Caring 15-minute neighbourhoods

Anastasia Soukhov[a,*], Léa Ravensbergen[a], Lucía Mejía Dorantes[b], Antonio Páez[a]

[a] *McMaster University, School of Earth, Environment & Society, Hamilton, Canada,*

[b] *Consultant, Karlsruhe, Germany,*

Keywords: Accessibility, Mobility of Care, Gender, 15-minute neighbourhood, Care Complete Neighbourhoods

1. Abstract

The "15-Minute City" concept has been embraced by global leaders to promote human-scale neighbourhoods with transport and land-use designs that support short trips to daily necessities. This paper bridges the 15-Minute City to "Mobility of Care", a framework that foregrounds travel to care destinations, travel done predominately by women. This focus contrasts the more commonly studied travel to employment and leisure destinations. While the 15-Minute City concept is flexible enough to consider all destination types, gendered examinations are relatively lacking in the literature, and little research to date has focused explicitly on care destinations. This gap is addressed in this paper by identifying which areas in the city of Hamilton, Canada are 'caring 15-minute neighbourhoods'. To do so, a database of care destinations was compiled to estimate the number (using the cumulative opportunities accessibility measure) and diversity of mix (using the entropy measure) of care destinations within a 15-minute walk from residential parcels. Using data-driven machine learning techniques (Self-Organizing Maps and Decision Trees), neighborhoods were classified into 'caring 15-minute neighbourhood' typologies that are examined across residential socio-economic profiles. Our results suggest that the majority of caring 15-minute neighbourhoods are in the urban core, where more lower-income households reside. In contrast, not caring 15-minute neighbourhoods in higher-income peripheral areas. Areas that make good candidates for urban policy intervention are identified, and the implications of enhancing 15-minute walkable caring access are discussed in relation to gender mainstreaming in transportation planning.

*Corresponding author

Email addresses: soukhoa@mcmaster.ca (Anastasia Soukhov), ravensbl@mcmaster.ca (Léa Ravensbergen), lucia.mejia.dorantes@gmail.com (Lucía Mejía Dorantes), paezha@mcmaster.ca (Antonio Páez)

Keywords: Accessibility; 15-Minute Neighborhoods; Chrono-Urbanism; Cities of Proximity; Mobility of Care; Inequality; Gender Gap;

2. Introduction

The "15-Minute City" has been recently adopted by leaders as a way to promote human-scaled cities (Teixeira et al., 2024). As introduced in Moreno et al. (2021), the 15-Minute City is a urban planning model based in chrono-urbanism, a theory that emphasizes the positive impact on quality of urban life when urban space becomes multi-rythmic, in opposition to the segregation of urban time and space for individual uses and mobility (Mulíček et al., 2015; Moreno, 2016). It is in opposition to the forces that supported the formation of single-use neighbourhoods such as industrial Fordism and single-use zoning (Mulíček et al., 2015; Moreno, 2016). The "15-Minute City" refers to a city where relevant destinations within a walkable (or bikeable or transit supportive) radius are reachable by all. This form of neighbourhood planning would allow individuals to reclaim time spent on car mobility, giving way to sustainable modes and prompting urban spaces that are responsive to human needs and environmental sensibilities (Allam et al., 2022).

The term 15-Minute City is relatively new but the concept is not, as it is simply a normative cumulative-opportunities accessibility measure (Paez et al., 2012). Its newfound fame under the moniker of chronourbanism comes to complement long-standing efforts to foster community and local travel to amenities in neighbourhood planning practice. As recent examples, planned neighbourhoods dominated post-WWII built urban form: the Neighbourhood Unit Concept in the western world (Brody, 2013) and a parallel concept of the "mikrorayons" neighbourhoods in the Soviet Union (Kissfazekas, 2022). Along different dimensions, these planning forms have been extensively critiqued (Talen, 2017). In this respect, neighbourhood planning approaches such as the 15-Minute City concept offer an opportunity for bottom-up approaches that leverage co-creation tools and meaningful resident participation to achieve equitable and just neighbourhood forms (Mahmoud and Morello, 2021). How to prescribe equitable urban forms that 'enable' contact with social opportunities (instead of 'engendering it' from the top-down) is still a matter for debate. Questions remain, including: what destinations really matter? What mode and travel time threshold is most appropriate? And who benefits? To be certain, these dimensions are under discussion among proximity-based planners who use accessibility-based tools (Silva et al., 2023; Silva and Altieri, 2022; Guzman et al., 2024).

From another perspective, feminist geographers, urban planners and other researchers agree that urban structure influences travel, but city planning falls short in planning for a neutral identity. In contrast, cities ought to be planned according to the multiple identities of the inhabitants (Vacchelli and Kofman, 2018; Urban Development Vienna, 2013). Researchers have demonstrated how mobility patterns differ according to gender (Law, 1999; Cresswell and Uteng, 2008; Levy, 2013; Little, 1994; Tronto and Fisher, 1990; **?**). The causes for this are varied, and related to gendered social norms and cultural factors that play a role in how, where, with whom, what for, and how far we move. Of note is that women tend to travel more frequently and for shorter distance (Roorda et al., 2010; Morency et al., 2011) and have more activities related to care (International Labour Organization, 2018) no matter at what life stage they are (García Román and Gracia, 2022). Combined, these findings indicate that the spatial organization of activities has a different impact according to gender, and therefore the 15-Minute City concept should not be gender blind.

This work builds a theoretical bridge between the 15-Minute City and mobility of care concepts to answer questions about what destinations matter and who benefits from proximity planning. The Mobility of Care term was coined in Sánchez de Madariaga (2013); it refers to all travel required to sustain the needs of a household, such as grocery shopping, escorting children, travelling to health appointments, and running errands. While decades of research have examined types of household-serving trips (e.g., shopping trips, escorting to school), Sánchez de Madariaga (2013) was the first to consider them all as one category. In doing so, care-related mobility can be shown to comprise a significant proportion of daily travel, characterizing approximately 30% of adults' daily trips (Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Ravensbergen et al., 2023). We argue that Mobility of Care is especially relevant to the 15-Minute City, as care trips are necessary for *all* people and they most often occur at the local level. Moreover, care trips are of particular gendered and socio-economic import, as women, and especially those in lower income households, complete the majority of care trips (Ravensbergen et al., 2023). Despite care travel's importance in advancing gender equality -and equity more broadly-, mobility of care and access to care destinations have been under-examined relative to employment destinations. This is especially pertinent in accessibility research that has largely focused on employment points of interest e.g., (Farber and Allen, 2019; Duarte et al., 2023; Ryan et al., 2023).

The objectives of this research are two-fold. First, we aim to theoretically bridge Mobility of Care with the 15-Minute City concept to re-imagine what local amenities matter from the perspective of care and to define an associated accessibility and diversity of accessibility measures. And secondly, we take a data-driven approach to classify areas into 'caring 15-minute neighbourhoods' typologies and examine associated residential profiles in an empirical examination of the city of Hamilton, Canada.

3. Review of neighbourhood planning literature

3.1. From the 15-Minute City to the NUC

In the last decades, the need for more sustainable, healthier, and livable cities has become a prominent concern. Planners and decision-makers have proposed a shift to neighbourhood planning principles centered on proximity to urban functions (Pozoukidou and Chatziyiannaki, 2021). In this context, the 15-Minute City is now in the public spotlight (Logan et al., 2022; Moreno et al., 2021). The 15-Minute City was introduced in Moreno et al. (2021) along with four dimensions: density (in terms of people per km^2), diversity (including mixed-land use and diversity of people), the temporal and spatial proximity to essential services, and digitalisation (q.v. Cervero and Kockelman, 1997). However, the framework presented has been criticized within academic and planning circles (e.g., Guzman et al., 2024; Mouratidis, 2024) among other things for shortfalls in terms of addressing pre-existing structural forces and individual characteristics that drive inequalities and influence who benefits or could benefit the most from such an approach (Di Marino et al., 2023; Willberg et al., 2023). A 15-Minute City for all people is an aspirational goal, but does not fully confront existing mobility and accessibility inequalities in need of redress. Without directed and context-specific solutions, this popular concept risks becoming an empty city branding exercise. (Pozoukidou and Chatziyiannaki, 2021; Gower and Grodach, 2022).

Reflective of the flexible and aspirational presentation of the 15-Minute City, the concept has been adopted by cities using a diverse range of definitions and tools along with indistinct universal approaches. A trail blazer in this respect was Portland (US) in the Portland Plan (City of Portland, 2010) of April 2012. Adopted before the '15-Minute City' concept of today, this plan aimed to foster inclusive city development based on prosperity, education, health, and equity over a 30 year horizon. Central to the plan was the promotion of neighbourhood self-sufficiency and connectivity to city centers and centres of employment. The progress report describes a high-level focus on equitable service delivery to all residents with equity concerning topics related to racial equity and people with disabilities (Portland Government, 2017), similarly taking on an "all populations" approach. Subsequently, other cities adopted proximity-based goals using similarly neutral approaches. For example, the 15-Minute City plan announced during the re-election campaign of Paris mayor Anne Hidalgo in 2020 emphasized six key social functions that should be easily accessible from any location (Ville de Paris, 2022). These locations included: housing, work, health care, groceries, education and leisure. The 15-Minute City concept inspired language in the agendas of other cities in the Western world such as Ottawa, in the Canadian context, who also adopted a 15-Minutes approach in their recent

Official Plan (d'Ottawa, 2021). Teixeira et al. (2024)'s global review finds that the 15-Minute City concept is in early phases of implementation around the world and the diverse range of definitions, strategies, and instruments present a significant knowledge and implementation gap. In other words: the 15-Minute City is aspirational but how do we get there and who will benefit?

The past can provide cautionary tales. While the 15-Minute City brand of planning is new, neighbourhood planning to improve society outcomes is not: in fact the literature has drawn parallels from the 15-Minute City to Clarence A. Perry's Neighbourhood Unit Concept (NUC) from the 1930s (Kissfazekas, 2022). The NUC is a socio-spatial normative scheme widely adopted by government agencies (and the real-estate community) in the Western world after the Second World War (Talen, 2017; Solow et al., 1969). Pairing well with the objectives of planning agencies at the time, Perry's NUC would allow for efficient mass-building of cellular units that prioritized the perceived functional needs of women and children: each unit providing proximate access to an elementary school and supporting community facilities, shopping, parks and housing (Talen, 2017; Brody, 2013). The NUC primarily prioritized local service provision, though Perry had confidence in good design's contribution to 'neighbourhood spirit' (Hall, 2014). By the end of the 1960s, planners' aspirational attempts to prescribe social meaning to the neighbourhood's physical form had been criticized to near extinction (Talen, 2017). A critique by social scientists was an overestimation of the impact of built environment on social life. Planners, on the other hand, could not reach consensus on the specificity of the neighbourhood (i.e., population size and the type, quality, and quantity of amenity) or how neighbourhood units connect between them and the rest of the region. In response to these criticisms, neighbourhood planning proponents redefined their deterministic terminology; their prescriptive physical form would 'enable' social contact with opportunities rather than 'engendering' it.

The redefined bottom-up approach to community and neighbourhood planning was adopted in the 1980s by American New Urbanists (Trudeau, 2013), from which the 15-Minute City eventually stemmed (Kissfazekas, 2022). However, the bottom-up effectiveness of these ideas remains to be seen due to the contemporary nature of the concept. Though, related research can be examined. In recent years, the question of *how can physical form be planned to enable an improved quality of life, for whom, and with what outcomes* has occupied the urban planning research agenda. For instance, the examination of low-income households access to transportation and their likelihood of gaining employment (Blumenberg and Pierce, 2017; Bastiaanssen et al., 2022) or the relationship between children's access to public transit and participation in after-school activities (Palm and Farber, 2020). A new wave of researchers and practitioners focused on local and context-specific relationships with the proximity to destinations have also emerged (Silva et al., 2023; Silva and Altieri, 2022). As reviewed in the city plans that have adopted 15-Minute City approaches, the NUC's criticisms, and recent urban planning research, the question of *how to enable improved quality of life through urban built environment* is highly context-sensitive, prompting the need for further investigation.

3.2. Tools: accessibility methods, diversity measures and typology-classification

In examining how to enable improved quality of life through urban built environment, accessibility measures have become an increasingly popular tool. These measures are a way to quantify the ease of reaching destinations from a given point in space and have been used to examine urban areas through just and sustainable city planning agendas (Vale and Lopes, 2023; Handy, 2020). The 15-Minute City is an amenity-provision neighbourhood planning concept aimed at enabling the creation of urban environments that enhance life quality, making it well-suited for analysis using accessibility methodologies (Guzman et al., 2024). Recent works have applied accessibility measures to investigate the 15-Minute City across different geographic scopes. For instance, in Naples, Italy (Gaglione et al., 2022), Barcelona, Spain (Graells-Garrido et al., 2021), Vancouver, Canada (Hosford et al., 2022), and in urban areas across Europe (Vale and Lopes, 2023). The "cumulative opportunity" measure has been applied in many 15-Minute City examinations. This measure quantifies how many destinations can be reached from a point in space within a given travel time threshold , pairing well with normative examinations (see Paez et al., 2012) that use travel time thresholds like x-minute cities [Logan et al. (2022). Furthermore, the cumulative opportunity measure is widely appreciated for its intuitive computation and popularity among practitioners (Handy, 2020; Handy and Niemeier, 1997; Cheng et al., 2019). However, accessibility measures other than the cumulative opportunity have also been applied, reflecting the diversity of measures in the literature (Guzman et al., 2024).

Another concept that complements the assessment of the 15-Minute City regarding the diversity of opportunity types is entropy. The entropy measure, based on the Shannon-Wiener index of species diversity, expresses relative evenness within a sequence (Whittaker, 1972). In urban studies and planning literature, the concept of entropy has been used to characterize land-use mix diversity (Frank et al., 2005; Ewing and Cervero, 2010; Moniruzzaman and Paez, 2012) including to understand mobility behaviour (McBride et al., 2020; Montero et al., 2023a,b), in the context of non-work trips (Cervero and Kockelman, 1997), walking (Lu et al., 2017; Mavoa et al., 2018), and suburban sprawl (Randall and Baetz, 2015). However, entropy indices are rare in accessibility analysis. There are examples of their use as parameters within accessibility scores for employment opportunities (Cheng and Bertolini, 2013; Dai et al., 2018) and, more recently, to describe the diversity in transit facilities (Yin et al., 2024). Given how 15-Minute Cities aim to provide access to numerous amenities, diversity of land-use is a key feature. In this way, the entropy measure theoretically complements the 15-Minute City.

Classification algorithms also show promise as a tool in the assessment of the 15-Minute City, as they have been useful in identifying mobility and spatial typologies within the transportation planning literature. Often, these algorithms take the form of machine learning approaches: in transportation, the use of Self-Organizing Maps (SOM) was pioneered by Delmelle (2012) and has been used to group U.S. neighbourhoods by minimizing dissimilarity in attributes (Delmelle, 2017) and to classify individuals' travel patterns according to the dissimilarity in mobility attributes and uses the Decision Tree algorithm to partition the data into interpretable classifications (Victoriano et al., 2020). Other approaches include the use of spatially constrained multivariate clustering, to develop urban form typologies related to the 15-Minute City (Burke et al., 2022) and the use of k-means to analyse travel behaviour and classify metro stations based on mobility patterns(Gan et al., 2020).

3.3. Mobility of Care and feminist 15-minute neighbourhoods

Rather than focusing on *all* destinations, it is valuable to examine those related to caring activities. This framing offers a feminist perspective on urban functions that matter from a care perspective, and connects well with the 15-Minute City concept. Caring activities, which fulfill the physical, psychological, and emotional needs of others, are among the most essential and fundamental activities in society (International Labour Organization, 2018). Yet, they are the most unequal, undervalued, and even devalued activities worldwide. Conventionally, caring activities have been borne on women's shoulders (Hayden, 1982; Hochschild and Machung, 2012). According to International Labour Organization (2018), women and girls perform more than three-quarters of the total amount of unpaid care worldwide, a gender gap that varies geographically (Ferrant et al., 2014). This unequal share of caring responsibilities leads to multi-faceted gendered differences: in career development, profession selection, contract type, pay gap, and time poverty, as recognized by various international organisations (EIGE, 2016; International Labour Organization, 2018). In terms of spatial and transportation planning, almost one third of daily trips are for care purposes (Sánchez de Madariaga, 2013; Sánchez de Madariaga and Zucchini, 2019; Ravensbergen et al., 2023). From this research motivation, Sánchez de Madariaga coined the term Mobility of Care in 2013 to refer to all travel required to sustain the needs of a household, such as grocery shopping, escorting children, travelling to health appointments, and running errands (Sánchez de Madariaga, 2013). While an undercurrent of research had examined these unique household-serving trips over the decades, her seminal work was the first to consider all these trips as one category and demonstrate how mobility of care is a significant proportion of daily travel.

The Mobility of Care concept also explicitly integrates inter-sectional equity considerations, a common criticism leveled at the 15-Minute City (Guzman et al., 2024). Perhaps unsurprisingly given the gendered division of care work discussed, women have consistently been found to complete more mobility of care trips than men. In one study, mobility of care comprised 32% of women's daily trips compared to 28% of men's. While this gap is significant, it was found to be far greater in lower income households where women complete 20% more care trips than men (Ravensbergen et al., 2023). Sánchez de Madariaga not only shows how important these mobility of care trips are, but also highlights the ways in which "mobility of care is systematically under-represented in any analysis of urban transport" (p. 37). As a product of the masculinst bias in planning, transport surveys and tools often do not directly capture mobility of care, which re-enforces the idea that these trips are not a significant part of daily mobility. In this respect, the feminist perspective of the cities of proximity is still underestimated with only few examples on the topic (Gil Solá and Vilhelmson, 2022; MacIntyre, 2022).

Pairing well with the focus on shorter trips and the potential use of sustainable modes within the 15-Minute City, Mobility of Care trips are more local, shorter-distance and trip-chained. Compared to the trip to work, mobility of care trips are more frequently completed by foot, and less frequently by transit or bicycle (Ravensbergen et al., 2023). However, little work to date examines walking to care destinations through the Mobility of Care framework. Though there is ample literature that examines walking to care destinations, such as schools (e.g., (Omura et al., 2019; Yu and Zhu, 2016; Napier et al., 2011)) and grocery stores (e.g., (Morioka et al., 2023; Negron-Poblete et al., 2016)), they tend to consider singular care destinations in research focusing on walkability. In summary, we reviewed the neighborhood planning framework from which the 15-Minute City concept stems and is situated within. We then reviewed tools common and useful in investigating the 15-Minute City. Finally, we introduced the Mobility of Care concept, theoretically linking it to the 15-Minute City to highlight the importance of care destinations for all but especially along gendered and socio-economic lines. The objectives of this work are two-fold, achieved through an empirical examination of Hamilton, Canada, a mid-sized city:

- First, by theoretically bridging Mobility of Care with the 15-Minute City concept, we re-imagine what local amenities matter and calculate associated accessibility and entropy measure for care destinations.

- Second, using a bottom-up data-driven approach, we apply machine learning methodologies to classification areas into *15-minute caring neighbourhoods* and investigation their associated residential profiles along socio-economic lines.

4. Data

4.1. Case study context

This work focuses on Hamilton, Ontario, a mid-sized city on the shore of Lake Ontario. Hamilton has a heterogenous land-use, with a populated and dense urban core, surrounded by suburban development, which is itself surrounded by rural communities. The Niagara Escarpment runs through Hamilton, and results in a city with two key elevations: a more dense lower city that contains the downtown core and the elevated suburban development referred to as 'the Mountain'. In this work, we analyse the residential parcel centroids, 143,882 locations. We aggregated the points at the level of Canadian Census Dissemination Area (DA) along with the population and population per parcel plots in Figure 1.

Hamilton also exhibits spatial disparities in social and economic indicators; their spatial distribution is visualised in Figure 2. The densely populated inner city is characterised by lower average incomes, and a higher prevalence of households living under the low-income cutoff thresholds (LICO). Notably, the suburban areas of the city tend to have a greater proportion of children and a lower proportion of one parent households.

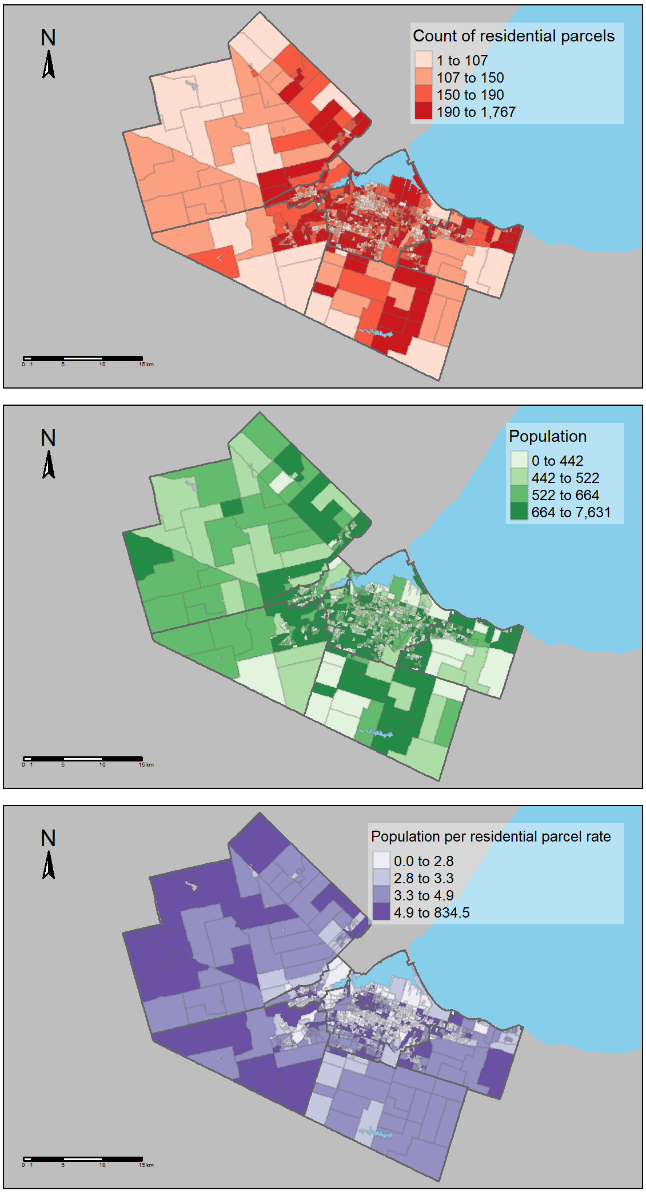

Figure 1: The number of residential parcels per DA in 2020 (top), the population (middle) retrieved from the 2021 Canadian Census, and the rate of population per parcel per DA (bottom). All scales in quartiles. Basemap shapefiles are sourced from the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

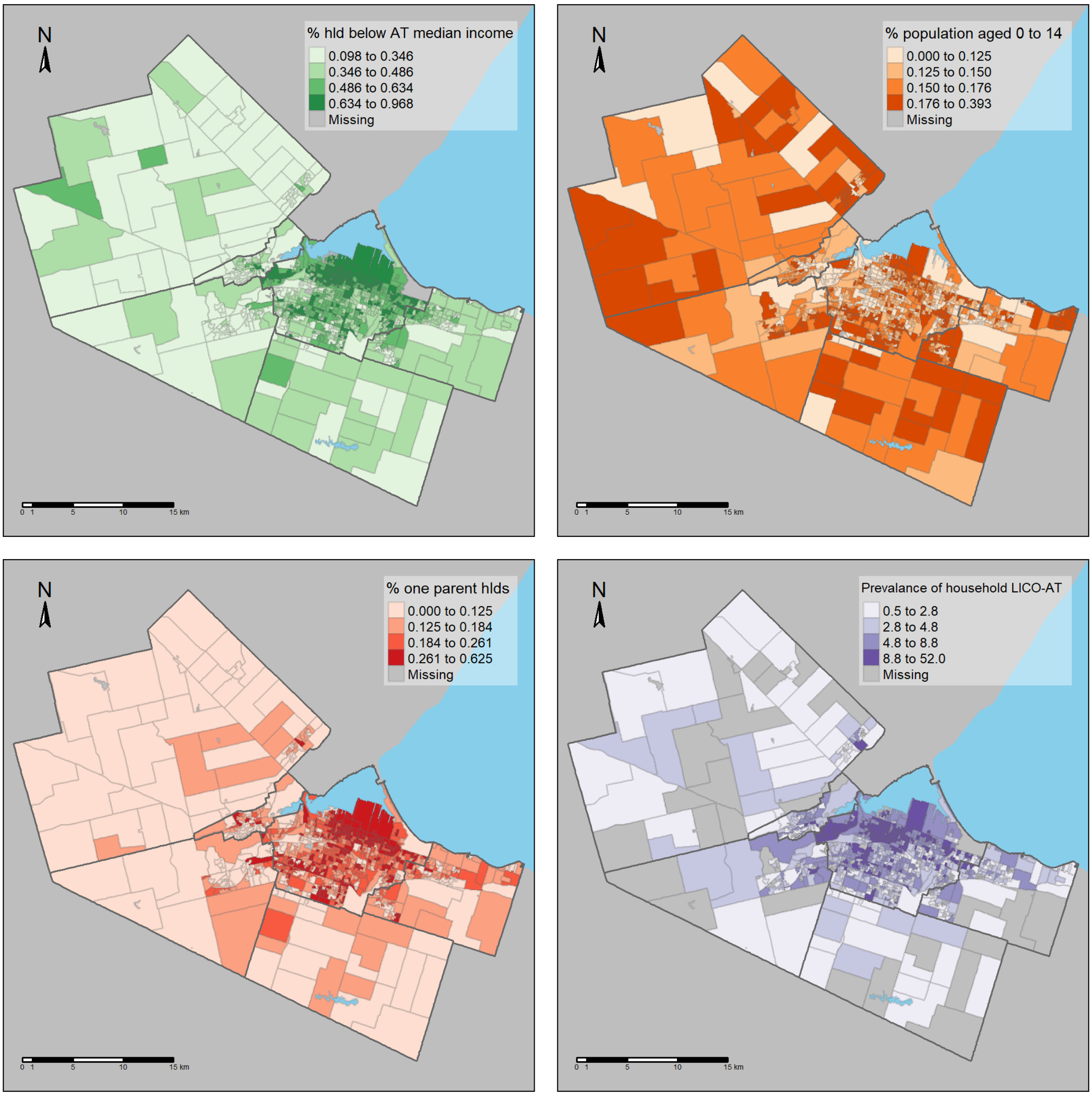

Figure 2: Socio-economic and demographic variables that characterise accessibility to care destinations retrieved from the 2021 Canadian Census. All scales in quartiles. Basemap shapefiles are sourced from the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

4.2. Care destination dataset

A spatial dataset of care destinations for Hamilton was compiled as detailed in (*work removed for double-blind review*). The dataset includes 14 types of care destinations that were classified into four categories: dependent-centric (e.g., the destinations for child- and elder-centric escorting trips), grocery-centric, health-centric, and errand-centric. Notably, these categories were generated following the travel purpose categories created in the mobility of care research by Sánchez de Madariaga and Zucchini (2019). Care categories, sources of data, and preparation notes are detailed in Table 1. The spatial distribution of destination type are visualised in Figure 3 by their category.

Table 1: Description of care destinations categories, notes on data preparation and associated data sources.

Care category	Care destination types	Sources
Depedent-centric	Schools, daycares, and community centres, recreation centres, parks, senior centres, long-term care homes, and retirement homes: 1,265 locations are included.	(Hamilton 2022a, 2023, 2022c, 2022d; Ontario 2023; Ontario GeoHub 2023)
Grocery-centric	Convenience stores and grocery stores (e.g., large retailers as well as speciality food grocers, health food grocers): 381 destinations are included.	(Axle Data 2023)
Health-centric	Hospitals, pharmacies, clinics, and dentist offices: 421 destinations are identified.	(Ontario GeoHub 2023; HNHB Healthline 2023)
Errand-centric	Libraries, post offices, and banks: 158 destinations are identified.	(Hamilton 2022b; Axle Data 2023; Canada Post 2023; BMO 2023; HSBC 2023; National Bank 2023; RBC 2023; Scotiabank 2023; TD Bank 2023).

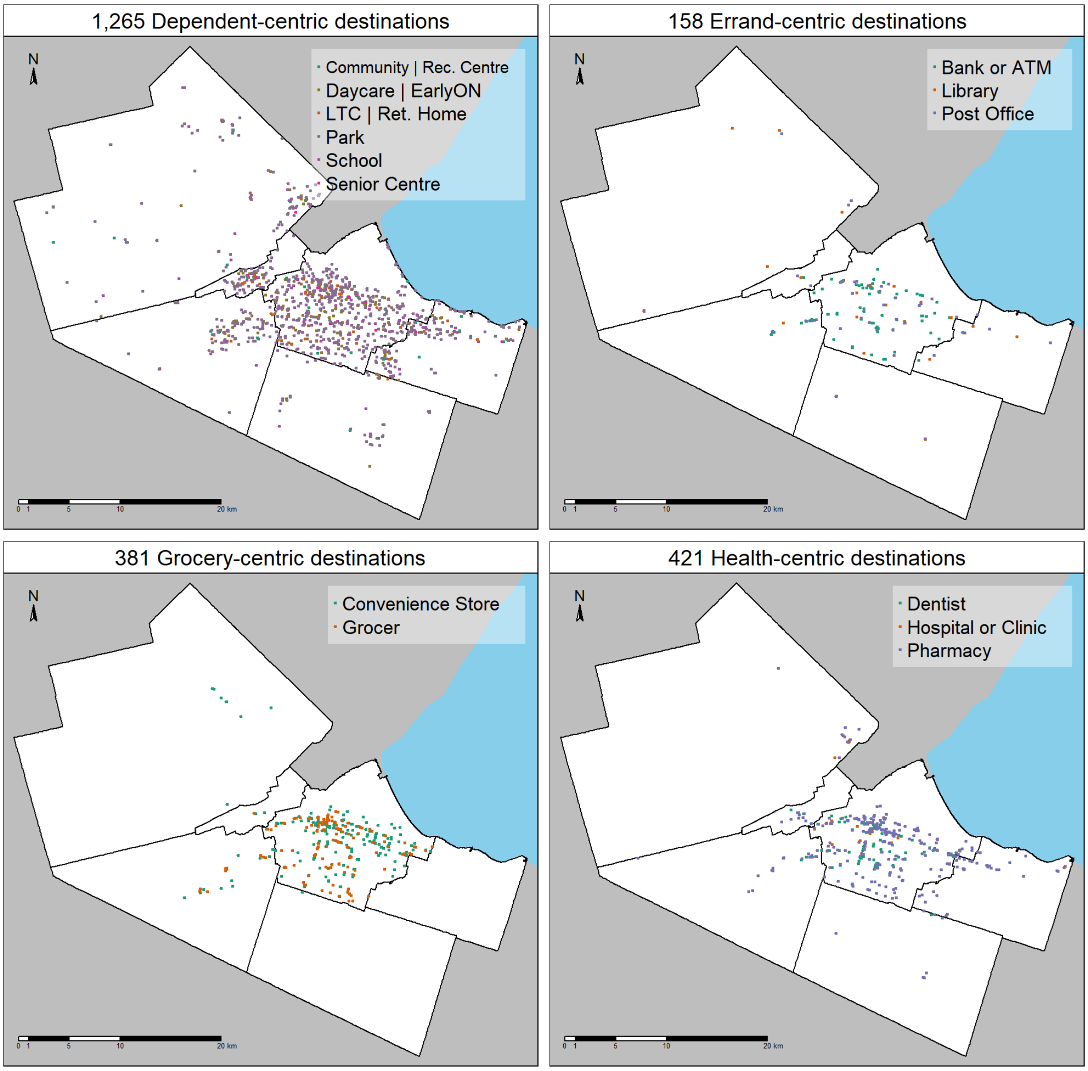

Figure 3: The locations of care destinations in Hamilton separated by the author-generated categories of: dependent-, errand-, grocery- and health- centric care categories. Basemap shapefiles are sourced from the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

4.3. Travel time to care destinations estimations

Travel behaviour to care-oriented destinations is often uncounted and hence comprehensive travel times to all destination types in Table 1 is unavailable. To overcome this gap, travel time from residential parcel locations in Hamilton and care destinations in Figure 3 are approximated assuming travel by foot at an average speed (3.6 km/hr). This estimation is done using the 'travel_time_matrix()' function from the {r5r} package (Pereira et al., 2021) using R version 4.3.2 (R Core Team, 2023). The inputs into the function are: the locations of 143,882 residential parcels as origins, the 2,225 care locations as destinations, and a OpenStreetMap road network including walking infrastructure (Geofabrik, 2023). In line with the 15-Minute City, a maximum walking travel time of 15 minutes is specified and an origin-destination travel time matrix of the shortest travel time from origin to destination is calculated. The resulting matrix contains 2,014,502 rows, representing walking travel times from each parcel to reachable care destinations within 15 minutes.

5. Methods

The following sub-sections detail the methods to classify Hamilton into spatial degrees of *caring 15-minute neighbourhood*. First, accessibility to each of the 14 destination types from each of the 143,882 residential parcel locations is described. Second, the entropy measures used to calculate the diversity of accessibility to each of the care categories is detailed. Third, we describe how accessibility and diversity values for each parcel are input into a Self-Organizing Map (SOM) algorithm, and how the resulting clusters are analyzed using a Decision Tree algorithm to narrate residential profiles based on socio-economic variables. In sum, this methodology presents a data-driven approach to examine what neighbourhoods in a city have the potential to provide 15-minute caring access, at what level of intensity and completeness, and the socio-economic characteristics of those who are most benefited or burdened.

5.1. Accessibility: the cumulative opportunity measure

To capture the quantity of access to each type of destinations, a cumulative opportunity accessibility score S_i^t is calculated. Scores for each of the 14 care destination types t is calculated for every parcel i. The calculation takes the following mathematical form:

$$S_i^t = \sum_j O_j^t \cdot f(c_{ij})$$

Where:

- i is a set of parcel point origin locations.
- j is a set of care destination locations of type t.
- O_j^t is a number of opportunities of category type t at j.
- c_{ij} is the travel cost between i and j.
- $f(\cdot)$ is an impedance function of c_{ij}; within the cumulative opportunity approach, it is a binary function that takes the value of 1 if c_{ij} is less than a selected value (Handy and Niemeier, 1997).
- S_i^t is the cumulative opportunity accessibility score, the sum of weighted opportunities reachable within $f(\cdot)$, at each i for each t.

5.2. Diversity in opportunity accessibility: the entropy measure

The entropy measure, as defined in Cervero and Kockelman (1997), is used to represent the diversity of care destination accessibility. For each parcel, a value between 0 to 1 is calculated, where 1 represents total evenness in the number of care opportunities in each category that can be reached. The mathematical formulation takes the following form:

$$D_i = \frac{-\sum_t [S_i^t / \sum_t S_i^t \times ln(S_i^t / \sum_t S_i^t)]}{ln(n_t)}$$

Where:

- i is a set of parcel point origin locations.
- t is a set of care destination types (e.g., school, grocery, park, etc.)
- n_t is the count of care destination types t. In this work, this value is 14.
- S_i^t is the cumulative opportunity accessibility score, the sum of weighted opportunities reachable within a 15-minute walk from i.
- D_i is the diversity score.

Notably, D_i represents evenness in the type of care categories a parcel can access. For example, if a parcel has an access score of $S_i^t = 0.5$ for all destination types, it will receive a diversity score of $D_i = 1$, just as if it had an access score of $S_i^t = 10$ for each destination. Conversely, a parcel may be assigned a low D_i score if its accessibility scores differ across categories, regardless of whether those scores are low or high.

5.3. Machine learning classification: SOM and Decision Trees

We use two machine learning techniques in this work. First, SOM is an unsupervised technique implemented to reduce the data dimensionality and create interpretable clusters related to the intensity and completeness of caring access. This is done by imputing each parcel as an observation with its associated accessibility and diversity attributes, and the data being rearranged onto a two-dimensional space based on its minimizing dissimilarity in its neighbourhood. An appropriate number of superclusters are selected and assigned labels based on the quantity and diversity of care access provided, i.e., the degree by each the parcel is located in a *caring 15-minute neighbourhood*. Then, a Decision Tree is run to characterise the socio-economic profiles of who resides in neighbourhoods associated with the superclusters. Together, this combined approach leverages the unsupervised data-driven classification power of the SOM with the interpretation of Decision Trees. The procedure used in this work is similar to that used in Victoriano et al. (2020). In this work, rather than each observation representing an individual's daily mobility behaviour (with associated variables), each observation represents a parcel location with calculated care accessibility and accessibility diversity scores.

For the SOM step, the function 'trainSOM()' from {SOMbrero} R package is used (Villa-Vialaneix, 2017). The input variables include the 143,882 parcels, each as individual observation along with 15 variables: the 14 calculated accessibility scores S_i^t, normalized to the min-max range score within each t, and one diversity value D_i. Otherwise, defaults for all other parameters are assumed, relying on the data-driven heuristics embedded in the 'trainSOM()' function. Consequently, a 100 node (10 by 10 grid) SOM structure using euclidean distance and square topology is produced. Simply put, the SOM algorithm proceeds as follows: a 2D grid of nodes is created as specified by the analyst, where a node represents a point in the reduced-dimensional space. Upon initialization, each node is assigned a random weight vector of the same dimension as the input data (in our case, 15). From the input data, a random observation with its associated weight vector (i.e., one parcel point with 15 variables) is selected and the Euclidean distance between its weight vector and all nodes in the grid are calculated. The node with the smallest distance (i.e., the smallest dissimilarity) is labelled the 'best matching unit' as it is the node that best represents the input observation. After this best matching unit is identified, its own weight and its neighbouring nodes are updated to become more like the input observation. The process of finding best matching units and updating their weights is repeated for every observation, multiple times, until the results converge. As mentioned, this competitive learning process produces a 100 node SOM structure where each observation (parcel) is assigned to 1 node with an associated dissimilarity index. The SOM output is typically examined through a dissimilarity dendogram and an associated dissimilarity variance explained plot to select an appropriately representative 'superclusters' (Villa-Vialaneix, 2017; Victoriano et al., 2020).

For the Decision Tree step, the supercluster-classified parcels identified in the SOM step are used as *labels* and socio-economic and demographic indicators related to the Mobility of Care literature are used as *features*. Features are retrieved from the 2021 Canadian Census (Statistics Canada, 2023). This step creates residential profiles of the superclusters, allowing us to explore the characteristics of residents within the superclusters in a data-driven way. To estimate the Decision Tree, the 'rpart()' function in the {rpart} R package is used (Therneau and Atkinson, 2023); default parameters for classification splitting along with each value being weighted by the population present in the associated DA is assumed. The Decision Tree algorithm is a supervised learning technique that begins by splitting a subset of the input data into branches based on a selected feature with the lowest impurity score (i.e., the least mixing of label membership within a branch). This process is recursively repeated for each data subset, selecting the next best feature. Ultimately, the data is classified into distinct classes, with class membership explained by traversing the branches defined by the features that characterise the partitions within the Decision Tree. Notably, the absence of features from the Decision Tree does not necessarily imply they are irrelevant for classification, rather, they are less relevant than other features. Put another way, when considering features that are highly correlated, such as income level and LICO, not all relevant variables may be present in the tree (Victoriano et al., 2020).

6. Results

6.1. Overview of access to care destinations

How many care destinations can be reached within a 15-minute walk is summed for each of the four care categories defined in Table 1. The median parcel value for each DA is visualised in Figure 4 and the median parcel diversity of care destinations accessible is presented in Figure 5. Together, Figure 4 and Figure 5 represent summaries of 15 variables that served as inputs into the SOM algorithm.

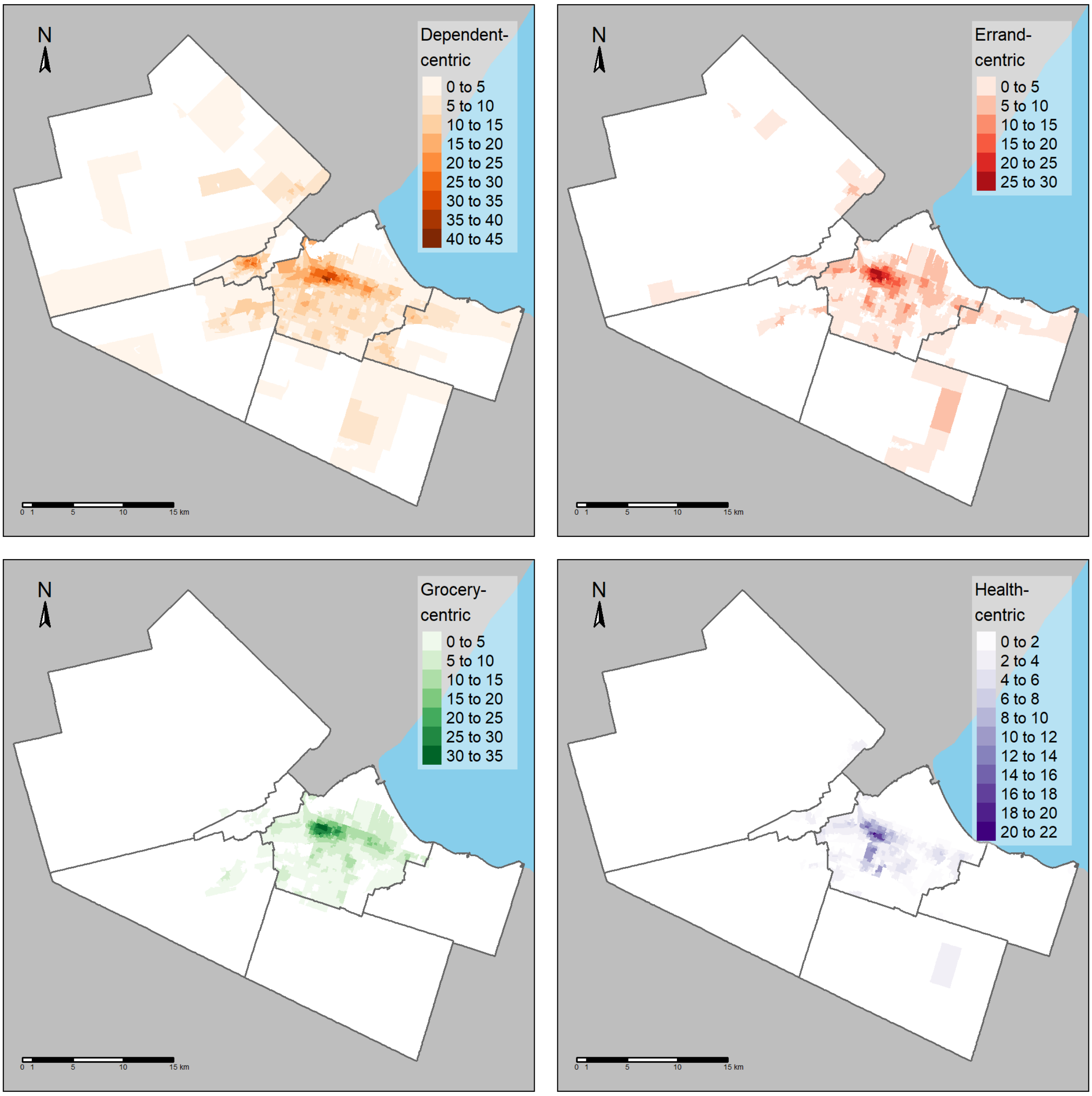

Figure 4: The number of care destinations that can be reached within a 15-min walk per care category for a median parcel in each DA. The values are a summary of the 14 acessibility scores that served as inputs into the SOM. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

Figure 5: The diversity measure based on the proportion of care category accessibility in Figure 4. These values are also a summary of the 15th input into the SOM. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

6.2. *Identification of completely caring 15-minute neighbourhood typologies*

In Figure 4, the concentration of opportunities for all category types is centered in the downtown of Hamilton, with the highest concentration being in the lower city (near the lake shore) and pockets of the high concentration further from the shoreline. Grocery-centric destinations appear to be the most concentrated, followed by health-centric and dependent-centric caring destinations. Errand-centric destinations are the most sprawled. In many ways, Figure 4 mirrors the spatial distribution of care destinations (Figure 3) as the range of 15-minutes of travel is small. In Figure 5, areas that have high care accessibility tend to have high diversity as well, though there are exceptions in pockets of the city outside the downtown core that have higher diversity but low levels of accessibility for all care categories. Similarly, there are areas with low diversity within the downtown core that have only moderate or high accessibility to certain care destination types.

Based on the SOM methodology discussed, 7 superclusters are identified from the 10 by 10 grid of SOM nodes. As diagnostics for the selection of the number of superclusters, the dissimilarity-index-based dendrogram with the proportion of parcels represented in each supercluster alongside the variance explained plot is visualised in Figure 6. Labels representing grades A to D qualifying the 7 superclusters are then assigned. These grades as also reflected in Figure 6 and represent the quantity of accessibility and diversity in accessibility per care category. Higher grades (A+ and A) corresponding to the highest accessibility and diversity, while lowest grades (D) representing lowest accessibility and diversity scores.

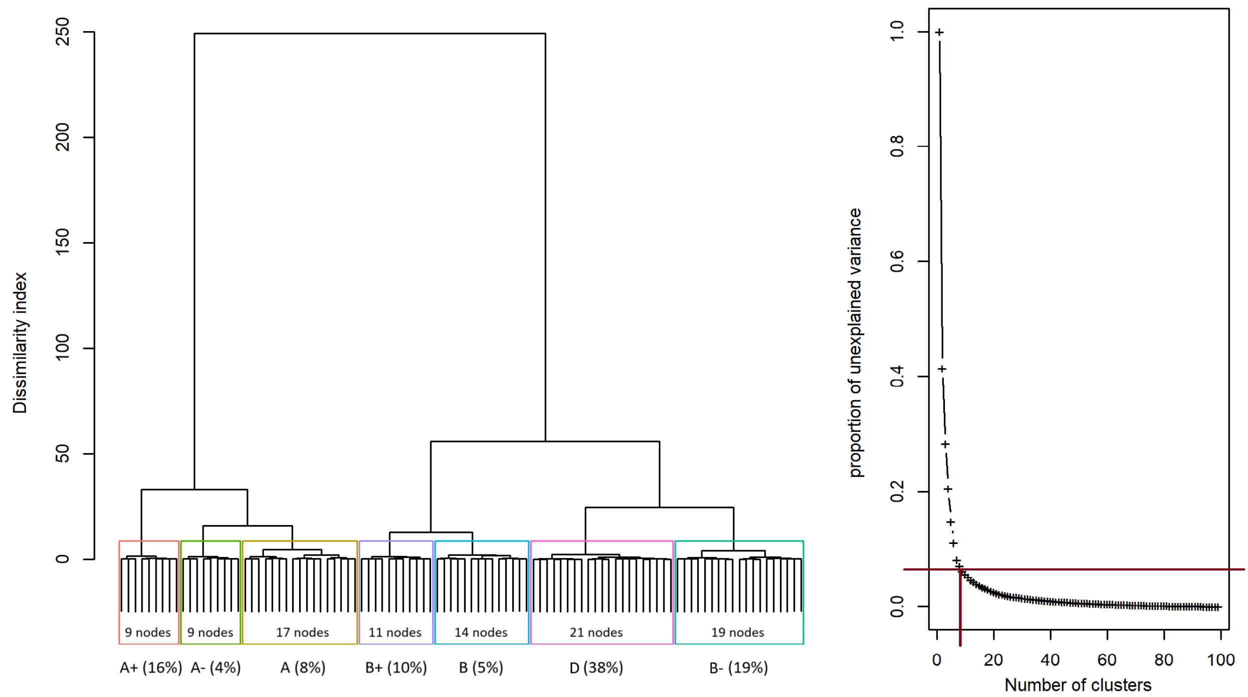

Figure 6: The 7 resulting superclusters from the SOM the 10 by 10 grid output represented in a dendrogram (left) and the proportion of variance unexplained by cluster (right).

The grade for each supercluster was carefully assigned by the authors by referring to descriptive statistics and their notable trends. These statistics are summarised in Table 2 and in the boxplots in Figure 7.

- A+ and A have exceptionally high caring accessibility for all destination types and high diversity scores in the top quantile or above. Together, these grades represent 24% of all parcels in the city.
- A- has high caring accessibility, but low diversity. Interestingly, A- is like A but with much higher dependent-centric destinations, particularly parks, schools, and daycares, with only moderately high scores for all other destination types. This disbalance lowers its overall diversity score. However, it can be characterized as a supercluster that demonstrates potential in being retrofitted to provide A+ or A level of completely caring access. 4% of all parcels are represented by the A- grade.
- B+ and B superclusters present about average completely caring access. These superclusters can serve as the benchmark for what 'average' completely caring access in Hamilton currently looks like. These grades represent 15% of all parcels.
- B- provides above average dependent-centric destination access, particularly parks, daycares and schools, but below average access to other destination types and hence has low diversity scores. B- is

like A- as it demonstrates complete caring 15-minute potential if retrofitted. As these parcels demonstrate caring access to some destinations, they may have the potential to be retrofitted to support complete access to all caring destination types. This grade represents 19% of all parcels.

- D superclusters demonstrate the lowest scores all-around, representing room for land-use improvement that addresses complete and caring 15-minute access. This supercluster characterizes the largest number of parcels, representing 38% of parcels in the city.

Table 2: Mean and (standard deviation) of each SOM classified cluster by input variable and additional summary variables. Variables included in the SOM algorthim are in regular case, while additional summary variables are indicated by ALL CAPITAL LETERS.

	A+	A	A-	B+	B	B-	D	TOTAL
GROCERY TOTALS	12.2 (5.7)	7 (3.1)	2.8 (2.6)	4.8 (2.5)	2.7 (2.2)	1 (1.6)	0.5 (1.2)	3.6 (5.1)
Convenience Store	8 (4)	4.5 (2.6)	2 (2.1)	3 (1.9)	1.8 (1.6)	0.8 (1.2)	0.4 (0.9)	2.4 (3.4)
Grocer	4.2 (2.8)	2.6 (1.5)	0.7 (0.9)	1.9 (1.2)	0.9 (1)	0.2 (0.6)	0.1 (0.4)	1.2 (2)
DEP. TOTALS	17.5 (5.8)	11.5 (4.3)	13.4 (3)	6.7 (2.4)	5.3 (2.4)	9.5 (2.4)	2.9 (2.1)	8.1 (6.2)
Comm. or Rec. centre	1.3 (1)	0.7 (0.9)	1 (0.8)	0.2 (0.4)	0.2 (0.4)	0.4 (0.6)	0.1 (0.3)	0.4 (0.8)
Daycare or EarlyON	4.9 (2.2)	3.3 (2.1)	3.9 (2.3)	1.8 (1.4)	1.6 (1.5)	3 (1.5)	0.6 (0.8)	2.2 (2.2)
LTC or retirment home	1.1 (1.3)	0.5 (0.8)	0.4 (0.7)	0.3 (0.6)	0.2 (0.5)	0.3 (0.6)	0.2 (0.4)	0.4 (0.8)
Park	6.9 (3)	4.8 (2.3)	5.6 (2.2)	3.2 (1.6)	2.5 (1.4)	3.9 (1.6)	1.7 (1.3)	3.6 (2.6)
School	2.8 (1.5)	2.1 (1.1)	1.9 (1.2)	1.2 (0.8)	0.7 (0.7)	1.8 (0.9)	0.4 (0.5)	1.3 (1.3)
Senior centre	0.5 (0.9)	0.3 (0.5)	0.5 (0.7)	0.1 (0.2)	0.1 (0.4)	0.1 (0.3)	0 (0.2)	0.2 (0.5)
HEALTH TOTALS	11.1 (6.3)	5.8 (2.8)	3.6 (1.8)	3.9 (1.8)	2.9 (1.9)	1.5 (1.4)	0.6 (1)	3.4 (4.7)
Dentist	4.1 (3.4)	2.2 (2)	0.8 (1.1)	1.4 (1.4)	0.9 (1.1)	0.3 (0.7)	0.1 (0.4)	1.1 (2.2)
Hospital or clinic	0.6 (0.7)	0.3 (0.5)	0.3 (0.6)	0.2 (0.5)	0.3 (0.7)	0.1 (0.3)	0 (0.2)	0.2 (0.5)
Pharmacy	6.4 (3.7)	3.3 (1.5)	2.5 (1.3)	2.3 (1.2)	1.7 (1.2)	1.2 (1.2)	0.4 (0.8)	2.1 (2.7)
ERRAND TOTALS	3.9 (2)	2.5 (1.4)	1.1 (1)	2.2 (1)	1 (0.6)	0.3 (0.6)	0.1 (0.4)	1.2 (1.8)
Bank or ATM	2.2 (1.8)	1.5 (1.2)	0.4 (0.5)	1.5 (1.1)	0.7 (0.7)	0.1 (0.3)	0 (0.2)	0.7 (1.2)
Library	0.5 (0.5)	0.3 (0.5)	0.2 (0.4)	0.1 (0.2)	0.1 (0.2)	0.1 (0.3)	0 (0.2)	0.2 (0.4)
Post office	1.2 (0.8)	0.7 (0.7)	0.5 (0.8)	0.6 (0.7)	0.3 (0.5)	0.1 (0.3)	0 (0.2)	0.4 (0.7)
Category diversity	0.9 (0.1)	0.8 (0.2)	0.3 (0.3)	0.9 (0.1)	0.6 (0.4)	0 (0.1)	0 (0)	0.3 (0.4)

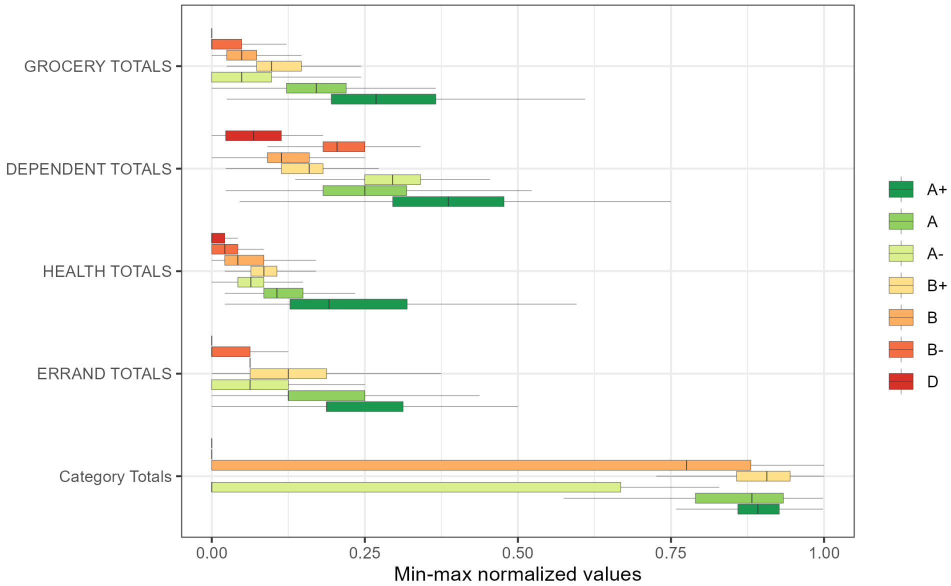

Figure 7: A boxplot demonstrating summary variables and category diversity that define the superclusters.

To spatially demonstrate where the superclusters are located, representative supercluster labels for each DA are visualised in Figure 8. This visualisation is created by grouping parcels by their DA, calculating the median supercluster label for each label, and selecting the label that is most dominant within that DA. For reference, the median number of parcels in each DA is 150 and supercluster label membership within a DA is typically pure, with the median membership being 80% of a single cluster.

The resulting superclusters visualised in Figure 8 are a combination of the cumulative opportunity and diversity of access measures translated into meaningful typologies through the SOM methodology. To reiterate, accessibility is the measure of *potential* interaction, e.g., how many care destinations one could reach within a 15-minute walk, these typologies are useful in identifying which areas of the city are providing regionally high levels of complete caring access, which areas are regionally average, and which areas are regionally below average. Furthermore, neighbourhoods which provide disbalanced access can be further investigated.

In Figure 8, it can be observed that the excellent and exceptional neighbourhoods (A, A+), which are very caring and very complete 15-minute neighbourhoods, are located within the center of the city and closest to the shoreline in the downtown core of Hamilton. The above and below average neighbourhoods (B+ B) are often proximate to the excellent and exceptional neighbourhoods and are more prevalent in south of the escarpment within the center Hamilton. The escarpment is a physical barrier, with few pedestrian-

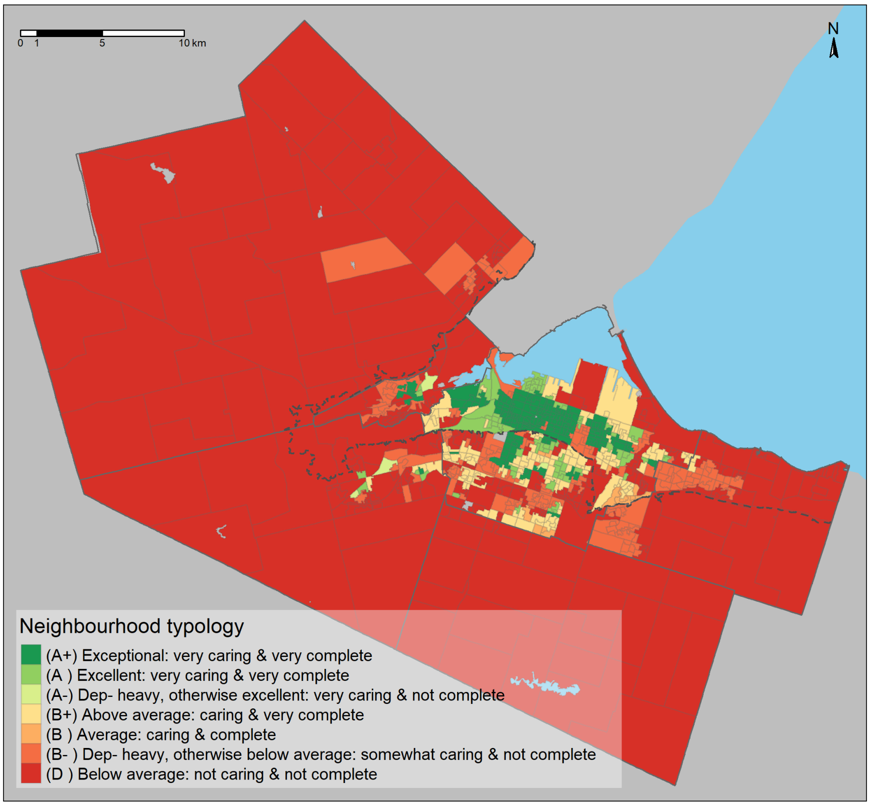

Figure 8: The maximum median parcel supercluster membership per DA. Escarpment is visualised as a grey dashed line. Basemap shapefiles are retrieved from the 2021 Canadian census (Statistics Canada, 2023), the Open Data Hamilton Portal (Hamilton, 2023) and the USGS (USGS, 2010).

accessible access points to traverse; hence the typologies describing neighbouring DAs separated by the escarpment are often different. Below average (D) neighbourhoods are located in peripheral areas outside the center of Hamilton, in areas where urban form is characterised by lower density residential housing and auto-dependent mobility.

Furthermore in Figure 8, A- and B- grades stand out as offering high access for children-centric destinations for their grade-group but below grade-group average access in other destination types. These neighbourhoods may be more suitable for populations who prioritize walkable access to destinations like schools, parks and daycares, and find access to other types of caring destinations less important. These neighbourhoods also stand out as demonstrating potential to be retrofitted to provide more complete access if additional destination types were located within their neighbourhoods.

6.3. Profiles of who does and does not reside in caring 15-minute neighbourhoods

To enhance the meaning of the superclusters beyond a descriptive and spatial conceptualisation of "caring" and "complete", *who?* resides in what neighbourhood is investigated through the Decision Tree results. The input features of the Decision Tree are the supercluster labels and the feature variables are various population-weighted socio-demographic characteristics of the 2021 Canadian Census, namely: median household income, % below the median household income, % LICO prevalence, average number of children per household, % population aged 0 to 14, % not in the labour force, % not employed, Gini index on adjusted household after-tax income, % visible minority, % single parent household, % who walk to work (relative to bike, care/truck/van, public transit and 'other'), % of owner household in core housing need (i.e., inadequate housing structure or paying higher than 30% income on housing), % of tenant households in subsidized housing, % of tenant households in core housing need, % no certification or with only a highschool diploma.

Of all the included input variables, *median household income* proved to be the most meaningful in partitioning the superclusters data. Figure 9 provides the Decision Tree with the significant splits in median household income and the proportion composition of supercluster along each branch for three terminal Decision Tree nodes. While the algorithm is unable to homogenously use each supercluster, Figure 9 is helpful to report a narrative of who may reside in what caring/complete supercluster. Particularly, the Decision Tree demonstrates a more pure supercluster membership for only two of the three terminal Decision Tree nodes: supercluster A+ (exceptional completely caring access) and D (not caring and complete access). For reference, the city-wide mean household income is 81,316 (SD: 25,239 and median: 80,000). The notable splits for income are >\$91,500, >\$68,750, or between \$68,750 and \$91,500; roughly split by lower income, middle income, and higher income median household brackets.

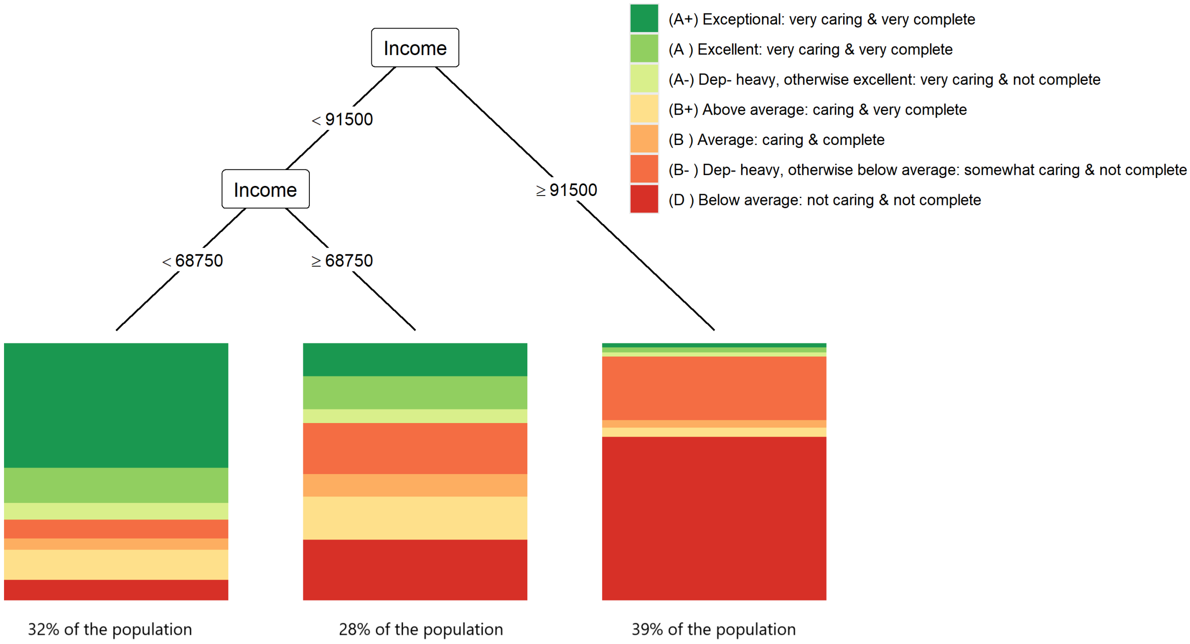

Figure 9: The Decision Tree demonstrating median household income splits and superclusters composition within each branch.

Describing Figure 9, the bar column on the right represents DAs with higher household income. In these DAs, the majority of parcels are labeled as D superclusters, i.e not caring or complete 15-minute neighbourhoods. Within this higher-income-representing bar column, the second highest proportion of supercluster membership are B- parcels. B- parcels are low in most amenity types except a few child-centric destinations and show promise in being more easily improved than the D parcels. The higher income column represents 39% of the population, the largest proportion of any of the three columns. The left column in Figure 9 corresponds to the lowest income, i.e., below 68,750 CAD median household income, and accounts for 32% the population. It is dominated by A+ parcels along with A and A- parcels, in the largest quantities relative to other bar columns, however, proportions of all other superclusters are also present. The middle column is defined by parcels with a mix of supercluster classifications and represents DAs with middle households incomes, between 68,750 CAD and 91,500 CAD representing 28% of the population.

Though median income was the most useful in partitioning the parcels by their supercluster labels in Figure 9, other variables are still important. Namely, the following variables in order of importance and correlation coefficient with the median household income variable in brackets, are listed: the % below the median household income (-0.89), % single parent household (-0.57), % no certification or with only a highschool diploma (-0.49), the average number of children per household (0.38), % not in the labour force (-0.41), % LICO prevalence (-0.67), and % who walk to work (-0.37).

It is notable that median household income is highly or moderately correlated with many of these important variables, and discussing these correlations is useful for interpretation alongside the Decision Tree diagram. For instance, single-parent families are most positively correlated with the proportion of households being in the bottom income distribution (-0.89) and lower or no diploma (0.6), and most negatively with the median after-tax household income (-0.57), reflecting nationwide trends (Statistics Canada, 2024,-). Though not all single-family households are below the LICO (i.e., single-family households are not highly correlated with LICO at the DA-level in Hamilton), DAs with higher concentrations of single-family households and LICO prevalence tend to have A+ access. Conversely, DAs with lower single-parent households are in DAs with a higher concentration of parcels with D access. These findings are notable from an equity perspective since economic disadvantaged often intersects with other socio-demographic characteristics.

7. Discussion

Geographically, Hamilton is city that offers very caring - and completely caring - 15-Minute neighbourhoods for some, but not all. There are evident spatial inequalities, with areas ranging from excellent (A+ and A), average (B+ and B), to well below average (D). Some areas, like those labelled A- and B-, show potential for improvement within their grade groups. While the downtown core has the highest concentration of *caring 15-minute neighborhoods*, certain areas outside the core do as well. This finding somewhat contrasts employment accessibility studies, such as El-Geneidy et al. (2016)'s assessment of public transit access to employment in the Greater Toronto Area (including Hamilton), where access is heavily concentrated in the downtown core, more so than appears to be present in this work. Though our paper uses a different methodology, both studies highlight distinct patterns: indeed, A+, A or A- care access is concentrated in the downtown core but it is also present in certain pockets outside of the center of Hamilton, leading to interesting conjectures. For instance, some of the A-grade neighborhoods in Hamilton likely follow land-use principles that emphasized residential proximity to amenities, similar to the NUC reviewed. The potential overlap of the NUC with caring 15-minute neighborhoods warrants further investigation.

Who currently resides in Hamilton's completely caring 15-Minute neighbhorhoods is also demonstrated to be a somewhat optimistic story. Parcels that provide A+ completely caring access tend to be in DAs that are economically disadvantaged. Economic disadvantage tends to intersect with other identities such as gender (Lightman and Good Gingrich, 2018). And as reviewed in this work, all women and especially those from lower income households tend to complete most mobility of care trips (Ravensbergen et al., 2023). Furthermore, lower-income households tend to also be single-parent households. Broadly, single-parent households are more likely to be time-disadvantaged (Nieuwenhuis and Maldonado, 2018), and tasked with a higher proportion of care duties (Craig, 2004). In this way, the most economically disadvantaged groups having A+ complete and caring access is an optimistic finding. However, Hamilton is experiencing gentrification (Ellis-Young, 2018); rents are rising along the future light rail transit corridor and throughout the city (Van der Merwe, 2021; Mayers et al., 2023). Toronto, Hamilton's larger and higher-rent neighbouring city, is spilling gentrification into Hamilton's downtown core, (re)producing neighbourhoods based on Toronto's middle class identities (Mayers et al., 2023). In these ways, the lower income residents of Hamilton's A+ neighbourhoods are more likely to be displaced, which is matter of wellbeing and justice. There are now few low-rent choices that provide the same exceptional level of access as the downtown core, hence lower household income residents that currently reside in A+ neighhourhoods will likely displaced in the coming years if current trends continue.

In discussing policy interventions that equitably increase completely caring 15-Minute neighbourhoods in Hamilton, this work's presents a methodology to create city-wide relative typologies and investigate who currently resides in what neighbourhood, as a stepping stone for further investigation. Neighbourhoods with the lowest grades (D) and with the highest potential in being improved (i.e., high accessibiltiy for certain types of destinations but not all) are neighbourhoods with B- and A- grades. However, the work's findings demonstrate a mismatch in household income and completely caring access: higher income areas are often the ones targeted for improvement. This raises important questions from the land-use policy perspective that need to be further analysed. For instance, is it equitable to focus policy on ameliorating neighbourhoods that are already higher-rent though they tend to be more rural, single-use zoned and car-dependent (parcels with D grades)? Further, of the parcels that provide high child-centrics but low otherwise, A- parcels (better access) tend to be in DAs with lower-income households more so than B- parcels (lower access than A-). From the perspective of ameliorating land-use to support the equitable distribution of 15-minute caring neighbourhoods which areas be targeted? Who should benefit, and how? If the policy initiative is targeted to specific neighbourhoods: sustainability linked to car dependency and equity are in tension. This harkens to what role a planned neighbourhood, and bottom-up planning approaches that include the evaluation of travel behaviour by socio-economic and demographic profile should be adopted to achieve equitable 15-

minute cities.

As is the case for all research, the results should also be interpreted along with methodological assumptions. This work measures spatial accessibility which is a measure of potential interaction with all reachable destinations from an origin. These destinations, however, may not be relevant to people at an origin, e.g., they may be underutilized (walkable access to 2 schools may be underused, as children often only attend 1 school), the trip physically undesirable (the walk may be along an arterial with high traffic speeds, making the trip unlikely to ever happen by foot), or the average walking speed assumed may not reflect the walking speeds of all populations (Willberg et al., 2023). Further, people who reside in these neighbourhoods may also disagree with the neighbourhood's label. The grade labels are region-relative (e.g., high accessibility in Hamilton may be subjectively insufficient for some) and they do not consider subjective perceptions that influence accessibility (e.g., though a neighbourhood has many opportunities, it may not feel safe to access them). Furthermore, accessibility is calculated from the point of residential parcels. Care trips are not necessarily completed from home, in-fact, they are often completed in complex trip-chains (Scheiner and Holz-Rau, 2015). In this way, the results flatten the dynamic patterns of care trips. These methodological assumptions should all be taken together when interpreting the results. In this way, the methodologyand findings presented identifies spatial and socio-economic trends that should be further investigated.

8. Conclusion

This study makes three types of contributions to the transportation and city planning literature: empirical, methodological and theoretical. At the empirical level, areas of the mid-sized City of Hamilton have been typified by their degree of '15-Minute Caring Neighbourhood' potential. Methodologically, we applied the longstanding accessibility measure of cumulative opportunities and entropy to classify spatial areas based on how many destinations could be reached in a 15-minute walk and the diversity of destination type. These values were then clustered using a novel machine learning approach, SOM, to generate meaningful typologies for discussion and further comparison with socio-economic composition of the area. We find A+ and A 15-minute caring neighbourhoods are located within the downtown core and in certain suburban pockets of the city, while the peripheral regions provide D level caring access. A- and B- areas are also identified as neighbourhoods that already support a high amount of children-centric destination access, and could be improved to provide better complete care access. Theoretically, our work puts forth an explicitly caring 15-Minute Neighbourhod conceptualisation, bridging the Mobility of Care and the 15-Minute City concepts. We discuss how measuring caring neighbourhoods can be explicitly considered within city planning.

Our work is of relevance to researchers and practitioners planning equitable and sustainable cities. Instead of prescribing an urban form design principle, such as "all local amenities should be within a 15-minute walking distance", it instead examines an empirical example to determine which areas in the city have the *potential* to be 15-minute neighbourhood based on the existing spatial accessibility offered by the urban environment and walking transport network. To this end, this data-driven methodology introduces a way to identify neighbourhoods that have potential, almost have potential, and are far from containing this potential to support future context-specific qualitative work.

9. References

Allam, Z., Nieuwenhuijsen, M., Chabaud, D., Moreno, C., 2022. The 15-minute city offers a new framework for sustainability, liveability, and health. The Lancet Planetary Health 6, e181–e183.

Bastiaanssen, J., Johnson, D., Lucas, K., 2022. Does better job accessibility help people gain employment? the role of public transport in great britain doi:10.1177/00420980211012635.

Blumenberg, E., Pierce, G., 2017. The drive to work: The relationship between transportation access, housing assistance, and employment among participants in the welfare to work voucher program 37, 66–82. doi:10.1177/0739456X16633501.

Brody, J., 2013. The neighbourhood unit concept and the shaping of land planning in the united states 1912–1968 18, 340–362. URL: http://www.tandfonline.com/doi/abs/10.1080/13574809.2013.800453, doi:10.1080/13574809.2013.800453.

Burke, J., Gras Alomà, R., Yu, F., Kruguer, J., 2022. Geospatial analysis framework for evaluating urban design typologies in relation with the 15-minute city standards 151, 651–667. URL: https://www.sciencedirect.com/science/article/pii/S014829632200563X, doi:10.1016/j.jbusres.2022.06.024.

Cervero, R., Kockelman, K., 1997. Travel demand and the 3ds: Density, diversity, and design 2, 199–219. URL: https://linkinghub.elsevier.com/retrieve/pii/S1361920997000096, doi:10.1016/S1361-9209(97)00009-6.

Cheng, J., Bertolini, L., 2013. Measuring urban job accessibility with distance decay, competition and diversity 30, 100–109. URL: https://linkinghub.elsevier.com/retrieve/pii/S0966692313000604, doi:10.1016/j.jtrangeo.2013.03.005.

Cheng, L., Caset, F., De Vos, J., Derudder, B., Witlox, F., 2019. Investigating walking accessibility to recreational amenities for elderly people in nanjing, china 76, 85–99. URL: https://linkinghub.elsevier.com/retrieve/pii/S1361920919308119, doi:10.1016/j.trd.2019.09.019.

City of Portland, 2010. 20-Minute Neighborhoods. URL: https://www.portlandonline.com/portlandplan/index.cfm?c=52256&a=288098.

Craig, L., 2004. Time to care: A comparison of how couple and sole parent households allocate time to work and children URL: http://hdl.handle.net/1959.4/34125, doi:10.26190/UNSWORKS/264. ISBN: 9780733421396 Publisher: UNSW Sydney.

Cresswell, T., Uteng, T.P., 2008. Gendered mobilities: towards an holistic understanding, Ashgate aldershot ed., pp. 1–12. URL: https://scholar.googleusercontent.com/scholar.bib?q=info:Po-VQJ3PdC8J:scholar.google.com/&output=citation&scisdr=CgXWBZyhEKud2of3eV8:AAGBfm0AAAAAYhfxYV9SlOGokXr0aTZfNjhPI6OvxW5I&scisig=AAGBfm0AAAAAYhfxYc8iC6UkrBP7WOJiAwZK5pn99p9G&scisf=4&ct=citation&cd=-1&hl=en.

Dai, T.q., Liu, Z.b., Liao, C., Cai, H.y., 2018. Incorporating job diversity preference into measuring job accessibility 78, 108–115. URL: https://linkinghub.elsevier.com/retrieve/pii/S0264275117312465, doi:10.1016/j.cities.2018.02.003.

Delmelle, E.C., 2012. Spatial temporal dynamics of neighborhood quality of life: Charlotte, NC. Ph.D. thesis. The University of North Carolina at Charlotte.

Delmelle, E.C., 2017. Differentiating pathways of neighborhood change in 50 u.s. metropolitan areas 49, 2402–2424. URL: https://doi.org/10.1177/0308518X17722564, doi:10.1177/0308518X17722564. publisher: SAGE Publications Ltd.

Di Marino, M., Tomaz, E., Henriques, C., Chavoshi, S.H., 2023. The 15-minute city concept and new working spaces: a planning perspective from oslo and lisbon 31, 598–620. URL: https://doi.org/10.1080/09654313.2022.2082837, doi:10.1080/09654313.2022.2082837. publisher: Routledge _eprint: https://doi.org/10.1080/09654313.2022.2082837.

d'Ottawa, V., 2021. Quartier du quart d'heure | Nouveau Plan officiel | Participons Ottawa. URL: https://participons.ottawa.ca/nouveau-plan-officiel/news_feed/quartier-du-quart-d-heure.

Duarte, L.B., da Mota Silveira Neto, R., da Silva, D.F.C., 2023. The influence of job accessibility on individual labor income: Evidence for the city of recife, brazil. Journal of Transport Geography 112. doi:10.1016/j.jtrangeo.2023.103684.

EIGE, 2016. Gender in employment. URL: https://eige.europa.eu/sites/default/files/documents/ti_pubpdf_mh0216898enn_pdfweb_20170124124440.pdf.

El-Geneidy, A., Buliung, R., Diab, E., van Lierop, D., Langlois, M., Legrain, A., 2016. Non-stop equity: Assessing daily intersections between transit accessibility and social disparity across the greater toronto and hamilton area (GTHA) 43, 540–560. URL: https://doi.org/10.1177/0265813515617659, doi:10.1177/0265813515617659. publisher: SAGE Publications Ltd STM.

Ellis-Young, M., 2018. "we're just trying to help...make it a positive place": Community organizations, gentrification, and neighbourhood change in hamilton, ontario.

Ewing, R., Cervero, R., 2010. Travel and the built environment: A meta-analysis 76, 265–294. URL: http://www.tandfonline.com/doi/abs/10.1080/01944361003766766, doi:10.1080/01944361003766766.

Farber, S., Allen, J., 2019. The Ontario Line: Socioeconomic Distribution of Travel Time and Accessibility Benfits. Report. Metrolinx. URL: https://metrolinx.files.wordpress.com/2019/10/read-the-full-report-here.pdf.

Ferrant, G., Pesando, L.M., Nowacka, K., 2014. Unpaid care work: The missing link in the analysis of gender gaps in labour outcomes. Boulogne Billancourt: OECD Development Center .

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form 28, 117–125. URL: https://linkinghub.elsevier.com/retrieve/pii/S0749379704003253, doi:10.1016/j.amepre.2004.11.001.

Gaglione, F., Gargiulo, C., Zucaro, F., Cottrill, C., 2022. Urban accessibility in a 15-minute city: a measure in the city of naples, italy 60, 378–385. URL: https://linkinghub.elsevier.com/retrieve/pii/S2352146521009509, doi:10.1016/j.trpro.2021.12.049.

Gan, Z., Yang, M., Feng, T., Timmermans, H., 2020. Understanding urban mobility patterns from a spatiotemporal perspective: daily ridership profiles of metro stations 47, 315–336. URL: https://doi.org/10.1007/s11116-018-9885-4, doi:10.1007/s11116-018-9885-4.

García Román, J., Gracia, P., 2022. Gender differences in time use across age groups: A study of ten industrialized countries, 2005–2015 17, e0264411. URL: https://dx.plos.org/10.1371/journal.pone.0264411, doi:10.1371/journal.pone.0264411.

Geofabrik, 2023. Ontario, canada - open street map data. URL: https://www.geofabrik.de.

Gil Solá, A., Vilhelmson, B., 2022. To choose, or not to choose, a nearby activity option: Understanding the gendered role of proximity in urban settings. Journal of Transport Geography 99, 103301. URL: https://www.sciencedirect.com/science/

article/pii/S0966692322000242, doi:10.1016/j.jtrangeo.2022.103301.

Gower, A., Grodach, C., 2022. Planning innovation or city branding? exploring how cities operationalise the 20-minute neighbourhood concept 40, 36–52. URL: https://www.tandfonline.com/doi/full/10.1080/08111146.2021.2019701, doi:10.1080/08111146.2021.2019701.

Graells-Garrido, E., Serra-Burriel, F., Rowe, F., Cucchietti, F.M., Reyes, P., 2021. A city of cities: Measuring how 15-minutes urban accessibility shapes human mobility in barcelona. PLoS One 16, e0250080. URL: https://www.ncbi.nlm.nih.gov/pubmed/33951051, doi:10.1371/journal.pone.0250080. graells-Garrido, Eduardo Serra-Burriel, Feliu Rowe, Francisco Cucchietti, Fernando M Reyes, Patricio eng Research Support, Non-U.S. Gov't 2021/05/06 PLoS One. 2021 May 5;16(5):e0250080. doi: 10.1371/journal.pone.0250080. eCollection 2021.

Guzman, L.A., Oviedo, D., Cantillo-Garcia, V.A., 2024. Is proximity enough? a critical analysis of a 15-minute city considering individual perceptions 148, 104882. URL: https://www.sciencedirect.com/science/article/pii/S0264275124000969, doi:10.1016/j.cities.2024.104882.

Hall, P., 2014. Cities of tomorrow: An intellectual history of urban planning and design since 1880. John Wiley & Sons.

Hamilton, 2023. City boundary. URL: https://open.hamilton.ca/datasets/dd522e1245b1461887d998c6c17edff7_13/explore?location=43.099541%2C-79.560176%2C9.73.

Handy, S., 2020. Is accessibility an idea whose time has finally come? 83, 102319. doi:https://doi.org/10.1016/j.trd.2020.102319.

Handy, S.L., Niemeier, D.A., 1997. Measuring accessibility: An exploration of issues and alternatives 29, 1175–1194. URL: http://journals.sagepub.com/doi/10.1068/a291175, doi:10.1068/a291175.

Hayden, D., 1982. The grand domestic revolution: a history of feminist designs for American homes, neighborhoods, and cities. First MIT press paperback edition ed., The MIT Press.

Hochschild, A., Machung, A., 2012. The second shift: Working families and the revolution at home. Penguin. URL: https://books.google.de/books?hl=de&lr=&id=St_6kWcPJS8C&oi=fnd&pg=PT25&ots=8IZZkZu4cf&sig=W1cAH6vLmc8SUYRgLvUUz3zfHWs&redir_esc=y#v=onepage&q&f=false.

Hosford, K., Beairsto, J., Winters, M., 2022. Is the 15-minute city within reach? evaluating walking and cycling accessibility to grocery stores in vancouver 14, 100602. URL: https://linkinghub.elsevier.com/retrieve/pii/S2590198222000641, doi:10.1016/j.trip.2022.100602.

International Labour Organization, 2018. Care work and care jobs for the future of decent work. Technical Report. International Labour Organization. Geneva. URL: https://webapps.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_633135.pdf.

Kissfazekas, K., 2022. Circle of paradigms? or '15-minute' neighbourhoods from the 1950s 123, 103587. URL: https://linkinghub.elsevier.com/retrieve/pii/S0264275122000269, doi:10.1016/j.cities.2022.103587.

Law, R., 1999. Beyond 'women and transport': towards new geographies of gender and daily mobility 23, 567–588. URL: http://journals.sagepub.com/doi/10.1191/030913299666161864, doi:10.1191/030913299666161864.

Levy, C., 2013. Travel choice reframed:"deep distribution" and gender in urban transport. Environment and Urbanization 25, 47–63.

Lightman, N., Good Gingrich, L., 2018. Measuring economic exclusion for racialized minorities, immigrants and women in canada: results from 2000 and 2010 22, 398–420. URL: https://doi.org/10.1080/10875549.2018.1460736, doi:10.1080/10875549.2018.1460736. publisher: Routledge _eprint: https://doi.org/10.1080/10875549.2018.1460736.

Little, J., 1994. Gender, Planning, and the Policy Process. Pergamon press ed. URL: https://books.google.de/books/about/Gender_Planning_and_the_Policy_Process.html?id=h1y0AAAAIAAJ&redir_esc=y.

Logan, T.M., Hobbs, M.H., Conrow, L.C., Reid, N.L., Young, R.A., Anderson, M.J., 2022. The x-minute city: Measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design. Cities 131, 103924. ISBN: 0264-2751 Publisher: Elsevier.

Lu, Y., Xiao, Y., Ye, Y., 2017. Urban density, diversity and design: Is more always better for walking? a study from hong kong 103, S99–S103. URL: https://linkinghub.elsevier.com/retrieve/pii/S0091743516302468, doi:10.1016/j.ypmed.2016.08.042.

MacIntyre, S., 2022. Her 20-minute neighbourhood. A critical feminist review of women's experiences of the 20-minute neighbourhood in Corstorphine, Edinburgh. Master's thesis. University of Groningen Faculty of Spatial Sciences Research. URL: https://frw.studenttheses.ub.rug.nl/3996/.

Sánchez de Madariaga, I., 2013. Mobility of Care: Introducing New Concepts in Urban Transport. book section 3.

Sánchez de Madariaga, I., Zucchini, E., 2019. Measuring Mobilities of Care, a Challenge for Transport Agendas.

Mahmoud, I., Morello, E., 2021. Co-creation pathway for urban nature-based solutions: Testing a shared- governance approach in three cities and nine action labs, in: Smart and Sustainable Planning for Cities and Regions: Results of SSPCR 2019—Open Access Contributions. Springer International Publishing. Green Energy and Technology, pp. 259–276. URL: http://link.springer.com/10.1007/978-3-030-57764-3, doi:10.1007/978-3-030-57764-3.

Mavoa, S., Boulangé, C., Eagleson, S., Stewart, J., Badland, H.M., Giles-Corti, B., Gunn, L., 2018. Identifying appropriate land-use mix measures for use in a national walkability index 11, 681–700. URL: https://www.jstor.org/stable/26622423. publisher: Journal of Transport and Land Use.

Mayers, R., Rallis, N., Doucet, B., Babin, C., 2023. In light of transit: Documenting the scales of urban change along the LRT line in hamilton, ontario n/a. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/cag.12890, doi:10.1111/cag.12890. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/cag.12890.

McBride, E.C., Davis, A.W., Goulias, K.G., 2020. Exploration of statewide fragmentation of activity and travel and a taxonomy of daily time use patterns using sequence analysis in california. Transportation research record 2674, 38–51.

Van der Merwe, J., 2021. Spillover gentrification? mid-sized cities within commuter sheds of global cities. URL: https://uwspace.uwaterloo.ca/bitstream/handle/10012/17628/VanderMerwe_Justin.pdf?sequence=4&isAllowed=n.

Moniruzzaman, M., Paez, A., 2012. Accessibility to transit, by transit, and mode share: application of a logistic model with spatial filters. Journal of Transport Geography 24, 198–205. doi:10.1016/j.jtrangeo.2012.02.006.

Montero, L., Mejía-Dorantes, L., Barceló, J., 2023a. Applying data analytics to analyze activity sequences for an assessment of fragmentation in daily travel patterns: A case study of the metropolitan region of barcelona. Sustainability 15, 14213.

Montero, L., Mejía-Dorantes, L., Barceló, J., 2023b. The role of life course and gender in mobility patterns: a spatiotemporal sequence analysis in barcelona. European Transport Research Review 15, 44.

Morency, C., Páez, A., Roorda, M.J., Mercado, R.G., Farber, S., 2011. Distance traveled in three Canadian cities: Spatial analysis from the perspective of vulnerable population segments. Journal of Transport Geography 19, 39–50.

Moreno, C., 2016. La ville du quart d'heure : pour un nouveau chrono-urbanisme. URL: https://www.latribune.fr/regions/smart-cities/la-tribune-de-carlos-moreno/la-ville-du-quart-d-heure-pour-un-nouveau-chrono-urbanisme-604358.html. section: La Tribune de Carlos Moreno.

Moreno, C., Allam, Z., Chabaud, D., Gall, C., Pratlong, F., 2021. Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. Smart Cities 4, 93–111. URL: https://www.mdpi.com/2624-6511/4/1/6, doi:10.3390/smartcities4010006.

Morioka, W., Kwan, M.P., Hino, K., Yamada, I., 2023. How accessibility to neighborhood grocery stores is related to older people's walking behavior: A study of yokohama, japan. Journal of Transport & Health 32, 101668. URL: https://www.sciencedirect.com/science/article/pii/S2214140523001044, doi:https://doi.org/10.1016/j.jth.2023.101668.

Mouratidis, K., 2024. Time to challenge the 15-minute city: Seven pitfalls for sustainability, equity, livability, and spatial analysis 153, 105274. URL: https://linkinghub.elsevier.com/retrieve/pii/S0264275124004888, doi:10.1016/j.cities.2024.105274.

Mulíček, O., Osman, R., Seidenglanz, D., 2015. Urban rhythms: A chronotopic approach to urban timespace 24, 304–325. URL: http://journals.sagepub.com/doi/10.1177/0961463X14535905, doi:10.1177/0961463X14535905.

Napier, M.A., Brown, B.B., Werner, C.M., Gallimore, J., 2011. Walking to school: Community design and child and parent barriers. Journal of Environmental Psychology 31, 45–51. URL: https://www.sciencedirect.com/science/article/pii/S0272494410000502, doi:https://doi.org/10.1016/j.jenvp.2010.04.005.

Negron-Poblete, P., Séguin, A.M., Apparicio, P., 2016. Improving walkability for seniors through accessibility to food stores: a study of three areas of greater montreal. Journal of Urbanism: International Research on Placemaking and Urban Sustainability 9, 51–72. URL: https://doi.org/10.1080/17549175.2014.990916, doi:10.1080/17549175.2014.990916.

Nieuwenhuis, R., Maldonado, L.C., 2018. Single-parent families and in-work poverty, in: Lohmann, H., Marx, I. (Eds.), Handbook on In-Work Poverty. Edward Elgar Publishing. URL: https://china.elgaronline.com/view/edcoll/9781784715625/9781784715625.00016.xml, doi:10.4337/9781784715632.00016.

Omura, J.D., Hyde, E.T., Watson, K.B., Sliwa, S.A., Fulton, J.E., Carlson, S.A., 2019. Prevalence of children walking to school and related barriers—united states, 2017. Preventive Medicine 118, 191–195. URL: https://www.sciencedirect.com/science/article/pii/S0091743518303359, doi:https://doi.org/10.1016/j.ypmed.2018.10.016.

Paez, A., Scott, D.M., Morency, C., 2012. Measuring accessibility: positive and normative implementations of various accessibility indicators. Journal of Transport Geography 25, 141–153. doi:10.1016/j.jtrangeo.2012.03.016.

Palm, M., Farber, S., 2020. The role of public transit in school choice and after-school activity participation among toronto high school students 19, 219–230. URL: https://linkinghub.elsevier.com/retrieve/pii/S2214367X19302431, doi:10.1016/j.tbs.2020.01.007.

Pereira, R.H.M., Saraiva, M., Herszenhut, D., Braga, C.K.V., Conway, M.W., 2021. r5r: Rapid realistic routing on multimodal transport networks with r5 in r. Findings doi:10.32866/001c.21262.

Portland Government, 2017. The Portland Plan Progress Report .

Pozoukidou, G., Chatziyiannaki, Z., 2021. 15-minute city: Decomposing the new urban planning eutopia 13, 928. URL: https://www.mdpi.com/2071-1050/13/2/928, doi:10.3390/su13020928. number: 2 Publisher: Multidisciplinary Digital Publishing Institute.

R Core Team, 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. URL: https://www.R-project.org/.

Randall, T.A., Baetz, B.W., 2015. A GIS -based land-use diversity index model to measure the degree of suburban sprawl 47, 360–375. URL: https://rgs-ibg.onlinelibrary.wiley.com/doi/10.1111/area.12182, doi:10.1111/area.12182.

Ravensbergen, L., Fournier, J., El-Geneidy, A., 2023. Exploratory analysis of mobility of care in montreal, canada. Transportation Research Record 2677, 1499–1509.

Roorda, M.J., Paez, A., Morency, C., Mercado, R., Farber, S., 2010. Trip generation of vulnerable populations in three

Canadian cities: a spatial ordered probit approach. Transportation 37, 525–548. doi:10.1007/s11116-010-9263-3.

Ryan, J., Pereira, R.H.M., Andersson, M., 2023. Accessibility and space-time differences in when and how different groups (choose to) travel. Journal of Transport Geography 111. doi:10.1016/j.jtrangeo.2023.103665.

Scheiner, J., Holz-Rau, C., 2015. Women's complex daily lives: a gendered look at trip chaining and activity pattern entropy in germany. Transportation 44, 117–138. doi:10.1007/s11116-015-9627-9.

Silva, C., Altieri, M., 2022. Is regional accessibility undermining local accessibility? 101, 103336. URL: https://www.sciencedirect.com/science/article/pii/S096669232200059X, doi:10.1016/j.jtrangeo.2022.103336.

Silva, C., Büttner, B., Seisenberger, S., Rauli, A., 2023. Proximity-centred accessibility—a conceptual debate involving experts and planning practitioners 4, 100060. URL: https://www.sciencedirect.com/science/article/pii/S266709172300016X, doi:10.1016/j.urbmob.2023.100060.

Solow, A.A., Ham, C.C., Donnelly, E.O., 1969. The concept of the neighborhood unit: Its emergence and influence on residential environmental planning and development. Graduate School of Public and International Affairs, University of Pittsburgh.

Statistics Canada, 2024. The daily — main highlights on income of families and individuals: Subprovincial data from the t1 family file, 2022. URL: https://www150.statcan.gc.ca/n1/daily-quotidien/240819/dq240819b-eng.htm. last Modified: 2024-08-19.

Statistics Canada, 2024-03-25. Prevalence of low income among persons in one-parent families headed by an immigrant parent: An intersectional analysis. URL: https://www150.statcan.gc.ca/n1/pub/45-20-0002/452000022024001-eng.htm. last Modified: 2024-03-25.

Statistics Canada, 2023. Governement of canada - census of population. URL: https://www12.statcan.gc.ca/census-recensement/index-eng.cfm.

Talen, E., 2017. Social science and the planned neighbourhood 88, 349–373. URL: https://go-gale-com.libaccess.lib.mcmaster.ca/ps/i.do?p=AONE&sw=w&issn=00410020&v=2.1&it=r&id=GALE%7CA493702956&sid=googleScholar&linkaccess=abs, doi:10.3828/tpr.2017.22. publisher: Liverpool University Press (UK).

Teixeira, J.F., Silva, C., Seisenberger, S., Büttner, B., McCormick, B., Papa, E., Cao, M., 2024. Classifying 15-minute cities: A review of worldwide practices 189, 104234. URL: https://linkinghub.elsevier.com/retrieve/pii/S0965856424002829, doi:10.1016/j.tra.2024.104234.

Therneau, T., Atkinson, B., 2023. rpart: Recursive Partitioning and Regression Trees. URL: https://github.com/bethatkinson/rpart. r package version 4.1.23, https://cran.r-project.org/package=rpart.

Tronto, J.C., Fisher, B., 1990. Toward a Feminist Theory of Caring, in: Abel, E., Nelson, M. (Eds.), Circles of Care. SUNY Press, Albany, NY, pp. 36–54. URL: https://books.google.de/books?hl=de&lr=&id=sAYy_oEw6NcC&oi=fnd&pg=PA29&dq=Towards+Feminist+Theory+of+Caring&ots=H93jKUsuvt&sig=LeJy-oufC87O8kIfxhnRrpbqEw8#v=onepage&q=Towards%20Feminist%20Theory%20of%20Caring&f=false.

Trudeau, D., 2013. New Urbanism as Sustainable Development? Geography Compass 7, 435–448. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/gec3.12042, doi:10.1111/gec3.12042. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gec3.12042.

Urban Development Vienna, 2013. Gender mainstreaming in urban planning and urban development.

USGS, 2010. Great lakes and watersheds shapefiles. URL: https://www.sciencebase.gov/catalog/item/530f8a0ee4b0e7e46bd300dd.

Vacchelli, E., Kofman, E., 2018. Towards an inclusive and gendered right to the city. Cities 76, 1–3. URL: https://linkinghub.

elsevier.com/retrieve/pii/S0264275117312040, doi:10.1016/j.cities.2017.10.013.

Vale, D., Lopes, A.S., 2023. Accessibility inequality across europe: a comparison of 15-minute pedestrian accessibility in cities with 100,000 or more inhabitants. npj Urban Sustainability 3, 55.

Victoriano, R., Paez, A., Carrasco, J.A., 2020. Time, space, money, and social interaction: Using machine learning to classify people's mobility strategies through four key dimensions 20, 1–11. URL: https://linkinghub.elsevier.com/retrieve/pii/S2214367X19302698, doi:10.1016/j.tbs.2020.02.004.

Villa-Vialaneix, N., 2017. Stochastic self-organizing map variants with the r package sombrero, in: JC, L., M, C., M, O. (Eds.), Proceedings of the 12th International Workshop on Self-Organizing Maps and Learning Vector Quantization, Clustering and Data Visualization (WSOM 2017), IEEE, Nancy, France. pp. 1–7.

Ville de Paris, 2022. Paris ville du quart d'heure, ou le pari de la proximité. URL: https://www.paris.fr/dossiers/paris-ville-du-quart-d-heure-ou-le-pari-de-la-proximite-37.

Whittaker, R.H., 1972. Evolution and measurement of species diversity. Taxon 21, 213–251.

Willberg, E., Fink, C., Toivonen, T., 2023. The 15-minute city for all? – measuring individual and temporal variations in walking accessibility 106, 103521. URL: https://linkinghub.elsevier.com/retrieve/pii/S0966692322002447, doi:10.1016/j.jtrangeo.2022.103521.

Yin, Z., Zheng, Y., Li, W., 2024. Incorporating facility diversity into measuring accessibility to transit: A case study in beijing 150, 05024018. URL: https://ascelibrary.org/doi/10.1061/JUPDDM.UPENG-4935, doi:10.1061/JUPDDM.UPENG-4935. publisher: American Society of Civil Engineers.

Yu, C.Y., Zhu, X., 2016. From attitude to action: What shapes attitude toward walking to/from school and how does it influence actual behaviors? Preventive Medicine 90, 72–78. URL: https://www.sciencedirect.com/science/article/pii/S009174351630161X, doi:https://doi.org/10.1016/j.ypmed.2016.06.036.