Identifying 15-minute neighbourhoods with complete caring potential

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# Abstract

The “15-Minute Neighbourhood” concept has been adopted by leaders around the world as a way to promote human-scale cities. The concept emphasizes a transport and land-use mix that supports short-trips to daily necessities by foot or bicycle from ones’ residence. This study adopts the 15-minute neighbourhood concept through the lens of “Mobility of Care”, a framework that foregrounds travel to care destinations, travel done predominately by women, in contrast to the better-studied travel to employment and leisure. While the 15-minute neighbourhood concept is flexible enough to consider all destination types, gendered examinations are relatively lacking in the literature and no research to date has focused explicitly on care destinations. In this study, we address these gaps by identifying which areas in Hamilton, Canada have the potential to be ‘caring 15-minute neighbourhoods’. To do so, a database of care destinations was compiled and used to estimate both the number (cumulative opportunities indicator) and diversity of mix (entropy measure) of destinations reachable within a 15-minute walk from all residential parcels. Parcel-level results were classified into ‘caring’ (quantity of reachable opportunities) and ‘complete’ (diversity of care destinations) neighbourhood typologies of varying degrees using machine learning techniques (Self-Organizing Maps (SOM) and hierarchical clustering). Inequalities in the relationship between the identified caring typologies and social-economic indicators of who currently reside in the neighbourhoods were then explored. Our results suggest the majority of ‘caring and complete’ neighbourhoods are within the urban core where a higher proportion of lower-income and single-parent households reside. Further, certain neighbourhoods in suburban and rural communities are ‘caring and somewhat complete’, showing the potential to become ‘complete’ through possible urban policy intervention. Taken together, this study offers a theoretical bridge to connect Mobility of Care and the 15-minute neighbourhoods concept, a data-driven classification and clustering methodology to assess neighbourhoods on a ‘caring and complete’ continuum, and discussion of relevant gender mainstreaming policy interventions.

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

# Introduction

The “15-Minute City” has been recently adopted by leaders as a way to promote human-scaled cities (e.g., Paris mayor Anne Hidalgo proposed a 15-minute city plan in her 2020 re-election campaign, 15-minute walkable neighbourhood guidance in Shanghai, China (Weng et al. 2019)), As defined 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 industrial Fordism, single-use zoning, and the segregation of urban time and space for individual uses and mobility (Mulíček, Osman, and Seidenglanz 2015; Moreno 2016). The 15-Minute City is one that accommodates the ability to reach essential destinations within a walkable, bikeable or transit supportive radius. It would allow individuals to reclaim time spent on car mobility and give way to sustainable modes; prompting urban spaces that are responsive to human needs and environmental sensibilities (Allam et al. 2022).

Though the term 15-Minute City is relatively new, neighbourhood planning practice aiming to foster community and local travel to amenities is not. 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). These planning forms have also been extensively critiqued: as summarized in Talen (2017), urban planners struggled to determine suitably universal design aspects such as neighborhood size, the type and quality of amenities, and local and regional connectivity. Social scientists also emphasized that top-down neighbourhood planning approaches overestimated the built environment’s influence on social life (Talen 2017). Neighbourhood planning approaches such as the 15-Minute City concept are being re-embraced, but from bottom-up perspective. However how to equitably prescribe urban form that ‘enables’ contact with social opportunities (instead of ‘engendering it’ from the top-down) is still under debate. For instance, questions such as *what* are destinations that matter, by what mode and travel time threshold, and *for whom* remain under discussion among proximity-based planners (Silva et al. 2023; Silva and Altieri 2022).

To add clarity to these questions surrounding the 15-Minute City concept, in this work we aim to build a theoretical bridge to “Mobility of Care” as introduced in Sánchez de Madariaga (2013). Mobility of Care is especially relevant to the 15-Minute City, as it is a purpose of travel that is necessary for all and often occurs at the local level. Namely, Mobility of Care 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, Mobility of Care is shown to be a significant proportion of daily travel, characterizing the trip purpose of approximately 30% of adults’ trips (Sánchez de Madariaga 2013; Sánchez de Madariaga and Zucchini 2019; Ravensbergen, Fournier, and El-Geneidy 2023). Notably, care trips take on tremendous gendered and socio-economic importance, as women, and especially those from lower income households, complete the majority of care trips (Ravensbergen, Fournier, and El-Geneidy 2023). Despite its importance for all and in advancing gender equality, the examination of 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 () and retail ().

We aim to theoretically bridge Mobility of Care with the 15-Minute City concept to clarify questions surrounding *what destinations within a 15 minute walkable radius matter*. We hypothesis that *care* destinations matter, they matter for all people but especially for women and lower-income women preforming care trips. In this vein, this work pairs this hypothesis with an exploratory clustering methodology to identify which neighbourhoods have the potential to support 15-minute access to care destinations in an empirical case study of Hamilton, Ontario, typical mid-sized Canadian city. More concretely, the research objectives are two-fold: after a review of the 15-Minute City concept and associated measurement tools, this work first introduces the Mobility of Care conceptualisation to re-imagine local amenities importance within the 15-Minute City concept, and second to apply a data-driven classification and clustering machine learning methodology to support the bottom-up examination of *15-minute caring neighbourhoods* through an empirical examination of Hamilton.

# Review of neighbourhood planning literature

## From the 15-Minute City to the NUC

In the last decades, the need for more sustainable, healthier, and liveable cities have received more attention. Planners and decision-makers have proposed alternatives to mobility-based neighbourhood planning to one 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). In Moreno et al. (2021) where the 15-Minute City concept was introduced, four universal dimensions are outlined: density (in terms of people per km), diversity (including mixed-land use and diversity of people), the temporal and spatial proximity to essential services, and digitalisation. The framework presented has been critised within academic and planning circles (Guzman, Oviedo, and Cantillo-Garcia 2024). Namely, critiques have centered on the concept’s inadequecy in addressing pre-existing structural forces and individual charctertes that drive inequalities in who does and who could benefit more from such a paradigm (Di Marino et al. 2023; Willberg, Fink, and Toivonen 2023). A 15-Minute City for all people is a utopic ideal, however how will existing inequalities in how people move through and benefit from the city be addressed. *Who is in the most need of the 15-Minute City before we all get there?*. Without directed answers to these context-sensitive questions makes this increasingly popular concept susceptible to becoming a place-branding slogan (Pozoukidou and Chatziyiannaki 2021).

Reflecting this flexible framework; cities that have adopted 15-Minute City concepts have done so using a diverse range of definitions and tools along with similar indistinct universal approaches. An early adopter was Portland, US in the Portland Plan (Portland 2010) of April 2012. It aims to foster an inclusive city development based on prosperity, education, health, and equity for a 30 year horizon. It promotes neighbourhood self-suffiency 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 (Government 2017); similarly adopting an “all populations” approach. Later, other cities also adopted proximity-based goals into their plans, taking similar neutral entity approaches. For instance, in the plan that later catapulted the 15-Minute City into public discourse: Paris mayor Anne Hidalgo proposed a 15-minute city plan in her 2020 re-election campaign that foregrounded six social functions of the city that should be easily accessible from any location, namely: housing, work, health care, groceries, education and leisure (Paris 2022). These ideas 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). From the review of worldwide practice literature in Teixeira et al. (2024), overall 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: the 15-Minute City seems nice but *how do we get there and whom will benefit*?

The past can shed light on cautionary tales. While the 15-Minute City concept 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, Ham, and Donnelly 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 sufficent 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). From the NUC’s conception until the end of the 1960s, planner’s attempts to prescribe social meaning to the neighbourhood’s physical form had been criticized to near extinction (Talen 2017). By social scientists, the overestimation on the impact of built environment on social life was critiqued. By other planners, the inability to agree on the specificity of the neighbourhood (i.e., population sized, and the type, quality, and quantity of amenity) as well as how neighbourhood units are connected to other neighbourhoods and the rest of the region. In response to these criticisms, neighbourhood planning proponents have redefined deterministic terminology: prescribed physical forms as ‘enabling’ rather than engendering, and the provision of social contact ‘opportunities’ instead of determined social behaviour. The re-defined bottom-up approach to community and neighbourhood planning has been adopted by New Urbanist from which the 15-Minute City stems (Kissfazekas 2022). But with *what bottom-up processes?*; small scale experiments are being tested () with preliminary small-scacle results. These processes are only in early stages so critiques of social scientists and planners from decades past still persist.

*How can physical form be planned to enable an improved quality of life, and for whom?* has also occupied urban planning research in recent years, exploring what are the impacts of built environment on residence’s outcomes. For instance, the examination of low-income households access to transportation and their likelihood of gaining employment (Blumenberg and Pierce 2017; Bastiaanssen, Johnson, and Lucas 2022) or the relationship between children’s access to public transit and participation in after-school activities (Palm and Farber 2020). Relatedly, a new wave of researchers and practitioners focused on local and context-specific relationships in 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 critisms, and recent proximity-based examinations, the question of *how to enable improved quality of life through urban built environment* has shown to be highly context-senstive with the need for further investigation.

## Tools: accessibility methods, diversity measures and typology-classification

In examining how to enable improved quality of life through urban built environment, an increasingly popular tool have been accessibility measures. They 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; S. Handy 2020). As the 15-Minute City is an amenity-provision neighbourhood planning concept which aims to enable urban environment that improves life quality, its analysis lends well to the use of accessibility tools (Guzman, Oviedo, and Cantillo-Garcia 2024). Foreseeably, recent works have applied accessibility measures to investigate the 15-Minute City across various geographic scopes. For instance, in Naples, Italy (Gaglione et al. 2022), Barcelona, Spain (Graells-Garrido et al. 2021), Vancouver, Canada (Hosford, Beairsto, and Winters 2022), and in urban areas across Europe (Vale and Lopes 2023). The “cumulative opportunity” measure has been applied to many 15-Minute City accessibility examinations. This form of accessibility quantifies how many destinations can be reached from a point in space within a given travel time threshold, pairing well with examinations that have a normative travel time threshold, like the 15-Minute City. Furthermore, the cumulative opportunity measure is widely appreciated for its intuitive computation and is popular among practitioners (S. Handy 2020; S. L. Handy and Niemeier 1997; L. Cheng et al. 2019). However, reflecting the diversity of the accessibility literature, accessibility measures other than the cumulative opportunity have also been applied (Guzman, Oviedo, and Cantillo-Garcia 2024).

Another method which compliments the assessment of the 15-Minute City as it relates to the diversity of opportunity types, is entropy. The entropy measure has been widely used to characterise the diversity of land-use mix in early work by Frank et al. (2005) based on the species diversity Shannon-Wiener index that expresses relative evenness throughout a sequence (this measure among other species diversity indices of the time are reviewed in Whittaker (1972)). It has also been used in social sciences to comprehend the occurrence of social events in a structured manner specially with regard to life trajectories (Ritschard and Studer 2018).In the realm of urban studies and planning literature the malleable concept of entropy has been used to characterise the diversity in land-use mix (Ewing and Cervero 2010), especially in the context of active modes (Lu, Xiao, and Ye 2017; Mavoa et al. 2018) and suburban sprawl (Randall and Baetz 2015). As well, it has been used to understand mobility behaviour (McBride, Davis, and Goulias 2020; Montero, Mejı́a-Dorantes, and Barceló 2023a, 2023b). Work that has used diversity indices alongside accessibility analysis are scarce, though examples of its use as parameters within accessibility scores in the case of employment opportunities (J. Cheng and Bertolini 2013; Dai et al. 2018) and more recently to describe the diversity in transit facilities (Yin, Zheng, and Li 2024) are present. To the authors knowledge, the use of an entropy measure to reflect the diversity in care destination amenity types and in context within a 15-minute neighbourhood, has yet to be done. However, entropy measures thematically compliments the 15-Minute City.

. In addition, a useful tool has been classification algorithms in the identification of spatial typologies and in profiling who may reside there. Those too have K means… Hierarchical… and SOM (Delmelle 2017)… regionlization techniques such as spatially constrained multivariate clustering (Burke et al. 2022) Use of tree diagrams! ….SOM is a type of artificial neural network (ANN) trained using unsupervised learning that produces a two-dimensional representation of the input space. It applies competitive learning by way of a neighbourhood function thereby preserving the topological properties of the input space and producing combinations of the input space that we can then intuitively profile. It has been used widely in XX but scarcely in transportation related research (Victoriano, Paez, and Carrasco 2020)

All-in-all, within the context of examining the 15-Minute City there has been a wide range of tools applied in the literature that appear appriorpiate. However, the question of *15-minute cities for whom* requires further examination. In this way, this work connects the 15-Minute City to another normative conceptualisation: Mobility of Care.

## Mobility of Care and feminist 15-minute neighbourhoods

As the 15-Minute City is in early stages of conceptualisation; an alternative way to conceive of *what* urban functions matter could be through a feminist lens. Instead of focusing on *all* destinations, it may be useful to examine destinations involved in caring activities. Caring activities meet the physical, psychological, and emotional needs of others, and are one of the most essential and fundamental activities in society (ILO 2018). Yet, they are the most unequal, undervalued, and even devalued activities worldwide. Traditionally, caring activities have been borne on women’s shoulders (Hayden 1982; Hochschild and Machung 2012). According to ILO (2018), women and girls perform more than three-quarters of the total amount of unpaid care, a gender gap that varies geographically (Ferrant, Pesando, and Nowacka 2014). This unequal share of caring responsibilities leads to multifaceted gendered differences: in career development, profession selection, contract type, pay gap, and time poverty, as recognized by various international organisations (EIGE 2016; ILO 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, Fournier, and El-Geneidy 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 decades of research had examined these unique household-serving trips, 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 adoption of the Mobility of Care concept within the 15-Minute City also explicitly incorporates equity considerations. Perhaps unsurprisingly given the gendered division of care work discussed above, 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 was significant, it was found to be far greater in lower income households where women complete 20% more care trips than men (Ravensbergen, Fournier, and El-Geneidy 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). Transport surveys and tools 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). Given the impact of caring activities on everyday life, the chrono-urbanism should specifically target the analysis of caring activities.

Mobility of Care also explicitly prioritizes shorter-distance and local trips, those that could be done by sustainable modes if sufficently supported, making the perspective highly compatible with the 15-Minute City paradigm.Compared to the trip to work, mobility of care trips are more frequently completed by foot, and less frequently done by transit or bicycle (Ravensbergen, Fournier, and El-Geneidy 2023). Further, evidence suggests that walking is more common for care than for work trips because care trips tend to be short (Ravensbergen, Fournier, and El-Geneidy 2023); if care destinations are closer to the home, it is more likely that these destinations are walkable. Ample literature examines the benefits and barriers to walking 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, Séguin, and Apparicio 2016)). However, little of this work uses the mobility of care framework. Instead, they tend to consider singular care destinations in research focusing on walkability.Furthermore, mobility of care trip characteristics differ from other trips, notably those of the commute to work. For instance, many of these trips are made through trip-chains, i.e., when a non-work-related stop is made during the commute. Women have been found to do so more than men, which is understood as being due to their need to balance unpaid-household serving care and paid employment (e.g., picking up groceries or children on the way home from work) (Ravensbergen, Fournier, and El-Geneidy 2023; Scheiner and Holz-Rau 2015).

Taken together, city planning is moving to a people-centered approach focusing on accessibility to basic needs. However, the 15-Minute City has faced criticism as it fails to provide sufficient guidance on how to reach the utopic goal of 15-Minute for all. We argue, that significance in what destinations matter within the 15-Minute City could be gained by adopting a Mobility of Care perspective. We develop this approach using a mid-size typical Canadian city of Hamilton and a novel care destination dataset as case study. The objectives of the paper are as follows:

1. To examine the potential accessibility to, and diversity of, care destinations in the case study. We identify to what degree are neighbourhoods caring and/or complete. To do so, we make use of machine learning techniques namely self organizing maps (SOM) as a data-dimensionality reduction technique and decision trips for the purpose of classification.
2. We then apply the same SOM methodology to determine profiles of population groups to understand who enjoys these neighbourhoods and who does not.

# Data

## Case study context

This study 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, approximately ~140,000 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](#fig-Fig1).

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| 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 2023b) and the USGS (USGS 2010). |

Hamilton also exhibits spatial disparities in social and economic indicators; their spatial distribution is visualised in [Figure 2](#fig-Fig2). 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). The suburban parts of the city tend to have a greater proportion of children and a lower proportion of one parent households.

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| 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 2023b) and the USGS (USGS 2010). |

## Care destination dataset

A spatial dataset of care destinations for Hamilton was carefully compiled. This includes 14 types of destinations that were placed by authors in ( *work removed for double-blind review* ) 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). Category sources of data and preparation notes are detailed in [Table 1](#tbl-Tbl1). The spatial distribution of destination type are visualised in [Figure 3](#fig-Fig3) by their category.

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| Table 1: Details on the preparation and data sources of care destinations.   | Care category | Sources | Data preparation notes | | --- | --- | --- | | Depedent-centric | (Hamilton 2022a, 2023, 2022c, 2022d; Ontario 2023b; Ontario GeoHub 2023) | Schools, daycares, and community centres, recreation centres, parks, senior centres, long-term care homes, and retirement homes: 1,265 locations are included. After manual review, all locations that typically do not serve children were removed including: Post-Secondary, Adult-Learning Centres, Group Homes, and Foster Care Centres. Further, through examination some Section 23 institutions defined as *“centres for children who cannot attend school to meet the needs of care or treatment, and rehabilitation”* (Ontario 2023a), were kept due to their innate connection to care. | | Grocery-centric | (Axle Data 2023) | Grocery stores, namely a place a household could buy groceries ranging from convenience stores to large retail stores: 381 destinations are identified. Data is filtered by Company Name, Suite Number, Address, City, Province, Phone Number and Postal Code. The type was then identified e.g., grocers specialty foods, grocers retail, grocer health food, grocer wholesale, grocer curbside, grocer delicatessen wholesale, grocer convenience. Data was cross-referenced to ensure all included locations were operational and legitimate grocery stores. | | Health-centric | (Ontario GeoHub 2023; HNHB Healthline 2023) | Hospitals, pharmacies, clinics, and dentist offices: 421 destinations are identified. Hospitals and pharmacies were retrieved while clinics and dentistry clinics were manually scraped from a healthcare services database and checked via Google Maps to remove non-operational locations and confirm dentistry-orientation. | | Errand-centric | Hamilton libraries (Hamilton 2022b), post office locations (Axle Data 2023; Canada Post 2023), and datasets of all national bank chains (BMO 2023; HSBC 2023; National Bank 2023; RBC 2023; Scotiabank 2023; TD Bank 2023). | Libraries, post offices, and banks: 158 destinations are identified. Post offices are retrieved from a mix of databases, and duplicates are removed. Banks are also derived from Data Axle and then cross-referenced to ensure data quality with a Bank Locator website for all national banking firms. | |

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| 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 2023b) and the USGS (USGS 2010). |

## Travel time to care estimations

Summarized in the literature review, empirical travel behaviour to care-oriented destinations is often uncounted and thus travel time is unavailable. Hence in this work, travel time from the residential parcel locations and care destination locations is approximated for walking assuming an average speed (3.6 km/hr) using the ‘travel\_time\_matrix()’ function from the {r5r} package (Pereira et al. 2021). The inputs into the function are: the 143,882 locations of residential parcels as origins, the 2,225 care locations as destinations, and a OpenStreetMap road network including walking infrastructure (Geofabrik 2023). In theme with what destinations can be reached within 15-Minutes, a maximum walking travel time of 15 minutes is selected, 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.

# Methods

In the following sections, the methods taken to calculate the accessibility to each of the 14 destination types from each of the 143,882 residential parcel locations are detailed. Then, the entropy measures used to calculate the diversity of accessibility to each of the care categories is described. Subsequently, the accessibility and diversity of accessibility values associated with each residential parcel location are then fed into a self-organizing map (SOM) data-reduction algorithm. How the resulting output is classified into 9 classifications using decision-trees that represent the amount of “caring access” and “completeness” of this access are then described. 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, as well as in who may be residing in areas that benefit the most.

## Accessibility: the cumulative opportunity measure

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

Where:

* is a set of parcel point origin locations.
* is a set of care destination locations of type .
* is a number of opportunities of category type at .
* is the travel cost between and .
* is an impedance function of ; within the cumulative opportunity approach, it is a binary function that takes the value of 1 if is less than a selected value (S. L. Handy and Niemeier 1997).
* is the cumulative opportunity accessibility score, the sum of weighted opportunities reachable within , at each for each .

## Diversity in opportunity accessibility: the entropy measure

To represent the diversity of care destination accessibility, the entropy measure is used. A value is calculated for each parcel that ranges between 0 to 1, where 1 represents total evenness in the number of care opportunities in each category that can be reached.

The mathematical formulation of takes the following form:

Where:

* is a set of parcel point origin locations.
* is a set of care destination types (e.g., school, grocery, park, etc.)
* is the count of care destination types . In this work, this value is 14.
* is the cumulative opportunity accessibility score, the sum of weighted opportunities reachable within a 15-minute walk from .
* is the diversity score. As represents evenness in type of categories, so if a parcel has a access score of =0.5 for all types of destinations it will be assigned = 1 in the same was as if it had a score of =10 for each type of destination. Contrariwise, a parcel can be assigned a low score if it has low but different accessibility scores for each category as well as if it has high but different scores for each category.

## Machine learning classification: self-organizing maps and decision trees

In this work, we use two machine learning techniques. First, SOM is an unsupervised technique implemented to reduce the data dimensional and create interpretable clusters related to the intensity and completeness of caring access. Then, a decision tree is deployed to further examine the cluster membership of parcels and another decision tree is run to characterise the socio-economic profile of who resides in neighbourhoods associated with certain (in)complete and (un)caring accessibility clusters. Together, this combined approach leverages the unsupervised data-driven classification power of the SOM with the interpretablity of decision trees. The procedure deployed in this work closes resembles the work of Victoriano, Paez, and Carrasco (2020), however instead of each observation representing an individual’s daily mobility behaviour (with associated variables) each observation is a parcel location with calculated care accessibility and diversity of type of care accessibility scores.

For the SOM step, the SOM algorithm implementation in the function ‘trainSOM()’ from {SOMbrero} R package is used (Villa-Vialaneix 2017). The input variables include the 143,882 parcels, each as individual observations along with 15 variables: the 14 calculated accessibility scores $S\_i^$, normalized to the min-max range score within each , and one diversity value . 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 gride) 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 (in our case 100 nodes) as specified by the analyst, where each node will represent 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 is calculated using Euclidean distance. The node with the smallest distance (i.e., the smallest dissimilarity) is crowned 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, Paez, and Carrasco 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 available from the most recent Canadian Census related to the mobility of care literature are used as *features*. This step is used to profile the superclusters in a data-drive way to explore who may reside in what supercluster. To estimate the decision tree, the ‘rpart()’ function in the {rpart} package assuming default parameters for classification splitting along with each value being weighted by the population present in the associated DA (Therneau and Atkinson 2023). As a summary of the decision tree algorithm, it 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 lowest amount of mixing of label membership in a branch). This process is recursively repeated for each subset of data for the next best features. Ultimately, the data is classified into distinct classes with class membership explained by traversing the branches defined by features that characterise the partitions in the decision tree. Noteably, the absence of features from the decision tree does not necessarily mean they are not relevant for classification, they are just 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, Paez, and Carrasco 2020).

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