I Spy the 15-Minute City: What Local Travel Behaviour and Land Use Say About the 15-30-Minute City in Montreal, Canada

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ABSTRACT
In the past three years the 15-minute city planning concept has captured the attention of policy makers and the public worldwide. Some regions have included it in their planning goals and others modified it to 30 minutes to make it more attainable in their local context. The goal of this research is to measure whether the 15- or 30-minute city goals are attainable in the North American context using Montreal, Canada as the case study. Our bivariate analysis finds very few destinations in Montreal where a high number of trips and high percentage of trips are ending using a sustainable mode of transport and below the 15- or 30-minute travel time threshold. We further investigate the land use patterns that align with the 15- and 30-minute city to recommend realistic planning goals and policy interventions that match the North American context and are sensible to income inequality. The findings from this research can be of interest to transport professionals and policy makers trying to implement the 15- or 30- minute city concepts to their regions.

Keywords: 15-Minute-City, 30-Minute-City, Travel Behaviour, Land Use

INTRODUCTION

The 15-minute city is a popular planning concept that has captured the attention of policy makers and the general public worldwide (TED Conferences, 2021). It's core definition—that everyone can meet all their daily needs within 15 minutes by active travel (cycling and walking) from their home—is an easy-to-understand framework that offers an attractive vision for what cities could become (TED Conferences, 2021). For city leaders around the world looking to combat chronic traffic congestion and overcome urban challenges magnified by the COVID-19 pandemic, the 15-minute city appears to represent a promising path forward. Unlike traditional vehicle-oriented transport planning strategies, this approach prioritizes sustainable and accessible local travel. With an emphasis on walking and cycling, efficiency in transport is redefined to focus on proximity to destinations rather than fast travel speeds. In 2020, Paris became the first major city to incorporate the 15-minute city into its planning policy (Municipalité de Paris, 2022). Mayors around the world have followed suit in hopes of bringing the urban conviviality promised by the 15-minute city to their own cities (Gongadze & Maassen, 2023). In parallel, there have been various efforts to apply the similar concept, with a higher travel time threshold, which is known as the 30-minute city (Levinson, 2019) where public transport is added as a mode of transport.

While the 15-minute city has resulted in a wave of enthusiasm around improving local accessibility, questions remain unanswered about how this strategy, developed in the Parisian context, could be applied in other cities (Birkenfeld et al., 2023). The concept of the 15-minute city was developed in response to increasing automobile dependency. Moreno envisioned a future for cities where all social functions including work, food, health, education, culture, and leisure are conducted within a 15-minute travel time radius using walking and cycling modes (TED Conferences, 2021). What this definition does not make explicit is what it takes to achieve such a vision. Most cities look very different compared to Paris and are characterized by unique built environments, travel patterns, and cultures. For this reason, Australian cities have been advocating for other versions of the x-minute city that align with their context (Levinson, 2019; Stanley & Stanley, 2014). In North America, the inherent separation of land uses and deeply rooted car culture makes achieving the 15-minute city particularly challenging. Residential neighborhoods are frequently placed in distinct areas away from commercial and business activity (Scott & Storper, 2015), which has cultivated regional commute patterns that lengthen travel times needed to reach desired destinations (Burd et al., 2021). It is clear that achieving any x-minute city requires a restructuring of both land use and transport systems. However, the aim of bringing all daily needs within a short walk or bicycle ride for every person in a city is a farfetched goal for many places. If the goal was softened to only strive for certain pockets of a city to achieve this lifestyle, who could afford to live there and who could not? For policy makers attracted to the 15-minute city concept, it is perhaps worth asking whether conducting all trips within a designated travel time is a helpful metric at all toward improving livability for residents.

The purpose of this study is to assess the extent to which existing land use and travel behaviour in the North American context align with the approach of 15- and 30-minute city goals. This study expands on the work of Birkenfeld et al. (2023) by exploring which destinations in Montreal, Canada are cultivating local travel patterns consistent with the 15- and 30-minute city concepts, and to identify any unique qualities of these areas. We expand Moreno's original definition of the 15-minute city to include public transit along with walking and cycling because it has been described as a 'quasi-active mode' (Ermagun & Levinson, 2017), contributing to active lifestyles (Winters et al., 2017) especially in the North American context (Crist et al., 2021; Daley et al., 2022). The 30-minute travel time threshold is assessed—expanding the definition further—to accommodate the scale of North American cities compared to their European counterparts.

Given the historic separation of land uses characteristic of North American cities, we are interested to learn what it looks like when neighborhoods begin to evolve toward more locally accessible landscapes. Findings from this study will help to clarify the baseline from which cities outside of Paris are starting from relative to the 15-or 30-minute city vision. It highlights how local accessibility at its best currently exists in a North American context and can help inform whether the 15 or 30-minute city goals are in fact helpful measures to strive for.

LITERATURE REVIEW

Despite the recent surge of interest in the x-minute city, the principles of the concept have been around for decades. Prioritizing efficient access to daily destinations and centering people and community in the development of cities matches the sentiment behind the "neighborhood unit", "human scale", and even "transit-oriented development" planning approaches of the last century (Dittmar & Poticha, 2004; Kissfazekas, 2022; Perry, 2015). What unites these strategies is their attention toward the value of people's time, energy, and collective wellbeing as resistance to the auto-oriented alienation of modern cities (Abdelfattah et al., 2022). A strong body of literature points to the positive satisfaction, mental health, and physical health outcomes of short travel distances and the use of active modes (Friman et al., 2017; Humagain & Singleton, 2020; St-Louis et al., 2014), including feelings of belonging associated with the social exposure of local travel (Alexander, 1967; te Brömmelstroet et al., 2017).

The x-minute city is the newest manifestation of local accessibility planning, responding to increased congestion and the relentless effort to travel faster and further (Moreno, 2022). To this end, it presents a paradigm shift toward higher-density, mixed-use neighborhoods that support access to essential social functions, including work, education, healthcare, commerce, and entertainment within x minutes using active modes of transport. However, efforts to bring the x-minute city to life have lacked appropriate metrics and policy direction, preventing successful implementation (Gower & Grodach, 2022).

Recent research has offered a range of strategies to operationalize the x-minute city model. Studies have investigated the optimal distribution of built environment features needed for local living (Gaglione et al., 2022) and evaluated accessibility to key destinations to measure progress toward the x-minute city goal (Caselli et al., 2022; Hosford et al., 2022). The ability to reach all daily needs within 15 or 30 minutes of active travel relies on proximity. Metrics such as Walk Score (Front Seat Management, 2014) and the multicriteria approach developed by Bartzokas-Tsiompras and Bakogiannis (2023) offer systems for gauging accessibility based on proximity to surrounding destinations. Other researchers have incorporated demographic data to highlight who is able to benefit from the most locally accessible locations based on socio-spatial inequalities (Calafiore et al., 2022; Weng et al., 2019).

While the x-minute city framework has been explored from different angles, most of these efforts have focused on travel potential, with few studies incorporating actual travel behaviour of local populations. Observed travel patterns provide valuable insights into mode choice, cultural transport norms, and where and when people move (De Witte et al., 2013; Horiuchi et al., 2023; Pucher & Renne, 2005). Additionally, the relationship between land use and travel behaviour, which is especially relevant to proximity-based planning of the x-minute city, has been well-documented (De Vos, 2015; Handy, 1992; Limtanakool et al., 2006; Maria Kockelman, 1997). An analysis of transport patterns in non-urban areas of Europe conducted by Poorthuis and Zook (2023) revealed the particular challenges that the locales faced regarding the 15-minute city concept. Centering the lived experiences and land use realities of different areas lends contextually appropriate findings about how the x-minute city concept could be extended to other areas (Poorthuis & Zook, 2023).

Given the rising enthusiasm from city leaders to pursue the x-minute city goal, surprisingly little research has leveraged travel behaviour data to test the applicability of the concept in different contexts (Birkenfeld et al., 2023). To address this gap, our study looks toward actual travel patterns and land use data to assess the relevance of the x-minute city in North America. This approach helps to identify what it would take to achieve the x-minute city for non-European urban environments and how helpful the framework is for reaching local accessibility and equity goals.

DATA AND METHODS

In this study, x-minute city activity is modeled using travel behaviour reported in the Montreal Origin-Destination (OD) survey. The survey is administered every five years by the regional public transport planning authority and our analyses draw from the 2018 edition, which is the most recently available. The data represents a 5% random sample of Montreal households, including a one-day weekday travel diary of every household member. Each observation represents one trip, with origin and destination data provided as latitude and longitude values. The survey collects sociodemographic information at the personal and household level, and a travel-based weighting factor is provided for every trip as an estimated projection of the number of trips it reflects in the region.

The OD data are used to explore the spatial distribution of 15- and 30-minute travel patterns in the Montreal region. For the purposes of this study, an x-minute trip is defined as a trip that was completed using walking, cycling, or public transit modes within the x-minute travel time threshold. First, each trip in the survey is evaluated for its compatibility with the x-minute trip definition. A spatial analysis of trip destinations is then conducted to locate areas that are particularly conducive to travel as defined by the 15- and 30-minute city concepts. Our goal is to identify and compare areas that are cultivating local travel patterns to those that are more regionally serving. Land use, household income, and population density data are analyzed to gain further insight into factors that characterize the most locally accessible areas.

Data Preparation

The survey data was first filtered to represent households that conducted all travel within the Montreal metropolitan area boundary. Trips were removed from the sample if the origin and destination locations were identical, trip details were missing, or other variables such as income were not reported. Because our analysis focuses on identifying local and regional destination hot spots, trips were removed if the trip purpose was "return home". Trips indicating modes other than walking, cycling, public transit, or driving were excluded because travel times could not be estimated accurately.

The x-minute city definition was then used to classify each survey trip as a 15-minute trip, 30-minute trip, or neither (all 15-minute trips were also labeled as 30-minute ones). To meet the definition, a trip must be completed within the given travel time threshold by walking, cycling, or public transit modes. Travel times between each origin-destination pair were produced through network routing using the r5r package in R, supported by sidewalk, bike lane, and roadway data from Open Street Map (OSM). For trips completed by walking or cycling, travel times were estimated using travel speeds of 4.5km/h and 16km/h, respectively (El-Geneidy et al., 2007; Silva et al., 2014). Public transit trips were routed through a network comprised of the OSM and General Transit Feed Specification (GTFS) data from all public transport agencies providing service in the study area. The r5r tool was used to calculate public transit travel times based on this network and the departure timestamp recorded for the given trip (Pereira et al., 2021). The OSM and GTFS files were downloaded from 2019 and public transport trips were simulated for Tuesday April 23rd, 2019. To our knowledge, no significant road network changes or public transport service adjustments occurred between the time of the survey and the date the travel time routing data was sourced. Travel times for car trips were not calculated as these trips were not completed using one of the qualifiable modes defined by the x-minute city framework and were automatically labeled as non-15- and 30-minute trips. Through the travel time calculations procedure, trips were removed from the sample if they had OSM network routing issues. The final cleaned sample totaled 146,556 trips including: 13,379 15-minute trips and 133,177 non-15-minute trips; 24,361 30-minute trips and 122,195 non-30-minute trips.

Spatial Analysis
To assess the distribution of trip destinations, a hexagonal grid was produced over the greater Montreal area to represent units of equal geographic size. Each hexagon measured about 860 meters across, or just over half a mile. This size was selected because it represents a reasonable local walking distance.

The trip destinations from the cleaned OD data were joined to the grid to count the number of trips ending in each hexagon. The travel-based weighting factors associated with the trips were used to scale each count to a region-wide travel estimate. Hexagons with fewer than 20 trip destinations from the OD survey were removed due to thin data. The number of hexagons with 20 or more sample trips totaled 1,496.

Two metrics of x-minute city behaviour were created based on this data. The first represents the number of 15- and 30-minute trips ending within the bounds of each hexagon. The second assigns a percentage based on the proportion of 15- or 30-minute trips ending in each hexagon compared to all trips ending in the hexagon. These variables provide different perspectives into measuring success toward the x-minute city goal; the former evaluating the quantity of local activity and the latter focusing on relative travel behaviour. We then combined the two metrics into a bivariate analysis to capture the interaction between them. To produce the bivariate analysis, each of the two metrics were divided into three bins. Hexagons were labeled with one out of nine categorical values based on the combination between the two sets of low, medium, and high bins (Figure 1).

Bin	**Number of x-minute trip destinations**	**Percent of x-minute trip destinations**
Low	100 - 500	5% - 15%
Medium	500 - 2,000	15% - 40%
High	2,000 +	40% +

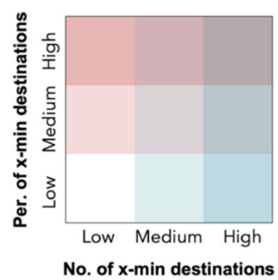

Figure 1. Bivariate variables

Land Use Analysis
With the hexagons reclassified based on magnitude and proportion of x-minute city activity, we analyzed the land use distribution across each hexagon type. Land use data were obtained from the Communauté métropolitaine de Montréal (CMM) open data portal (Montréal, 2021). The CMM data are compiled from various public data sources across the region, reflecting land use designations at the most precise geographic area available. The land use designation of each geographic unit corresponds to the primary land use assigned as identified by public records from the given year. It is possible for secondary uses or uses not mentioned in the records to be excluded from the CMM database. For this study, historical land use designations from 2018 were used to align with the 2018 OD survey data.

Analyzing land use against the 15- and 30-minute city metrics helps address our research aim of identifying characteristics of the most locally accessible areas in Montreal through the x-minute city lens. To do so, the land use data were merged with the hexagonal grid and divided by hexagon-type according to the bivariate legend (for both the 15- and 30-minute thresholds). We focused on the hexagon types represented by the four corners of the legend to capture differences among areas with the highest and lowest extents of x-minute activity. For each of the eight hexagon-types (four for each of the 15- and 30-minute analyses), the total land area dedicated to each use was summed and divided by the total land area of all hexagons in the category. The output of this analysis allowed for a look into differences in land use proportions among areas that are the most locally and regionally serving.

Census Variables

Census data was used to further investigate the socioeconomic characteristics of these areas. The cancensus package in R was used to draw household median income and population density from the 2021 Canadian Census at the census tract level (von Bergmann et al., 2021). The mean values of these variables were calculated for every cell in the hexagonal grid, weighted by the proportional land area of each census tract in the given hexagon. Household median income and population density were then grouped and averaged for each of the hexagon types defined in the bivariate legend.

RESULTS

X-Minute City Metrics

Figure 2 shows the results of the first x-minute city metric by count of trips and percentage of trips ending in each hexagon. For the number of trips ending in a hexagon (Figure 2A) a high concentration is observed in areas with frequent public transit. Hexagons shaded in the darkest blue represent areas attracting 4,000 trips per day or more in x-minutes. Trips that align with the 15-minute city definition ends in downtown Montreal, dense neighborhoods northwest of downtown, and near metro line junctions (Figure 2A). Trip distribution assessed against the 30-minute threshold follows a similar pattern and reveals more hexagons with high trip counts (Figure 2C).

The second metric, calculated as the percent of x-minute trip destinations compared to all trip destinations, points to very few areas that have high proportions of 15-minute trips (Figure 2B). The darkest red color marks areas where almost 1 out of every 2 trips ending there align with the x-minute trip definition. Downtown, which has some of the highest counts of 15-minute trips, has notably low proportions of local activity. This is to be expected since it is a major job and commercial hub that attracts travel from across the region. The mixed-use neighborhoods to the northwest and south of downtown tend to have at least 10% 15-minute city activity, with a couple hotspots reaching 40% or more. For the 30-minute threshold, consistently high proportions of qualified trips extend along and surrounding the metro lines to the northwest and south of downtown (Figure 2D). Some additional areas with 40% or more 30-minute trips arise to the north and southeast along the metro lines. For both the 15- and 30-minute analyses, local activity is concentrated around the center of the city, while surrounding suburban areas indicate very low proportions.

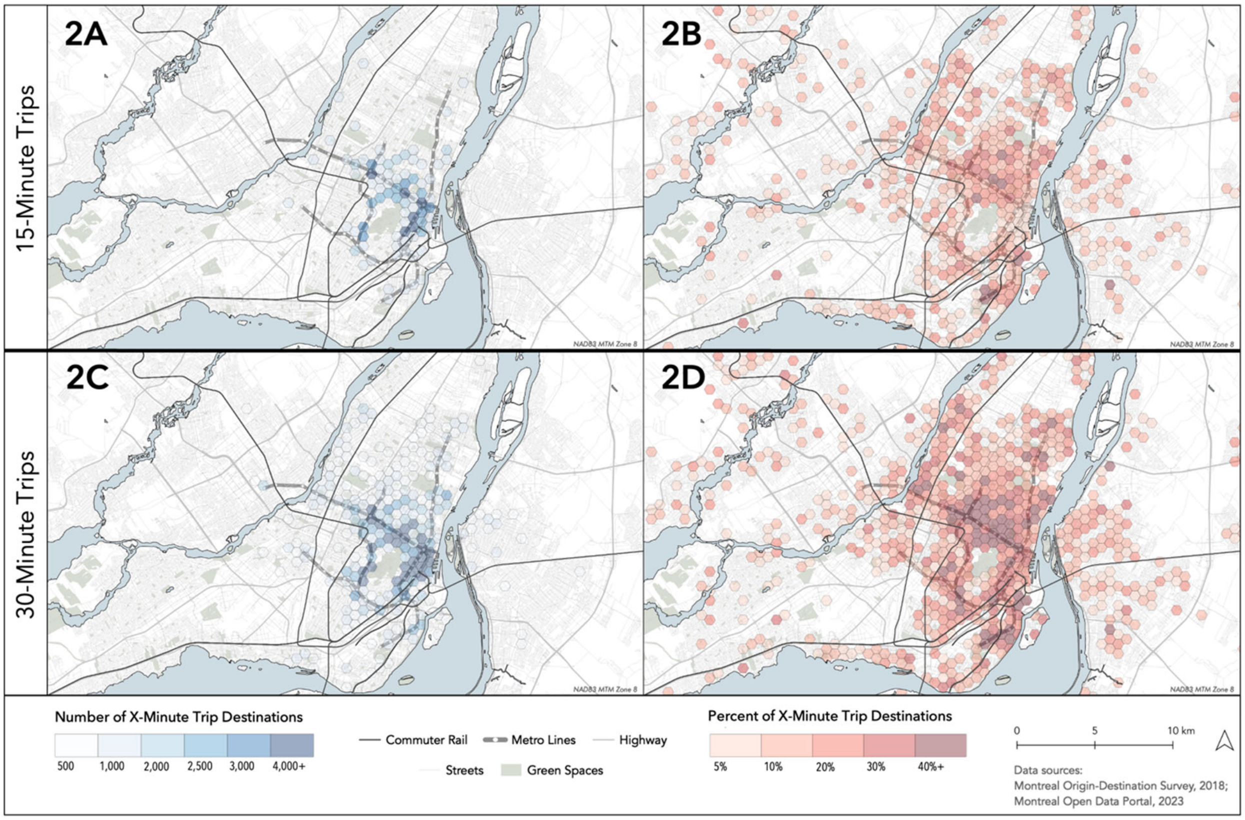

Figure 2. The number (blue) and proportion (red) of x-minute trip destinations ending in each hexagonal area, based on the 2018 Montreal Origin-Destination one-day weekday travel survey. The top two maps measure against the 15-minute threshold and the bottom two maps are based on the 30-minute threshold.

Bivariate Analysis

Combining the trip count and percentage metrics into a single variable offers a view into the interaction between density and local activity. This bivariate measure differentiates areas based on the x-minute city framework to help us understand what the 15- and 30-minute city looks like in different parts of the city. In Figure 3A (15-minute threshold) and Figure 3B (30-minute threshold), the dark purple color highlights areas that have the highest number and highest percentage of x-minute trips. Hexagons with this classification represent the densest and most locally-serving parts of Montreal. There are 3 hexagonal areas that meet the 15-minute definition of this category and 33 that meet the 30-minute one in the entire region (860 hexagons). The areas in dark red also have high proportions of x-minute trips but they have significantly lower trip counts. These areas most likely represent medium- to low-density residential neighborhoods with a few small commercial establishments that don't attract customers from far away. There are 6 of these hexagons on the 15-minute map and 12 on the 30-minute one.

Since "return to home" trips are removed from the calculations, the results of the bivariate analysis reveal how well destinations in each hexagon serve the local community. As such, even though areas marked in dark red have high proportions of x-minute city activity, the low counts of these trips indicate they are likely not accommodating a diversity of needs. On the contrary, areas marked in dark purple have both high counts and high proportions of x-minute activity, signaling that more trips are being accomplished locally. This positions areas in dark purple to be the parts of Montreal that are the most aligned with the x-minute city concept.

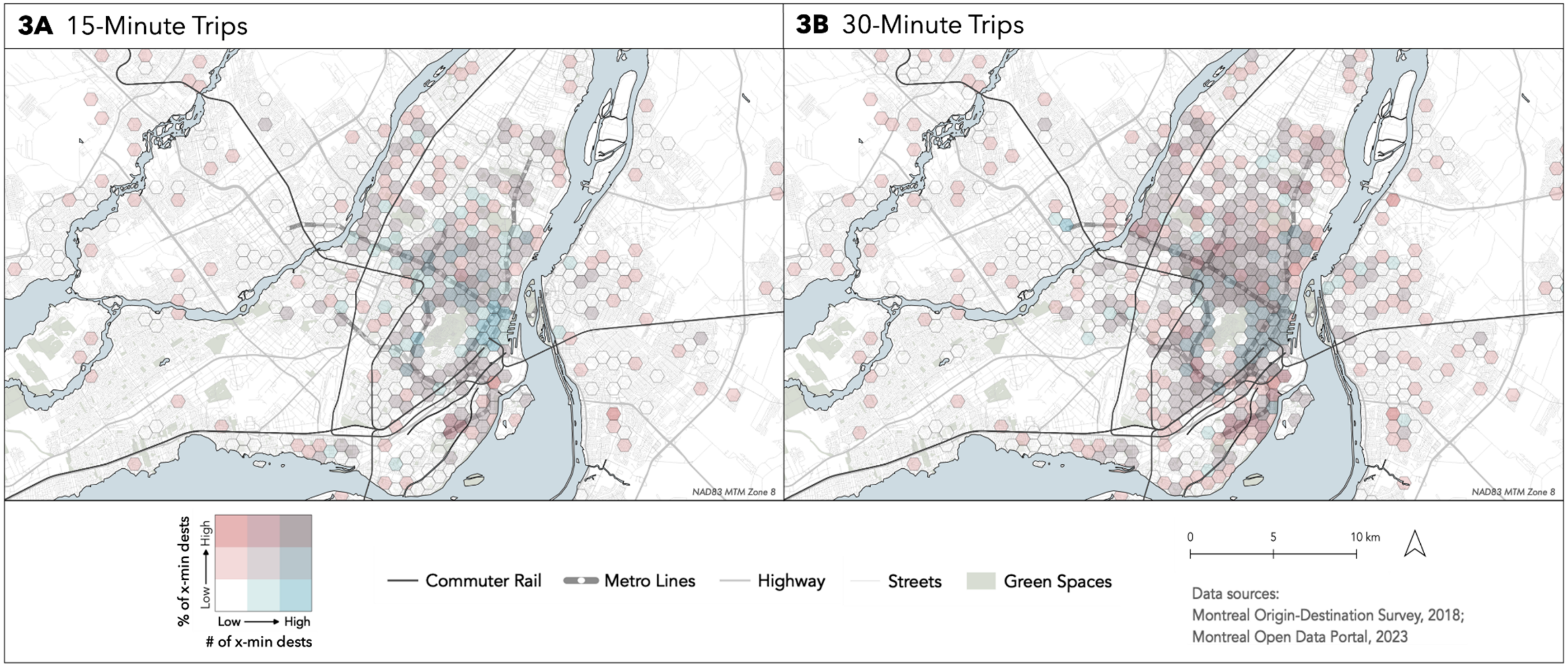

Figure 3. Bivariate analysis of 15-minute trip destinations ending in each hexagonal area.

Hexagons depicted in white are the least compatible with x-minute city concept. These areas have low numbers of x-minute trips and low proportions of them. This kind of travel behaviour is indicative of locations that attract automobile travel and trips longer than the x-minute travel time. The dark blue shaded hexagons are also characterized by low proportions of x-minute trips, but they attract a high number of them. In the 15-minute bivariate analysis, downtown Montreal is the most prominent hub of this kind of activity. It is an area that attracts travel from across the region while also offering a plethora of destinations that can be reached via a short walk, bike ride, or public transit trip from within.

In addition to the spatial visualization, it is helpful to consider the distribution of hexagonal areas across the two metrics. Figure 4 presents a two-dimensional histogram with the number of x-minute trip destinations on the x-axis and the percent of x-minute trip destinations on the y-axis. Hexagons measured against the 15-minute threshold are displayed in blue and the 30-minute threshold is depicted in red. Dotted lines are drawn to delineate the low, medium, and high bins represented in the bivariate legend. The graph indicates a high concentration of hexagonal areas that have a low number and low percent of x-minute trips, also depicted in white on the bivariate maps (Figure 3). This type of travel behaviour reflects common land use and transport patterns in many North American cities, characterized by separated land use and automobile dependency. The points that fall in the eight other sections of the graph represent parts of the city that are challenging this traditional land use and transport arrangement to support smaller scale travel. The points in the top three sections of the graph, also seen in dark reds and purple on the bivariate maps, reflect areas of the city that are cultivating travel patterns that most closely align with x-minute city goals—that is, to provide an environment where residents meet all their daily needs within x-minute travel radius using sustainable modes. However, it is worth noting that none of the hexagonal areas are anywhere close to achieving the 100% x-minute city that aligns with the original definition of the concept. Areas with the highest proportions of local travel reach between 40-50% when measured against the 15-minute threshold and approach 60% against the 30-minute threshold.

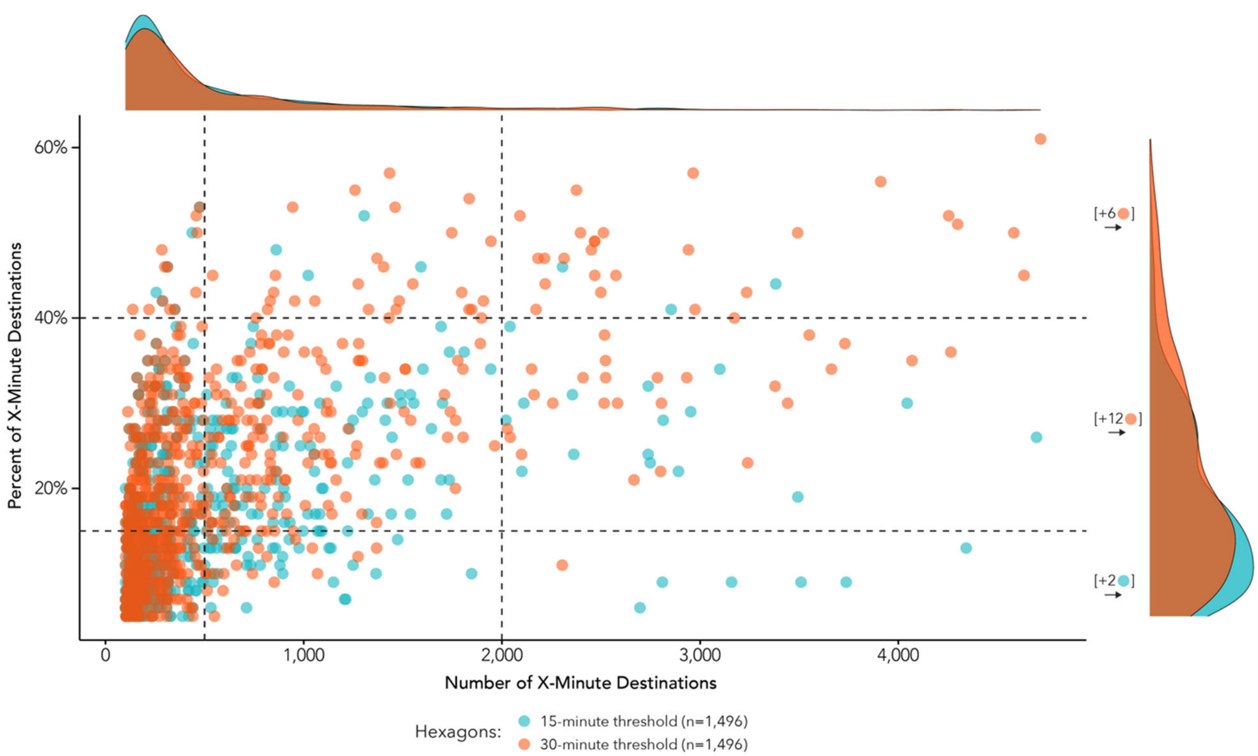

Figure 4. Two-dimensional histogram of bivariate metrics.

These patterns beg the question of whether it is feasible or even desirable to aim for the 100% x-minute city target. As cities around the world implement the x-minute city concept, it is important to consider what kind of urban environment this goal represents and how it aligns with the existing land use and transport context in diverse settings. Perhaps in Montreal, a 40% or 50% x-minute city environment represents the most achievable and ideal manifestation of local accessibility. These results point to the value of looking toward current travel behaviour to understand what the x-minute city means in different contexts and to create more locally informed x-minute city targets.

Land Use Assessment

Land use policy, which determines the spatial arrangement of people and places, has a major impact on travel behaviour and accessibility. A city's ability to plan for better local accessibility relies on strategic zoning decisions that support shorter travel distances. Using the x-minute city categories defined by the bivariate legend, land use data is assessed within each hexagonal area to understand the relationship between land use and travel patterns in Montreal. Figure 5 presents the zoning designations of hexagon samples from each of the four corners of the bivariate legend measured against the 15-minute travel time threshold.

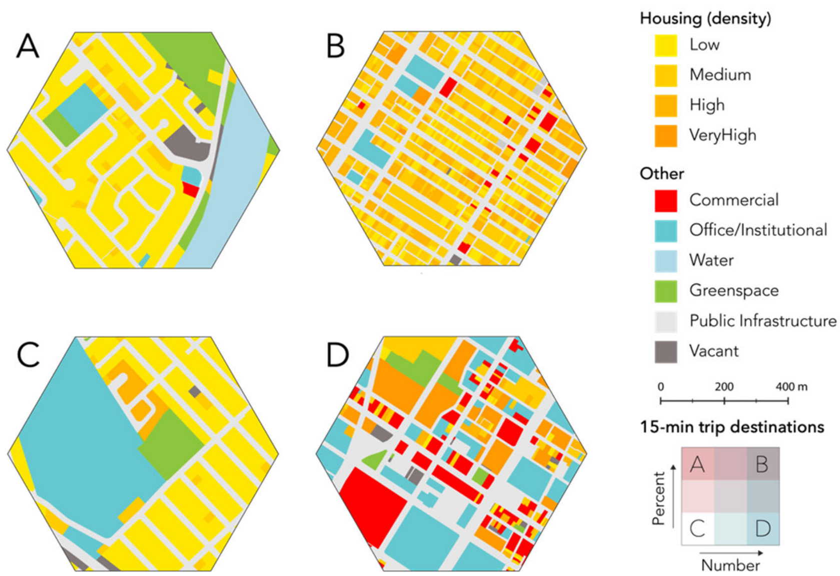

Figure 5. Zoning designations of sample hexagonal areas that correspond to the 15-minute city bivariate categories.

Zoning designation samples that align with the 30-minute city bivariate categories are displayed in Figure 6. Areas that attract high counts and percentages of x-minute trips (category B), tend to have smaller land parcels, finer grain zoning designations, and more grid-oriented street networks. Categories A and C, which have the lowest counts of x-minute trips, appear to have larger allocations of low-density housing. While all samples include some office/institutional spaces, categories C and D have particularly sizable areas designated for this use.

The total land area of all hexagons within each bivariate category were then grouped and analyzed in Figure 7. The "n=" below each graph indicates the total number of hexagonal areas that align with that category of the legend. Note that the land area percentages do not add up to 100% because some zoning designations were removed from the graphs (including public infrastructure, agriculture, golf, greenspace, water, and vacant space) for simplicity.

Figure 6. Zoning designations of sample hexagonal areas that correspond to the 30-minute city bivariate categories.

In this visualization, land use distinctions between areas that are and are not locally accessible become clear. Most notably, hexagonal areas that most closely align with x-minute city goals (category B) have proportions of medium- and high-density housing that are not observed in any other area. This pattern is consistent across both the 15- and 30-minute analyses. Category A hexagons have similarly high proportions of x-minute trips as seen in category B, however, the exceedingly high rates of low-density housing in these areas lead to lower counts of x-minute trips. Category A represents the highest degree of land use separation, with low rates of any use other than low-density housing. Although these areas cultivate local accessibility in terms of percent x-minute trips, they are unable to serve a diversity of needs and they encourage car use.

Category C demonstrates a similar emphasis on low density-housing. However, the larger proportion of land allocated toward commercial and office/institutional uses attracts more travelers who spend greater than x minutes to get there and/or commute by car. The high number of hexagons that align with category C speaks to the land use reality of separated uses and car dependency that characterizes much of Montreal. Category D hexagons have the highest proportions of very high-density housing and office/institutional. As major job and commercial hubs, these areas attract travelers from around the region while also serving the needs of residents living within.

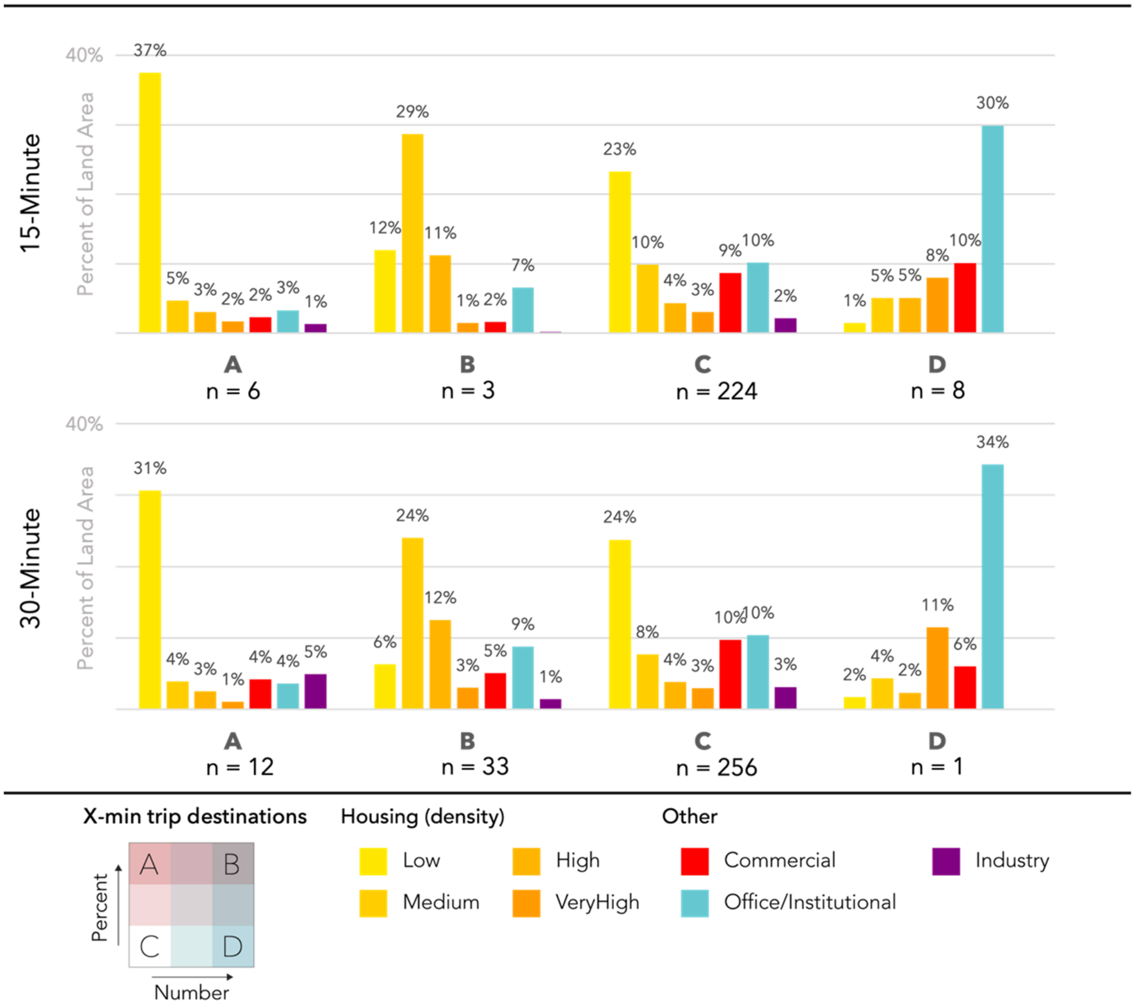

Figure 7. Land use allocations within areas corresponding to each bivariate category.

Income and Population Density

Despite having some of the lowest rates of very high-density housing, category B areas have the highest population density of all hexagon types (Figure 8). The high rates of medium- and high-density housing in category B paired with destinations and transport systems that cater to nearby residents creates some of the most densely populated and locally-serving environments in the city. Interestingly, 15-minute category B hexagons have a significantly higher median household income compared to 30-minute category B hexagons. This implies that the 15-minute city target in Montreal is more aligned with higher income lifestyles while the most accessible 30-minute areas are enjoyed by a more diverse socioeconomic population. Category A areas are home to some of the highest earning households in Montreal.

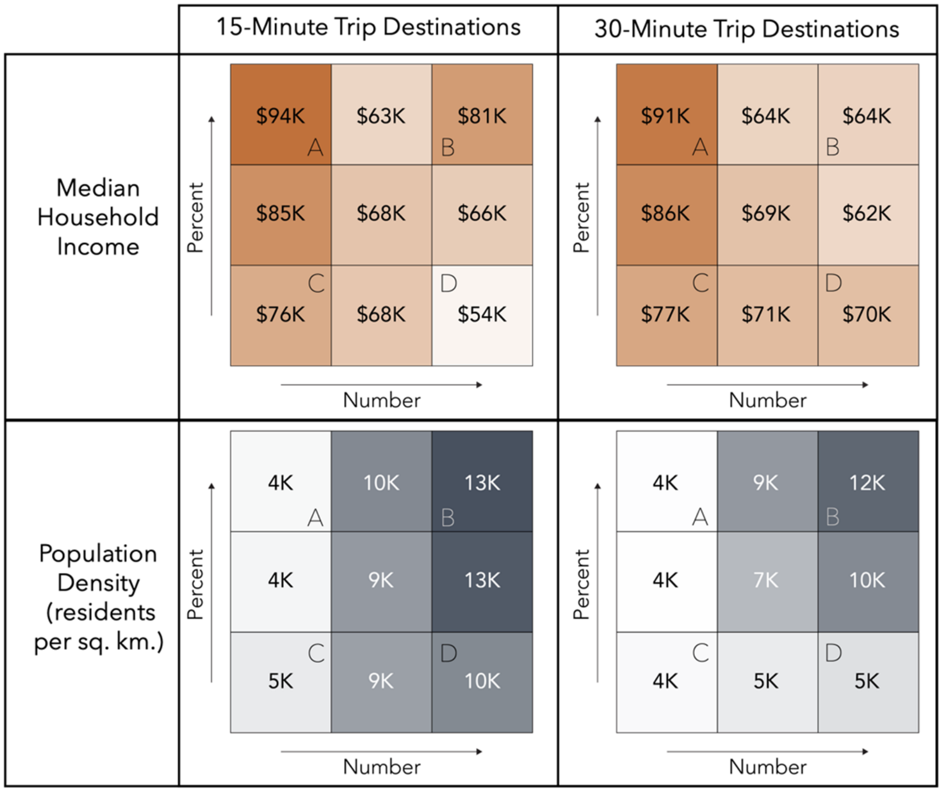

Figure 8. Average median household income and population density, by bivariate category

CONCLUSION

While the x-minute city concept offers an attractive vision for the future of cities, little is known about what it means to achieve this goal in different global settings. Our study addresses this question by analyzing observed travel behaviour and land use data to explore how the x-minute city model can be used to understand local travel patterns in the North American city of Montreal. Our aim was to identify which parts of Montreal are most conducive to x-minute city activity and determine whether this planning framework is a helpful tool to create a more locally accessible city. Findings show that very few areas of Montreal currently attract the type of trips that align with the 15- and 30-minute city. This is largely attributed to the fact that most North American cities were developed with intentionally separated land uses, which lengthen travel times. There are, however, distinct land use patterns that characterize the parts of Montreal that have the most x-minute city activity. These areas have the highest rates of medium- and high-density housing in the city.

Our findings demonstrate the importance of looking toward local travel behaviour to create contextually informed x-minute city targets. In the areas that most resemble the x-minute city in Montreal, around 40-60% of all trips ending there were completed in x minutes or less using walking, cycling, or public transit. These rates represent what the highest degree of local accessibility looks like in Montreal and could serve as a feasible goal for other areas of the city. This study expands the original definition of the 15-minute city to include public transit and assesses the larger travel time threshold of 30 minutes. The 30-minute target proves to be more economically equitable than the 15-minute one, which in Montreal is more aligned with higher income lifestyles. This study is not intended to propose the best x-minute city metrics for Montreal, but to instead challenge the idea that the original concept is universally applicable. Policy makers interested in implementing the x-minute city framework should first gain an understanding of the travel behaviour landscape in their region to learn how to cultivate local accessibility and guide x-minute city plans and metrics.

The use of OD data comes with certain limitations in our analysis. The Montreal OD survey samples a one-day weekday travel diary from respondents, meaning our analysis does not account for weekend travel nor for variability in travel over multiple days. Additionally, the analysis was limited to using modelled travel time instead of observed travel time, which may introduce bias into the results. Future research on this topic would benefit from data based on a multi-day activity-based travel diary. There are many opportunities for future research to build on the findings from this study. Using more detailed information about destination types and trip purposes would provide more insight into the specific mix of establishments that characterize the most locally accessible areas. Future work may expand the bivariate metric developed in this study to account for diversity of trip types to capture the ability of different areas to serve a range of needs. Measuring x-minute activity based on the trip origins would add further depth to the destination-based analysis presented here.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: Study conception and design: Birkenfeld & El-Geneidy; Data collection: Birkenfeld & El-Geneidy; Analysis and interpretation of results: Birkenfeld & El-Geneidy; Draft manuscript preparation: Birkenfeld & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

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