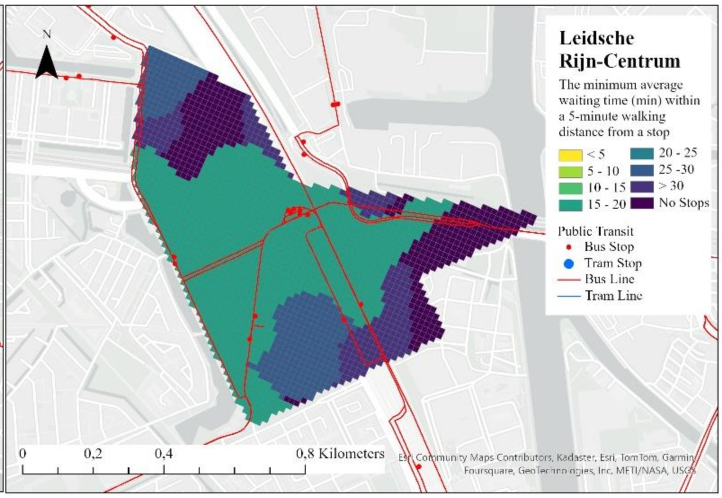
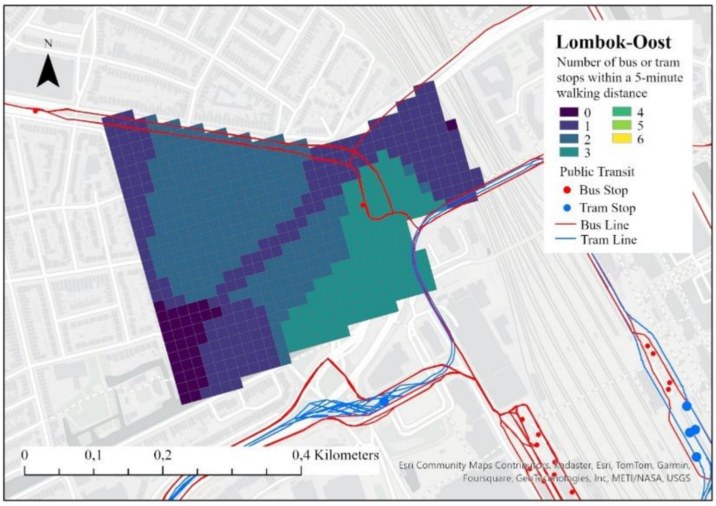
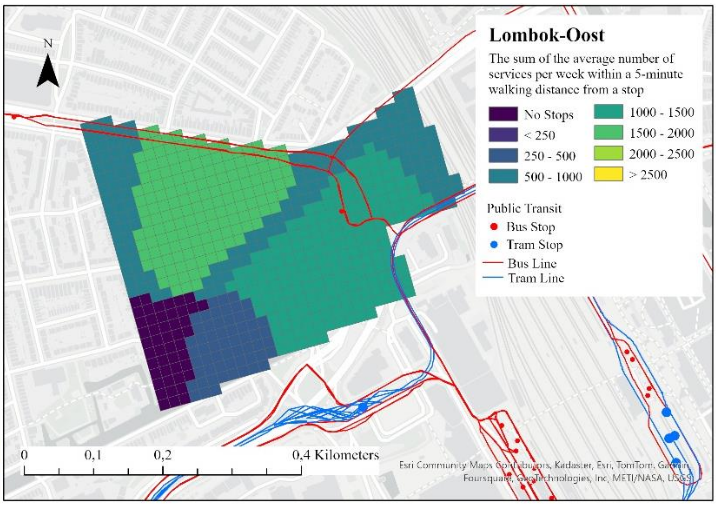


Figure 24 (A): Number of Bus or Tram Stops within 5M



(B): Total Service Options within 5M



(C): Minimum waiting time between services within 5M

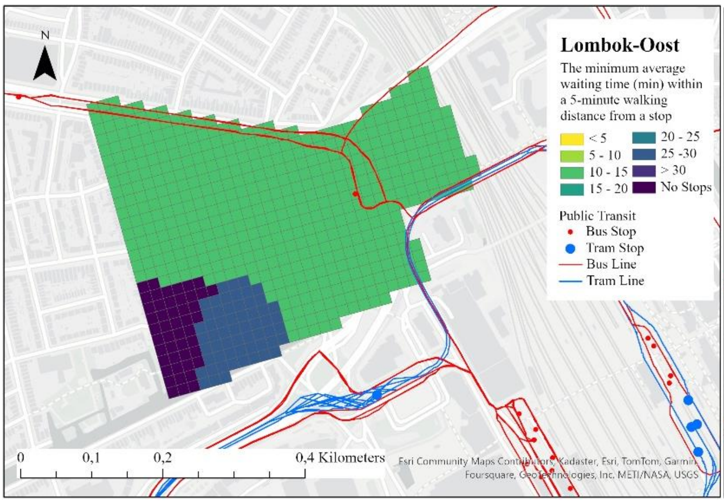
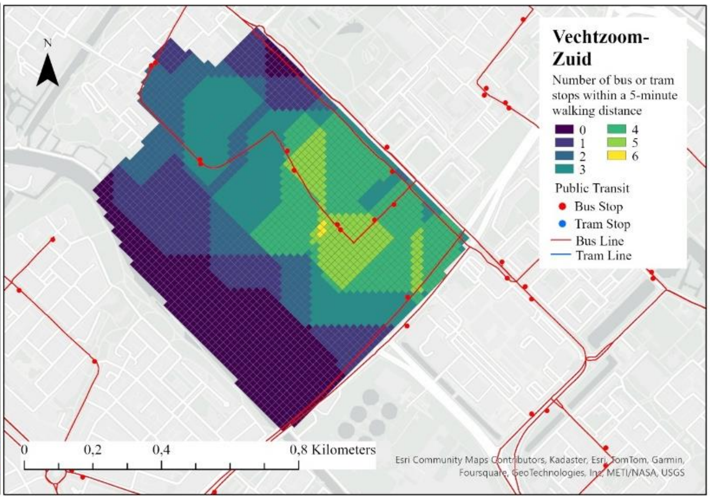
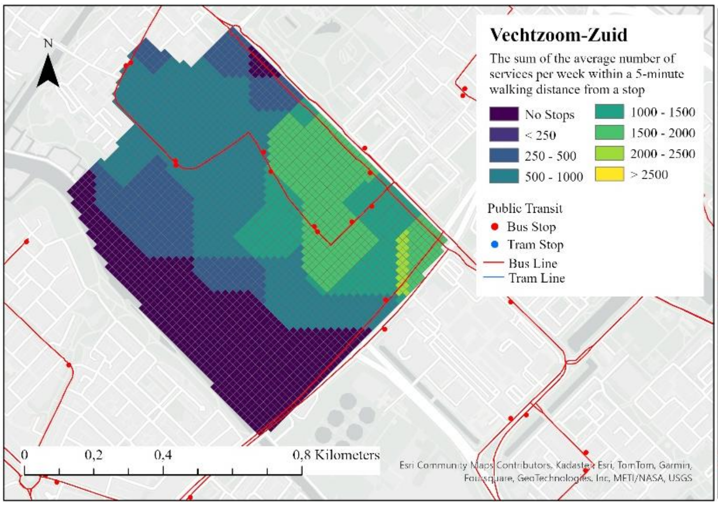


Figure 25 (A): Number of Bus or Tram Stops within 5M



(B): Total Service Options within 5M



(C): Minimum waiting time between services within 5M

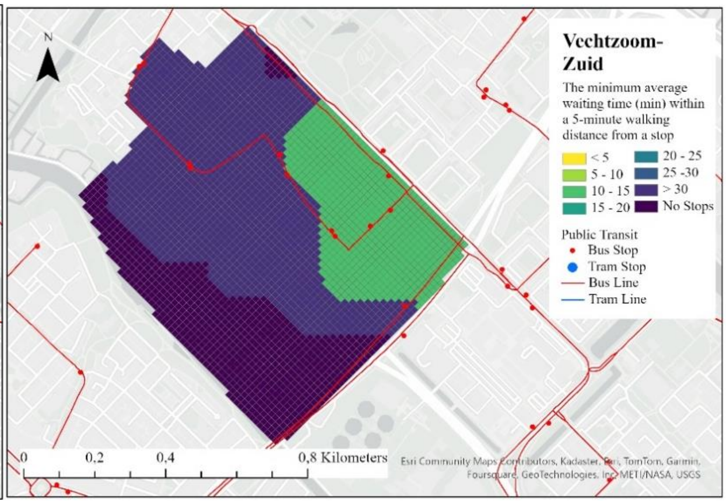
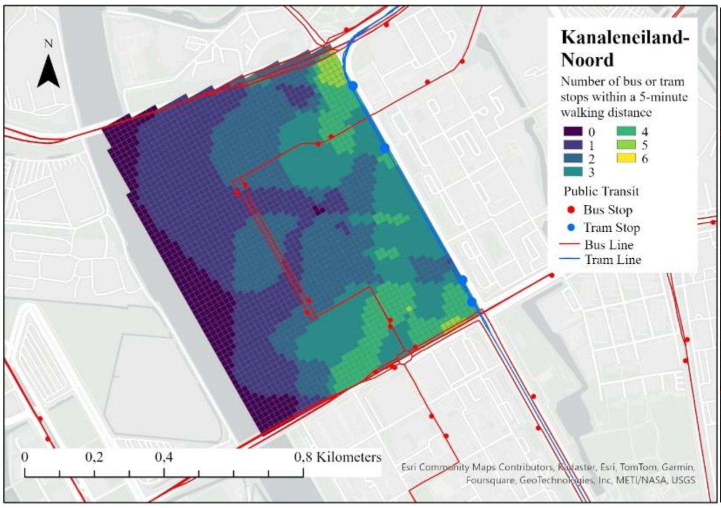
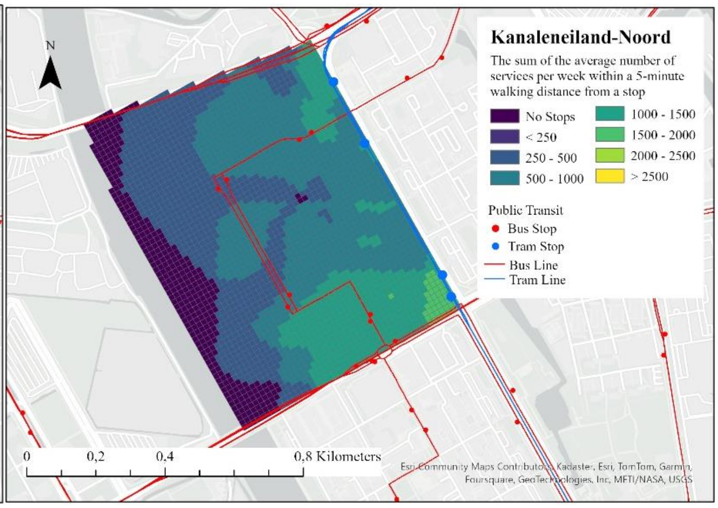


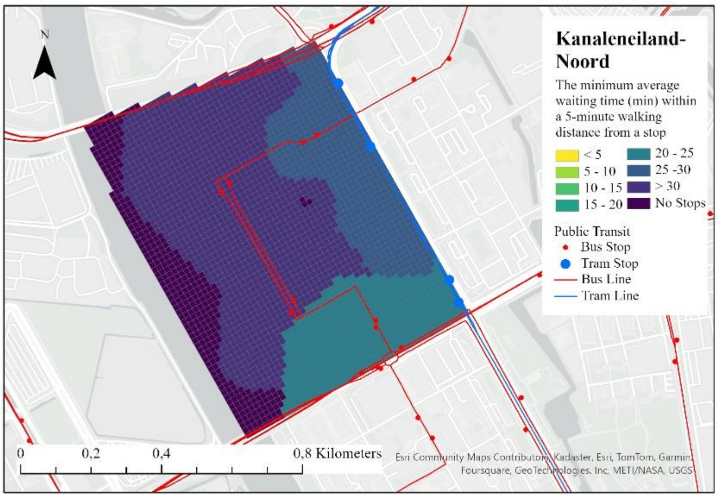
Figure 26 (A): Number of Bus or Tram Stops within 5M



(B): Total Service Options within 5M



(C): Minimum waiting time between services within 5M



5.2.3 Lombok-Oost

Figure 24(A) illustrates that most of Lombok-Oost has access to at least one bus stop within a five-minute walking distance, except for the west southern corner, which has no stops. The east southern part, located near the tram and train station, has greater access, with 2-3 stops within this range. The northern part, near Vleutenseweg, has access to two stops. Figure 24(B) shows that the northern part of Vleutenseweg has more services, with 2000-2500 weekly, compared to the southern part near the tram station, which has 1000-1500 services. This indicates that while the northern area might have fewer bus stops nearby, the frequency of services passing through is higher. This is particularly relevant as it suggests a higher overall connectivity and convenience for residents, as more frequent services can reduce waiting times and improve overall transit efficiency. Figure 24(C) demonstrates that for almost all of Lombok-Oost, the average waiting time for the next bus is around 10-15 minutes, which is fairly good.

5.2.4 Vechtzoom-Zuid

In Vechtzoom-Zuid, the availability and frequency of bus and tram services show notable variation. Figure 25(A) reveals that the number of bus or tram stops within a five-minute walking distance range from 0 to 6. Areas near the river Vecht have low access, with no stops available. In contrast, a bus line runs straight through the middle of Vechtzoom-Zuid, providing high accessibility with up to 6 stops within this range. Figure 25(B) indicates that the central area, where this bus line runs, also has the highest number of service options. This is because the concentration of stops along this central corridor allows for more frequent and varied bus services, enhancing overall connectivity for residents. Figure 25(C) highlights the differences in average waiting times for bus services. The central part of Vechtzoom-Zuid, benefiting from multiple stops and frequent services, has a lower average waiting time of 10-15 minutes. In contrast, the outer areas experience significantly longer waiting times, exceeding half an hour.

5.2.5 Kanaleneiland-Noord

Figure 26(A) illustrates a mix of accessibility levels. A bus line runs through the district, while a tram line runs along its eastern edge, resulting in better access to bus and tram stops in the eastern side (2-4 stops, with some small areas having up to 5 stops). The western side, however, has almost no bus or tram stops, making it less accessible with only 0-1 stops within a five-minute walking distance. Figure 26(B) shows that the southern part of Kanaleneiland has a higher number of service options. This is due to the presence of both a tram stops and a bus station in this area, which provide more frequent and varied services compared to standard bus stops. Consequently, residents in this southern section benefit from increased connectivity and more transportation options. Figure 26(C) highlights that the average waiting time for bus services in Kanaleneiland is relatively high. Residents generally wait at least 20-25 minutes for the next bus, with waiting times exceeding half an hour in most areas.

The neighbourhoods of Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord in Utrecht vary widely in terms of public transport accessibility and service provision. Wittevrouwen and Leidsche Rijn-Centrum benefit from central locations and proximity to major transport hubs, resulting in better access to multiple bus and tram stops with higher service frequencies. In contrast, Lombok-Oost and Vechtzoom-Zuid exhibit more balanced accessibility within neighborhoods, albeit with disparities in service frequencies between central and peripheral areas. Kanaleneiland-Noord shows a mixed picture with significant differences between its eastern and western sections, reflecting varying levels of access to public transport infrastructure. Within the concept of the

10-minute city, it is notable that none of these neighborhoods fully meet the criteria, as each area has locations where not a single bus or tram stop is reachable within a 5-minute walk.

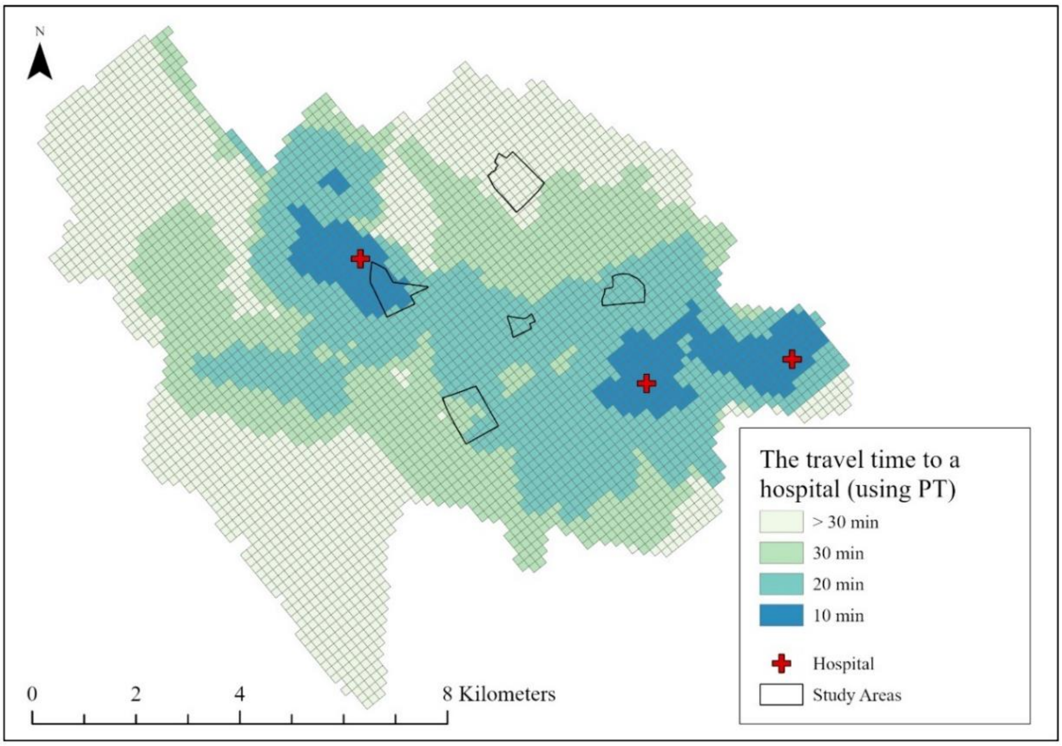
5.3 Access to Hospitals using Public Transportation

The third sub-question examines the extent to which hospitals in Utrecht are accessible using public transportation from the study areas. A time-based and data-driven distance analysis was conducted, considering travel times of 30 minutes, 20 minutes, and 10 minutes using public transit and walking.

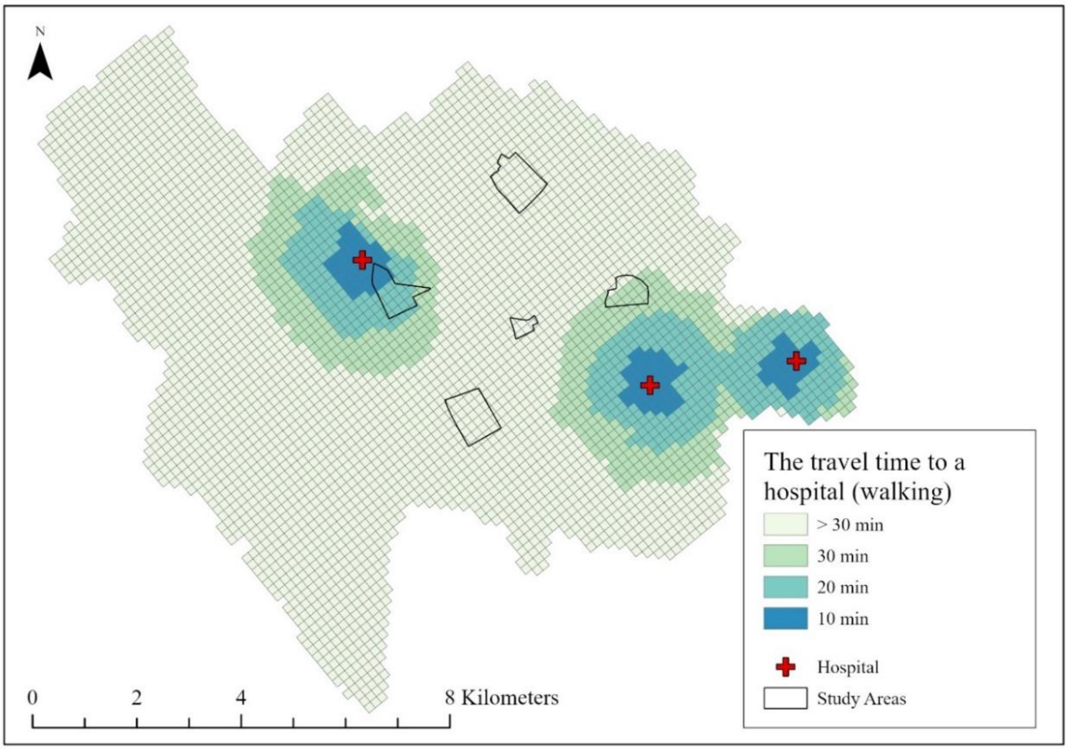
Figure 27(A) shows the areas within varying travel times to reach hospitals using public transit. The areas closest to hospitals, shaded in dark blue, indicate travel times of 10 minutes or less. Light blue areas represent 20-minute travel times, green areas indicate 30-minute travel times, and the lightest green areas show travel times exceeding 30 minutes. Hospitals are marked with red crosses, and study areas are outlined in black. The central and eastern parts of the map demonstrate the best accessibility by public transit, with substantial areas falling within the 10-minute and 20-minute zones. In contrast, the more peripheral areas show longer travel times.

Figure 27(B) displays travel times to hospitals when walking. As in (A), the dark blue areas indicate the shortest travel times of 10 minutes or less, followed by light blue (20 minutes), green (30 minutes), and lightest green (more than 30 minutes). Hospitals and study areas are similarly marked. The accessible areas are more compact compared to those in Figure (A), reflecting the slower nature of walking. The immediate surroundings of the hospitals fall within the 10-minute and 20-minute zones, but the accessible areas become sparse beyond these distances.

Figure 27 (A): Total travel time using public transit to access hospitals

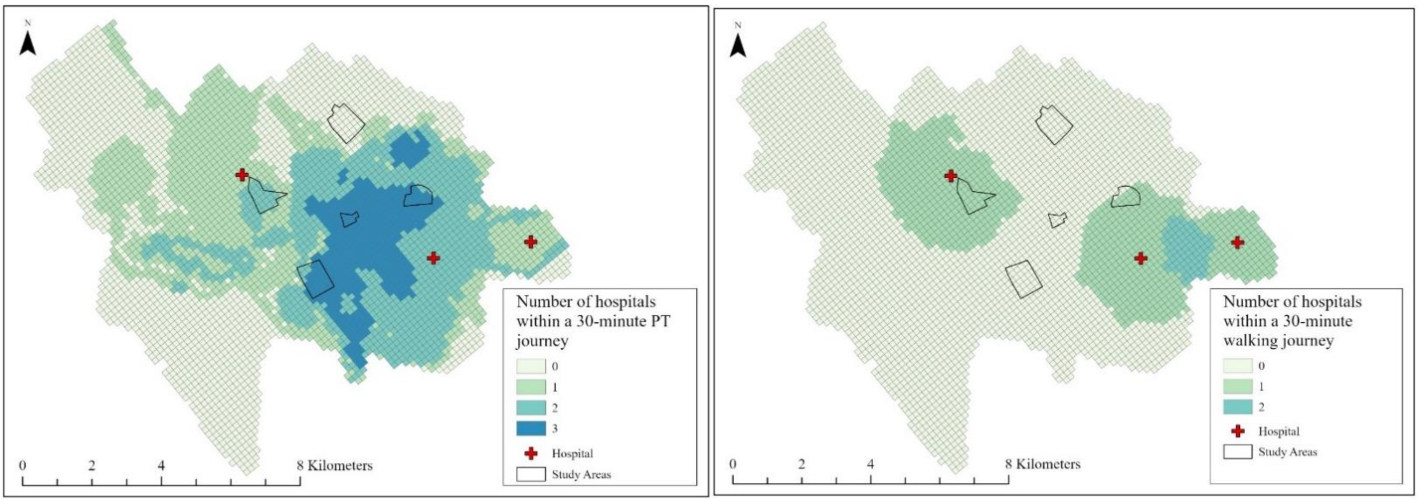


(B): Total travel time walking to acces hospitals

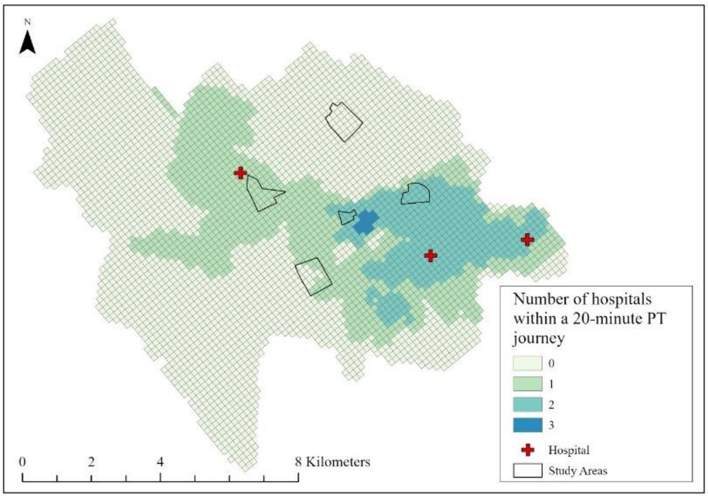


Public transit significantly expands the area within which hospitals can be accessed quickly compared to walking. Large portions of the central and eastern regions can reach hospitals within 20 minutes using public transit, while walking limits this accessibility to the immediate vicinity of the hospitals. The outer regions show substantial differences in accessibility, with public transit providing more extensive coverage and shorter travel times compared to walking. In Vechtzoom-Zuid, both maps show that the area falls outside the 30-minute range for accessing hospitals, indicating poor connectivity. Wittevrouwen, on the other hand, is reachable within 20 minutes using public transit and within 30 minutes when walking. Lombok-Oost is accessible within 20 minutes by public transit but takes longer than 30 minutes when walking. Leidsche Rijn is particularly well-served, being reachable within 10 minutes by public transit and primarily within 20 minutes on foot. Kanaleneiland falls within the 20 to 30-minute range using public transit, but it lies outside the 30-minute range when walking.

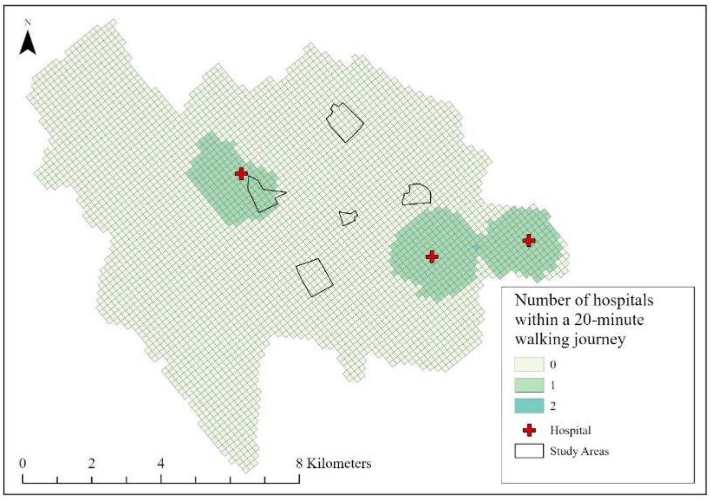
Figure 28 (A): Number of hospitals using PT (30 Minutes) (B): Number of hospitals walking (30 Minutes)



(C): Number of hospitals using PT (20 Minutes)



(D): Number of hospitals walking (20 Minutes)



In figures 28A-D, accessibility to hospitals is compared based on travel mode (public transit vs. walking) within specified travel times. Figure 28A indicates that a larger number of hospitals are reachable within a 30-minute public transit journey compared to walking (Figure 28B). Within the inner city, most areas can access all three hospitals within a 30-minute public transit trip, whereas walking only reaches the outer parts of the inner city within the same timeframe. This trend is further illustrated in figures 28C and 28D, where a small portion of the inner city of Utrecht retains access to all three hospitals within a 20-minute public transit journey, whereas none of these hospitals are reachable by foot in the outer areas.

5.4 10-Minute City Goals

The fourth sub-question investigates how accessibility varies when using different criteria or definitions of what amenities or services should be reachable within ten minutes. To address this, three scenarios were created. The first scenario considers all urban indicators discussed in the other sub-questions. The second scenario focuses exclusively on the indicators specific to the 10-minute city concept, while still including the 10-minute radius to a hospital. The third scenario considers only primary amenities, excluding access to a hospital. Please refer to Table 1: All indicators for the multi-criteria analysis, in the appendix for a comprehensive list of these indicators.

5.4.1 Scenario One

The figures 29A-E present a multi-criteria analysis (S1) based on various accessibility indicators, including the number of general practitioners (GPs) accessible within a 10-minute walking distance, the number of GPs accessible within 10 minutes using public transport (PT), the number of bus or tram stops accessible within a 5-minute walking distance, the average number of bus or tram services per week within a 5-minute walking distance, the average waiting time between services within a 5-minute walking distance, and the time required to access a hospital using PT or by walking.

The results of Wittevrouwen (29A) show a diverse range of accessibility scores across the area. The central region is marked by pink areas (5.0-6.0), indicating excellent accessibility to healthcare and public transport services. Yellow areas (3.0-4.0) represent moderate accessibility, which is common throughout much of the region. The outer edges of Wittevrouwen display green and light blue areas (1.0-3.0), signifying limited accessibility to the services considered. Overall, Wittevrouwen demonstrates a mix of high accessibility in central zones and moderate to low scores in peripheral areas. The Leidsche Rijn-Centrum map (29B) features yellow areas (3.0-4.0), suggesting moderate accessibility to GPs, bus/tram stops, and services. Notably, there are pink areas (6.0-7.0) in the central regions, reflecting optimal accessibility to healthcare and public transport services. Conversely, the outskirts of Leidsche Rijn-Centrum exhibit green areas (1.0-2.0), which indicate limited access to the considered services.

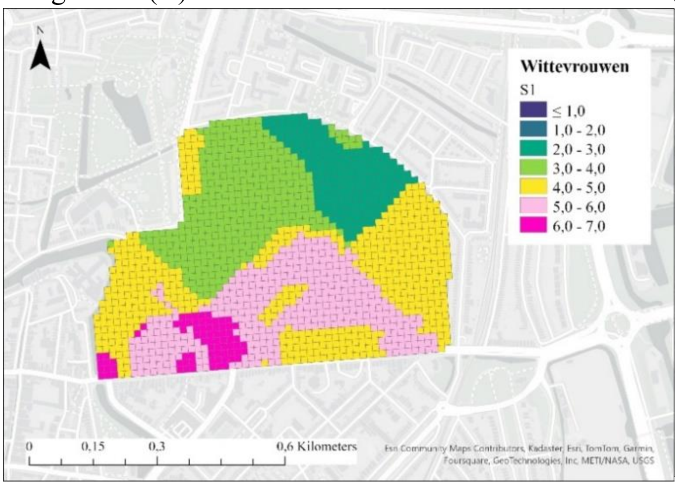
The Lombok-Oost map (29C) shows that central regions are marked by dark blue and purple areas (4.0-5.0), which signify good accessibility to healthcare and public transport services. Light blue areas (2.0-3.0) suggest moderate accessibility, which is prevalent in many parts of Lombok-Oost. Green areas (1.0-2.0), found mainly on the outskirts, indicate lower accessibility scores, pointing to fewer accessible services in these regions. Lombok-Oost reveals a more uniform distribution of accessibility scores compared to Wittevrouwen and Leidsche Rijn-Centrum.

The Vechtzoom-Zuid map (29D) shows a range of accessibility scores from lower values near the Vecht (<1.0-1.0) to higher values (4.0-5.0) in the upper central and northern parts of the area. Most of Vechtzoom-Zuid has at least a score of 2.0-3.0, indicating moderate accessibility. This area also features more higher-scored regions (4.0-5.0) compared to Kanaleneiland-Noord. Conversely, Vechtzoom-Zuid contains the largest areas with a score between 1.0-2.0 among all study areas, indicating a significant variation in accessibility levels within this region. This gradient highlights the disparity in service distribution, with areas further from the Vecht generally exhibiting better accessibility.

The Kanaleneiland-Noord map (29E) shows that almost the entire area has at least a score of 1.0-2.0, with very few parts scoring below 1.0 near the Amsterdam-Rijnkanaal. Accessibility scores increase near the tram and bus stations, ranging from 2.0-3.0 to 3.0-4.0 and even 4.0-5.0 near the bus station in the south. While Kanaleneiland-Noord has fewer low-scored areas compared to Vechtzoom-Zuid, it also has fewer high-scored areas. This indicates that Kanaleneiland-Noord has a more consistent but moderate level of accessibility throughout the region, with significant improvements in areas close to major public transport hubs.

The neighborhoods of Wittevrouwen, Leidsche Rijn-Centrum, Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord each demonstrate unique accessibility characteristics. Wittevrouwen and Leidsche Rijn-Centrum feature highly accessible central areas, with surrounding regions showing moderate to lower accessibility. Lombok-Oost exhibits a more uniform distribution of moderate accessibility throughout. Vechtzoom-Zuid displays a gradient from higher accessibility in the north to lower accessibility near the Vecht river. Kanaleneiland-Noord shows consistent moderate accessibility across most of the area, with improvements near major transport hubs. These patterns underscore varying levels of service accessibility within these urban locales, influencing the quality of healthcare and public transport available to residents.

Figure 29 (A): Multi-Criteria Score S1



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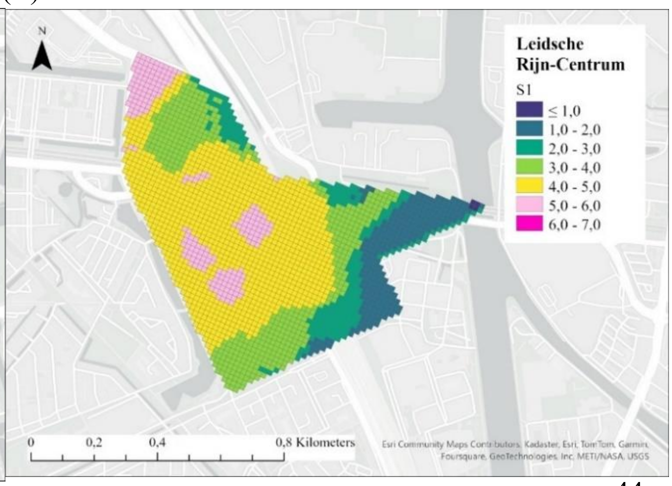
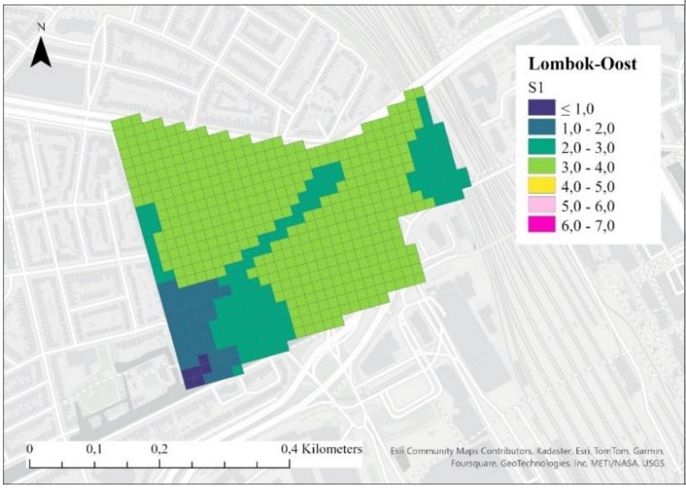


(C):



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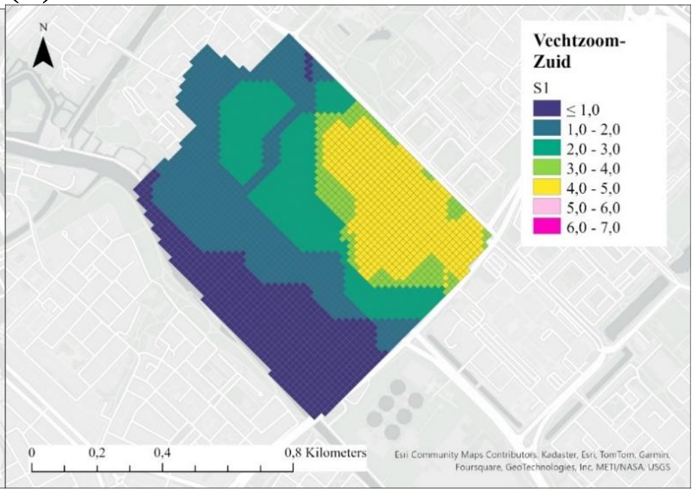

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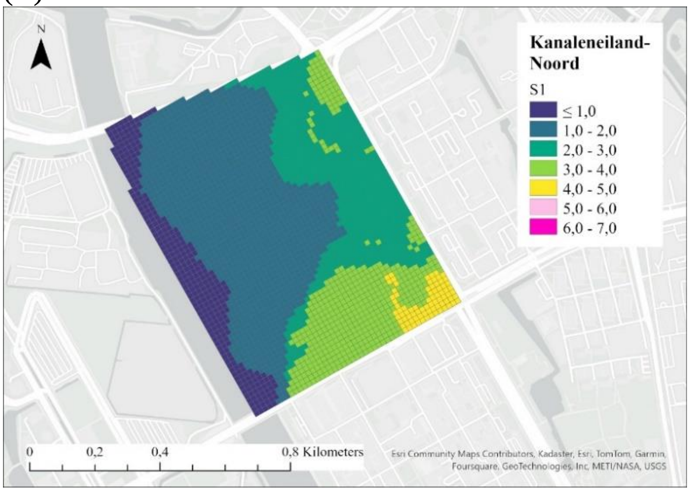


5.4.2 Scenario Two

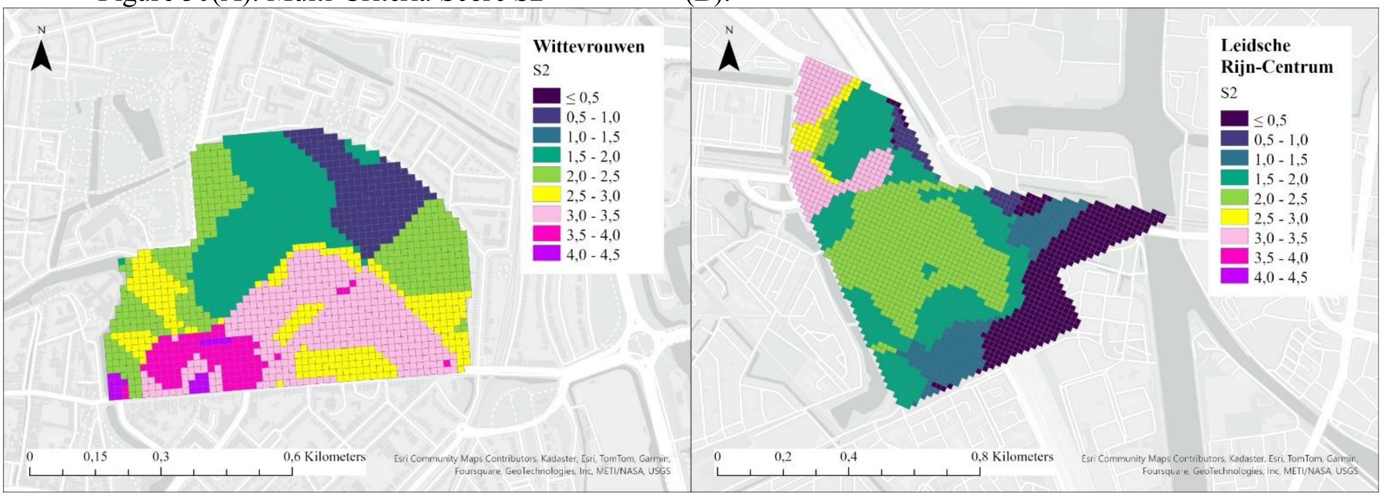
The figures 30A-E present a multi-criteria analysis (S2) based on accessibility indicators that align with the goals of a 10-minute city and include the access to secondary amenities but still in a 10-mintue frame. These indicators include the number of general practitioners (GPs) accessible within a 10-minute walking distance, the number of GPs accessible within 10 minutes using public transport (PT), the number of bus or tram stops accessible within a 5-minute walking distance, the average number of bus or tram services per week within a 5-minute walking distance, the average waiting time between services within a 5-minute walking distance, and the number of hospitals accessible within 10 minutes walking or using PT.

Figure 30A illustrates a diverse range of accessibility indicators within Wittevrouwen. Areas surrounding the Biltstraat exhibit notably higher scores, ranging from 2.5 to 4.5, denoted by yellow to pink shades. In contrast, northern parts display lower accessibility scores, varying between 0.5 and 2.0 in dark blue to green hues. Overall, Wittevrouwen demonstrates the highest accessibility values among all study areas considered, reflecting a concentrated distribution of healthcare facilities and public transport services. In Figure 30B, Leidsche Rijn-Centrum showcases a spectrum of accessibility scores ranging from less than 0.5 to 3.5. Areas adjacent to the bridge in the eastern part score the lowest (<0.5) in dark blue, while central and northern regions near hospitals and bus stations show higher scores, ranging from 2.0 to 3.5.

Figure 30C depicts Lombok-Oost with accessibility scores ranging predominantly between 0.5 and 2.5. The lower left corner shows the lowest scores (<0.5), while the remainder of the area consistently scores between 2.0 and 2.5. This area exhibits less variation compared to others in the study, likely due to its smaller size and relatively uniform distribution of accessibility indicators across the neighborhood. Vechtzoom-Zuid in Figure 30D demonstrates a wide range of accessibility scores, from less than 0.5 to 4.5. Areas near the Vecht river show lower scores (<0.5), while central and eastern parts display higher accessibility scores ranging from 2.0 to 4.5. Figure 30E portrays Kanaleneiland-Noord with accessibility scores ranging from less than 0.5 to 3.0. Areas near the Amsterdam-Rijnkanaal exhibit lower scores (<0.5 to 1.0), whereas sections proximate to tram and bus stations achieve higher scores, ranging from 1.5 to 3.0.

Across the five study areas analysed, notable differences in accessibility patterns emerge. Wittevrouwen is the most accessible, particularly around Biltstraat, due to its dense and centralized distribution of healthcare facilities and public transport, consistently scoring the highest. In contrast, Leidsche Rijn-Centrum shows varied accessibility, with lower scores in the eastern parts but higher scores near central and northern hubs. Lombok-Oost presents a more uniform distribution of access, albeit at a generally lower level compared to Wittevrouwen, reflecting less spatial variability. Vechtzoom-Zuid displays pronounced disparities, from low scores near the Vecht river to some of the highest scores in the central and eastern areas, indicating both areas of limited and exceptional access. Kanaleneiland-Noord, while generally lower in overall scores, improves in accessibility near its transport hubs, showcasing a gradient from low to moderate scores influenced by proximity to infrastructure. These differences underscore how spatial and infrastructural characteristics shape accessibility, with Wittevrouwen and parts of Vechtzoom-Zuid leading in overall accessibility, while other neighborhoods exhibit more varied or moderate access levels.

Figure 30(A): Multi-Criteria Score S2 (B):



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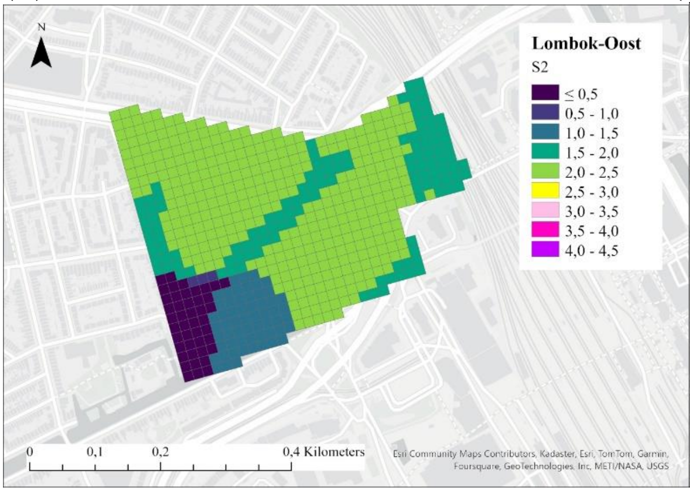

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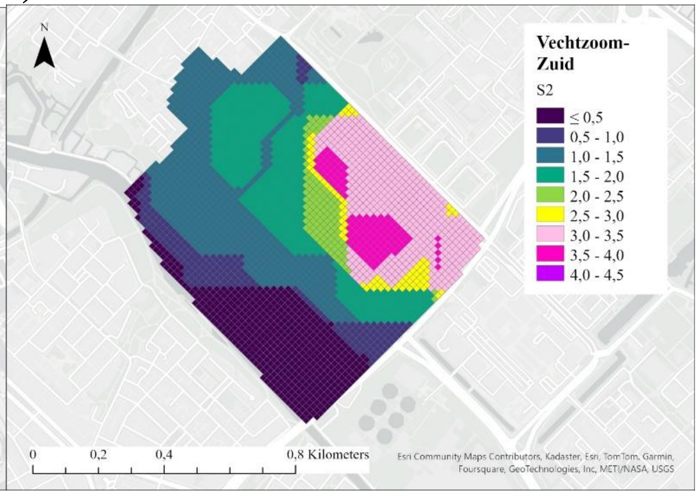

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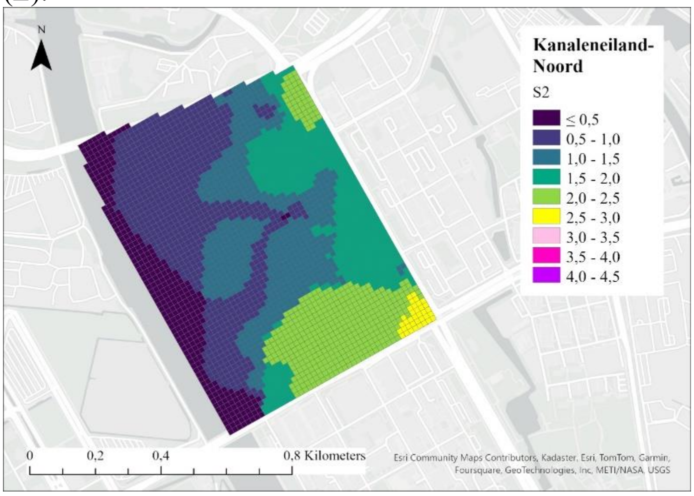


5.4.3 Scenario Three

The figures 31A-C present a multi-criteria analysis (S3) based on accessibility indicators that align with the goals of a 10-minute city. These indicators include the number of general practitioners (GPs) accessible within a 10-minute walking distance, the number of GPs accessible within 10 minutes using public transport (PT), the number of bus or tram stops accessible within a 5-minute walking distance, the average number of bus or tram services per week within a 5-minute walking distance, and the average waiting time between services within a 5-minute walking distance.

Figure 31A illustrates the accessibility scores for the Wittevrouwen neighborhood. This area exhibits a wide range of scores, from less than 1.0 to 7.0-8.0. The southwestern parts of Wittevrouwen have the highest scores, ranging between 5.0-6.0 and 6.0-7.0, indicated by pink and magenta hues. These high-scoring zones suggest superior access to GPs and public transport. Central areas also show relatively high accessibility with scores between 4.0-5.0 (yellow). Conversely, the northeastern part of the neighborhood displays lower scores, falling between ≤1.0 to 2.0-3.0, marked by dark blue to teal shades. Overall, Wittevrouwen has a significant portion of its area scoring between 3.0-4.0 (green), indicating moderately high accessibility across the neighborhood.

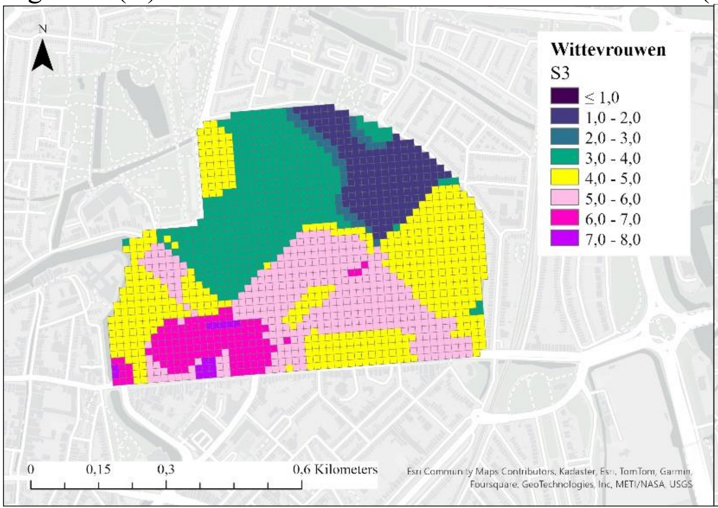
Figure 31B highlights the accessibility distribution in Leidsche Rijn-Centrum. This neighbourhood's scores range from ≤1.0 to 4.0. The lowest scores (≤1.0), shown in dark blue, are found primarily in the east southern parts. High scores are more dispersed, with areas scoring between 2.0-3.0 and 3.0-4.0

mostly located along the western and central areas. The majority of Leidsche Rijn-Centrum displays low to moderately low accessibility scores, suggesting limited access to GPs and public transport compared to other regions. Figure 31C depicts the accessibility scores in Lombok-Oost. The neighbourhood's scores range from ≤1.0 to 5.0 with the lowest scores (≤1.0) found in the southwestern part, shown in dark blue. The highest scores (4.0-5.0), indicated in yellow, are concentrated mainly in the northwestern parts of Lombok-Oost. These areas benefit from better access to GPs and public transport services. Most of Lombok-Oost falls within the 2.0-3.0 (teal) and 3.0-4.0 (green) score ranges, reflecting moderate levels of accessibility across the neighborhood.

Figure 31D showcases the accessibility scores for Vechtzoom-Zuid. The neighbourhood's scores vary from ≤1.0 to 7.0. The areas along the southern and border regions of Vechtzoom-Zuid have the lowest accessibility, with scores of ≤1.0, depicted in dark blue. Moving towards the upper regions, the scores improve, with most areas achieving at least 1.0-2.0 (blue) and predominantly 2.0-3.0 (teal). The central eastern parts, especially near the bus stations, show significantly higher scores between 5.0-7.0 (yellow and magenta), indicating excellent access to public transport. This distribution suggests that while peripheral areas may struggle with accessibility, the central zones provide good access to essential services. Figure 31E presents the accessibility scores for Kanaleneiland-Noord, which range from ≤1.0 to 5.0. The areas near the Amsterdam-Rijnkanaal, along the left border of the neighborhood, have the lowest scores (≤1.0), marked by dark blue. As you move towards the right border, the scores gradually increase, starting from 2.0-3.0 (teal) to 3.0-4.0 (green) and reaching 4.0-5.0 (yellow) in the southern part of the neighborhood. Most of Kanaleneiland-Noord achieves a score of at least 1.0-2.0 (blue), but less than half of the neighborhood scores 3.0-4.0 (green).

Wittevrouwen stands out with its broad range of high scores, particularly in the southwestern and central parts, indicating superior overall accessibility to GPs and public transport services. Conversely, Leidsche Rijn-Centrum shows a more constrained accessibility range, with most areas scoring between ≤1.0 and 4.0, and higher accessibility concentrated in its western and central regions. Lombok-Oost displays moderate accessibility, with scores clustering around 2.0-4.0, and the highest scores found in its northwestern part. Vechtzoom-Zuid presents a notable variation, ranging from ≤1.0 in the southern borders to as high as 7.0 in the central east near bus stations, highlighting significant differences within the neighborhood. Finally, Kanaleneiland-Noord shows a gradient of accessibility from low scores near the Amsterdam-Rijnkanaal to higher scores towards the southern and right borders, reflecting a mix of low to moderate accessibility. Overall, Wittevrouwen and Vechtzoom-Zuid exhibit higher accessibility levels, while Leidsche Rijn-Centrum and Kanaleneiland-Noord tend to have more areas with lower scores.

Figure 31(A): Multi-Criteria Score S3



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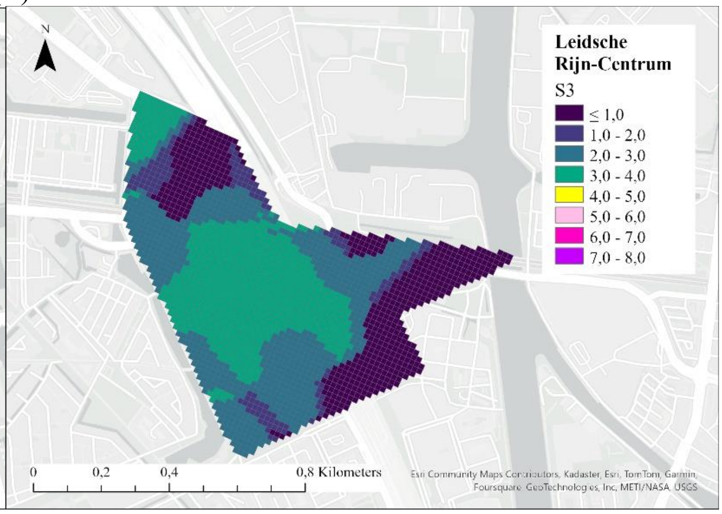

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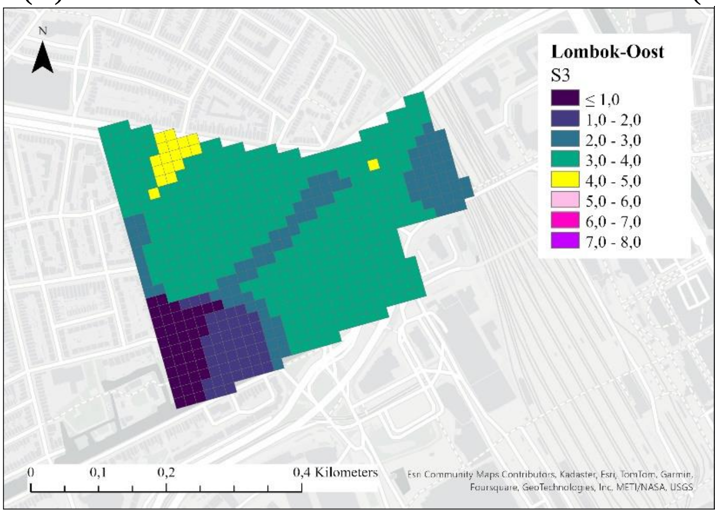

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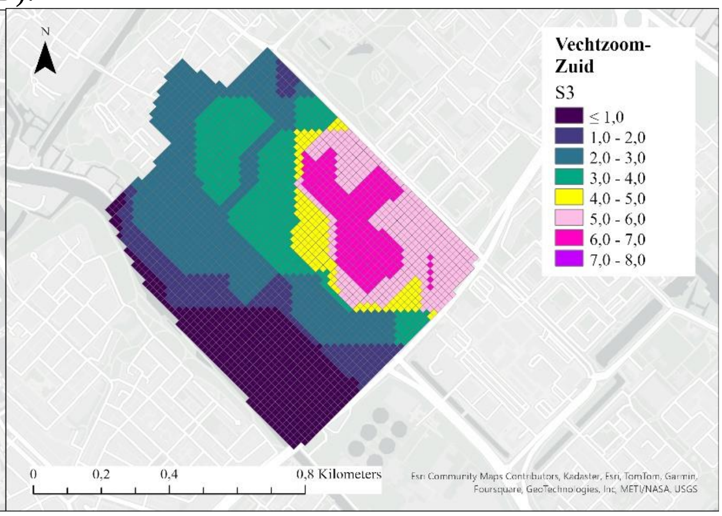

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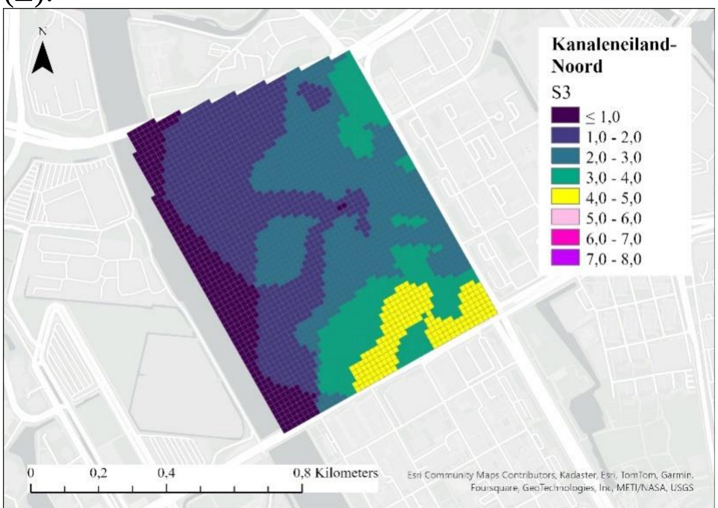

Wittevrouwen, in Scenario 1, features highly accessible central areas, while Scenario 2 highlights it as the most accessible, particularly around Biltstraat, and Scenario 3 shows a broad range of high scores, indicating superior overall accessibility. Leidsche Rijn-Centrum demonstrates varied accessibility in Scenario 1, with lower scores in the east, Scenario 2 shows higher scores near central and northern hubs, and Scenario 3 indicates a constrained range, with higher scores in western and central regions. Lombok-Oost exhibits a uniform distribution of moderate accessibility in Scenario 1, a uniform distribution of access at a generally lower level in Scenario 2, and moderate accessibility with the highest scores in the northwestern part in Scenario 3.

Vechtzoom-Zuid, in Scenario 1, displays a gradient from higher accessibility in the north to lower near the Vecht river. Scenario 2 presents pronounced disparities, with high scores in the central and eastern areas, and Scenario 3 shows significant variation, ranging from low scores in the southern borders to high near bus stations. Kanaleneiland-Noord, according to Scenario 1, shows consistent moderate accessibility with improvements near transport hubs. In Scenario 2, it has lower overall scores but improves near transport hubs, while Scenario 3 depicts a gradient from low scores near the Amsterdam-Rijnkanaal to higher scores towards the southern and right borders, reflecting a mix of low to moderate accessibility.

While all three scenarios utilize similar indicators and analyze the same neighborhoods, the inclusion of secondary amenities in Scenario 2 and the different patterns of accessibility scores across scenarios highlight the impact of varying criteria on the analysis of service accessibility within a 10-minute frame.

6. Conclusion

The central focus of this research has been to evaluate the extent to which the current public transportation infrastructure supports the objectives of the 'ten-minute city' concept in facilitating access to healthcare facilities in Utrecht. Conducted as a quantitative investigation, this study provides a comprehensive analysis of current transportation networks and their effectiveness in meeting the accessibility needs of residents across different urban areas.

The results show that, in examining the alignment of Utrecht's public transportation system with the 'ten-minute city' concept concerning healthcare accessibility, a nuanced understanding has emerged across five distinct neighborhoods. The first sub-question examined the accessibility of general practitioners (GPs) from residential homes in the study areas. In Wittevrouwen, all residents have access to at least 2 GPs by walking and up to 8 GPs by public transport (PT). Leidsche Rijn-Centrum exhibited moderate accessibility to GPs, while Lombok-Oost generally showed lower GP accessibility. Vechtzoom-Zuid and Kanaleneiland-Noord also varied in accessibility, with Vechtzoom-Zuid scoring relatively high and Kanaleneiland-Noord relatively low. The second sub-question analysed the accessibility and service frequency of bus and tram stops within a 5-minute walking distance from residential areas. Wittevrouwen and Leidsche Rijn-Centrum boasted better access and service frequencies compared to Lombok-Oost, Vechtzoom-Zuid, and Kanaleneiland-Noord, where access to stops and service options were more limited, especially towards peripheral areas.

The third sub-question assessed accessibility to hospitals using public transportation within specified travel times. Public transit significantly expands the area within which hospitals can be accessed quickly compared to walking, showing the relevance of public transportation in enhancing healthcare accessibility. The Utrecht region is focusing on the mobility concept of the "wheel with spokes" as the backbone for the mobility transition and as the foundation for urban development (Ruimtelijke Strategie Utrecht, 2021, pp 113-115). This focus, on a more efficient transportation system will undoubtedly enhance travel time, ensuring Utrecht might become a 10-minute city.

The fourth sub-question investigated how accessibility varies when using different criteria or definitions of what services should be reachable within ten minutes. The analysis shows that areas such as Wittevrouwen and Leidsche Rijn-Centrum exhibit generally high accessibility scores, especially near central facilities and transit hubs. The varying scores in Vechtzoom-Zuid underscore the significance of defining criteria for the '10-minute city'. Meanwhile, Lombok-Oost and Kanaleneiland-Noord display minimal differences across various scenarios.

This quantitative research highlights that while Utrecht's public transportation system significantly enhances healthcare accessibility across diverse neighborhoods, notable disparities persist in achieving the objectives of a 10-minute city. It is evident that in all study areas, there are sections that lack access to essential amenities within the specified timeframes. Two exceptions are Wittevrouwen and Vechtzoom-Zuid, they consistently provide access to at least one GP within a 10-minute walking distance. In all neighborhoods, there are areas where access to a bus or tram stop within a 5-minute walk is not guaranteed. Moreover, when considering access to hospitals as a secondary amenity within a 10-minute walk or public transit journey, only parts of Leidsche Rijn partially meets this criterion.

The 'ten-minute city' concept emphasizes proximity to essential services, including healthcare, to enhance urban livability and sustainability (Moreno et al., 2021). While the presence of multiple amenities within a 10-minute radius contributes to overall accessibility, the need for ensuring at least one critical amenity, such as a GP practice, within this distance is more relevant to be called a 10-minute city (Moreno et al., 2021). Therefore, the findings indicate that the studied areas in Utrecht do not fully meet the criteria of being called a 10-minute city by walking or using public transportation, concerning access to public transportation and healthcare amenities.

7. Discussion

Although the conclusion indicates that the studied areas are not fully realized as 10-minute cities, it is important to highlight several points for discussion. The number and types of services within a 15-minute city are not universally agreed upon, as different studies use varying definitions and categories of destinations (Knap, Ulak, Geurs, Mulders & van der Drift, 2023, p.12). Therefore, one could argue that under different circumstances, Utrecht might be a 10-minute city. According to Knap et al. (2023, p.12), Utrecht already qualifies as a 15-minute city by bicycle. This study did not include the bicycle as a way of transporting, therefore can not state that it is not a 10-minute city by bicycle. Moreno et al. (2021, p. 14) highlight another notion of a 15-minute city, questioning why exactly 15 minutes and not another duration, such as 17 or 20 minutes. Utrecht already being a 15-minute city raises the question of why cities should strive to become a 10-minute city instead. Therefore, it is important to note that while a city can aim to be a 10-minute city, the criteria for achieving this status can vary significantly from one city to another, as each city sets its own conditions and standards.

The study utilizes Geo-Point and GTFS data extensively for spatial analysis and public transport evaluation. However, there is limited discussion on the reliability and accuracy of these datasets, which is crucial for ensuring robust findings. Geo-Point data, sourced for bus and tram stop locations, and GTFS data, used for public transport schedules, are fundamental to assessing accessibility metrics. The methodology involves calculating average waiting times at bus and tram stops, a critical metric for understanding public transport efficiency and accessibility. However, the study acknowledges potential inaccuracies due to temporary stops or data anomalies. These issues were addressed by manually filtering out erroneous data rows based on temporal and spatial criteria. While this approach mitigates some data inconsistencies, it is essential to recognize its limitations. Temporary stops or irregular services can skew waiting time calculations, impacting the reliability of results. Future research could explore statistical methods or sensitivity analyses to assess the robustness of waiting time calculations and account for outliers or anomalies more comprehensively.

Integrating the TravelTime API for isochrone mapping represents an innovative approach to assessing travel time accessibility. The accuracy of travel time calculations heavily depends on the quality of underlying street network data and transit schedules used by the API. Variations or inaccuracies in these datasets could introduce biases in the generated isochrones, thereby influencing spatial accessibility assessments. The multi-criteria analysis to assess the overall accessibility, applied equal weighting of all indicators. Equal weighting assumes that each indicator contributes equally to achieving the objectives of a 10-minute city, which may not align with urban planning goals or stakeholder priorities. A critical reflection on indicator prioritization could enhance the analysis's relevance and utility.

Therefore, a further qualitative study on residents' preferences in choosing transportation modes is essential to gain insights into the specific importance of the 10-minute city concept and its most relevant indicators. Does, becoming a 10-minute city, truly make a difference for the residents of Utrecht in choosing to walk rather than using their cars? The study did not account for various other significant factors such as demographics and individual choices, which can significantly influence accessibility and the effectiveness of public transportation services (Handy & Niemeier, 1997, p.1) This also involves the cost implications of travel, as transportation expenses can influence mode choice and accessibility for different socio-economic groups within the city (Páez, Scott & Morency, 2012, pp. 9-11). These factors play a crucial role in shaping how people interact with their urban environment and should be considered in future assessments.

Based on this study, an additional recommendation not addressed herein involves examining community engagement in the planning process for the successful implementation of the 10-minute city concept. Integrating residents' preferences and feedback ensures that changes align closely with their needs and expectations, thereby enhancing public support and improving the utilization of public transit systems. Furthermore, it is crucial that the services designated as primary and included within the 10-minute reach are those that residents consider important and desirable. This alignment ensures that the amenities provided meet the actual needs and preferences of the community, thereby increasing the effectiveness and appeal of the 10-minute city concept.

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Appendix

Table 1. All indicators for the multi-criteria analysis

Indicator	Description	Value Meaning	S1	S2	S3
GP_Walking	Number of GPs accessible within 10 minutes walking	0 = 0 GPs reachable walking 1 = 1 GP reachable walking Etc.	Included	Included	Included
GP_PublicTransport	Number of GPs accessible within 10 minutes of using PT (bus/tram)	0 = 0 GPs reachable using PT 1 = 1 GP reachable using PT Etc.	Included	Included	Included
BTStop_Walking	Number of bus or trams stops (both directions) * accessible within 5 minutes walking	0 = 0 bus/tram stops reachable walking 1 = 1 bus/tram stops reachable walking	Included	Included	Included
BTService	Average number of bus or tram services per week accessible within 5 minutes walking	100 = 100 buses/trams pass by the bus/tram stop on average per week. 1000 = 1000 buses/trams pass by the bus/tram stop on average per week.	Included	Included	Included
BTWaitingT	Average waiting time between services within 5 minutes walking	5 = 5-minute waiting time between services on average 25 = 25-minute waiting time between services on average	Included	Included	Included
HP_PublicTransport	Number of minutes using PT to access a hospital	0 = Travel time is longer than a 30-minute PT journey to reach a hospital. 1 = A hospital is reachable within a 30-minute PT journey. 2 = A hospital is reachable within a 20-minute PT journey. 3 = A hospital is reachable within a 10-minute PT journey.	Included	Excluded	Excluded
HP_Walking	Amount of minutes walking to access a hospital	0 = Travel time is longer than a 30-minute walk to reach a hospital. 1 = A hospital is reachable within a 30-minute walking journey. 2 = A hospital is reachable within a 20-minute walking journey. 3 = A hospital is reachable within a 10-minute waking journey.	Included	Excluded	Excluded
MIN30_Walking	Number of hospitals accessible within 30 minutes walking	0 = 0 hospitals reachable walking 1 = 1 hospital reachable walking Etc.	Excluded	Excluded	Excluded
MIN20_Walking	Number of hospitals accessible within 20 minutes walking	0 = 0 hospitals reachable walking	Excluded	Excluded	Excluded

		1 = 1 hospital reachable walking Etc.			
MIN10_Walking	Number of hospitals accessible within 10 minutes walking	0 = 0 hospitals reachable walking 1 = 1 hospital reachable walking Etc.	Excluded	Included	Excluded
MIN30_PT	Number of hospitals accessible within a 30-minute PT journey	0 = 0 hospitals reachable using PT 1 = 1 hospital reachable using PT Etc.	Excluded	Excluded	Excluded
MIN20_PT	Number of hospitals accessible within a 20-minute PT journey	0 = 0 hospitals reachable using PT 1 = 1 hospital reachable using PT Etc.	Excluded	Excluded	Excluded
MIN10_PT	Number of hospitals accessible within a 10-minute PT journey	0 = 0 hospitals reachable using PT 1 = 1 hospital reachable using PT Etc.	Excluded	Included	Excluded