JOURNEY-TO-WORK BY PUBLIC TRANSIT: RECENT EVIDENCE FROM THE FOUR LARGEST URBAN CENTRES IN CANADA

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Introduction

Over the past six decades, intense highway development encouraged suburbanization in many Canadian cities. The suburbs were seen as the optimal location to live due to the trade-offs between commuting and housing costs. That is, the additional commuting cost from the suburbs was balanced out by the low land and housing costs (Axisia, 2009). This phenomenon is also explained by Anderson et al. (1996). According to Anderson et al. (1996), suburbanization can be categorized as the outcome of two concurrent spatial trends: 1) the increase of population and employment in urban areas, and 2) the dispersion of land use activities within these urban areas. This results in converting the form of cities from a compact to a sprawled over time which in turn give rise to increased commute times. The later has been encouraged by the ease of owning motorized vehicles across Canada.

Urban sprawl along with the wide spread of motorized vehicles downplayed the role of public transit in Canada. As such, the use of public transit in Canadian cities is less common compared to other developed countries like Europe and Japan. Obviously, the low usage of transit and high auto-dependency is no sustainable in the long run especially in larger cities. Therefore, academics, planners, community organizations among other stakeholders have been working on strategies to decrease the number of motorized trips and promote more transit usage in urban areas (Cervero & Kockelman, 1997). A major thrust of the conducted research to date have been to explore the impacts that socio-economic and demographic factors have on public transit usage (see for example Wiley et al. 2011). However, less have been done to identify if the built environment has any role to play when it comes to transit ridership.

The research conducted in this paper is concerned with transit ridership for the 2011 Journey-to-Work in the four largest Canadian metropolitan areas. The analysis is focused on evaluating the degree at which the built environment, depicted by the design of the road network, affects transit ridership while controlling for socio-economic variables. The analysis also investigates whether these factors are systematic across the four studied metropolitan. Meeting these objectives will contribute to the existing body of literature and will allow planners to better understand the relationship between urban form and transit ridership in large metropolitan areas. The statistical analysis will use the Simultaneous Auto-Regressive (SAR) modeling technique given the spatial nature of the problem in hand.

This paper consists of five sections. The next section discusses urban form and its relation to transportation, the nature of the road network and its expected effect on transit ridership, and the factors that have been used in previous studies to explain transit ridership. Section three outlines the data sources followed by a brief description of the study areas. This section is concluded by describing the modeling approach. The results from the analysis will be discussed in section four. This section is followed by a discussion of the contributions made by this research and recommendations for future research.

Background

Urban Form

Anderson et al. (1996) defined urban form as the spatial configuration of different land use activities “buildings”, which is the outcome of the land development process. In general, urban form in Canada emerged from the traditional monocentric to the more commonly sprawled or dispersed pattern that is observed in many cities nowadays. Arguably, the change in urban form can influence the nature of intraurban trips but is not the only factor that determines them (Anderson et al. 1996). Monocentric urban form belongs to the so called compact form. The latter is characterized by high density, mixed land use (apartments, commercial space and offices) and strong presence of public transportation systems (OECD, 2012, p. 31).

Historically, metropolitan areas were monocentric because their central locations represented the sole functional point for all types of social and economic activities (OECD, 2012, p. 31). However, this is not the case anymore in most urban areas. Several metropolitan areas evolved to have multiple central locations of high densities that are components of a wider spatial functional entity. As such, that gave rise to polycentricism. In a polycentric metropolitan area, the central city location is not widely dispersed but is typically linked to satellite centres via the public transportation systems (OECD, 2012, p. 32). Hence, one can conclude that a monocentric urban form is more affiliated with mixed density and walking. Whereas, a polycentric urban form is more affiliated with public transit. Both forms fall under the broader compact urban form.

By comparison, a sprawled city is typically an area with an excessive spatial growth resulting in inefficient urban structure. Inefficiency is due to the strong presence of low-density and leapfrog developments that are scattered in outer suburbs. This form portrays high level of segregation in land uses and lacks centralized planning (Nam et al. 2011; Behan et al. 2008). The segregation of land uses has been blamed to increase commuting and energy consumption due to auto dependency. The negative sentiment against urban sprawl development encouraged urban planning initiatives that have been focused on promoting compact urban form. The focus has been to promote mixed land use development and more reliance on public transportation for journey to work. OECD (2012, p.45) stresses that compact urban form can make a more sustainable usage of space in cities. For instance, it is noted that compact development plays a significant role in reducing CO_2 emissions from both the transportation and building sectors, lowering the dependency on automobiles, reducing traveled distances and fuel consumption.

Quantifying the type of urban form is an important step towards understanding the nature of travel in a given city. Tsai (2005) showed that the *Global Moran's I statistic* can be used to quantify the type of urban form based zonal population and employment. This was possible by simulating various urban form patterns and calculating the *Moran's I* value that is associated with each type. More specifically, values close to one indicate autocorrelation and clustering in space, thus represent a monocentric type of urban form. On the other hand, values close to zero indicate random scattering or a polycentric urban form. Lastly, values close to negative one represent a 'chessboard' development pattern indicating a sprawled urban form.

Transit Ridership Analysis

According to the literature, two groups of factors can influence transit ridership: 1) land use and 2) socio-demographic. On the land use side, different measures have been proposed in the literature: mixed density index (MDI) (Behan et al. 2008), entropy index (EI) (Cervero & Kockelman, 1997; Frank & Pivo, 1994) and accessibility index (Cervero et al. 1999). The MDI is an index that computes the level of mixing between population and employment density within a given geographic area. Generally, high MDI values are linked with higher job housing balances. In other words, higher level of population and employing mixing could be affiliated with shorter commuting distances and greater transit ridership (Behan et al. 2008). On the other hand, EI is a descriptive statistic that measures land use heterogeneity to determine the evenness of the distribution of land use types and is calculated to range between 0 and 1 (Cervero & Kockelman, 1997; Frank & Pivo, 1994). Potoglou and Kanaraglou (2008) noted that an EI of zero implies a single type of land use, while a unity indicates the presence of mixed land uses (i.e. heterogeneity) in the zone. Thus, the closer EI is to 1 the easier the access to active modes of transportation (namely: transit, walking, and/or biking). Gravity formulation is used to determine the accessibility of a given zone from all other zones. This will depend on the size of land use activities (employment or housing) in all the zones comprising the study area but is scaled by the amount of travel time it takes to reach the zone from all other zones (Cervero et al. 1999). Besides land use, the nature of the road network has been used as it is also expected to have an influence on public transit. For instance, Axisia (2009) introduced a categorical variable in his analysis, which equals to '1' for gridded street network and '0' for curvilinear street network in suburban Toronto. The results showed that gridded road networks are more likely to utilise transit trips. This can be due to the fact that gridded networks have more transit routes and greater efficiency leading to higher transit modal shares (Marshall & Garrick, 2010; Messenger & Ewing, 1996).

As for socio-demographic variables, the literature considered a host of factors which include: age (Axisia, 2009; Cervero, 2002; Chee & Fernandez, 2013; Patterson et al. 2005), gender (Axisia, 2009; Cervero, 2002; Chen et al. 2007, Chee & Fernandez, 2013), household size (Axisia, 2009; Sultana & Weber, 2007), income (Axisia, 2009; Cervero, 2002; Potoglou & Kanaroglou, 2008), minority (Axisia, 2009; Sultana & Weber, 2007), and population density (Axisia, 2009). The evidence from the literature suggest that senior population (older than 55 years old) are more likely to use public transport in daily travel, and males tend to travel longer than females. Therefore, females are less likely to use public transit. Large households are seen to have a negative impact on public transit as they are more likely to own at least one car. Similarly, people with high income are more likely to own a vehicle and thus are less likely to patronize public transit. As for the visible minorities, it was concluded that they are more likely to use public transit since they usually travel less distance to work. Finally, population density was found to have a positive effect on transit ridership.

Modeling Approach

Study Areas

This paper considers the four largest Census Metropolitan Areas (CMAs) in Canada; Toronto, Montreal, Vancouver, and Ottawa. Toronto is the provincial capital of Ontario, Canada and is located in Southern Ontario on the northwest shore of Lake Ontario. According to the 2011 Canadian Census, Toronto had a population of 5,583,064 living in 2,079,459 dwellings. Also, the regional district has a land area of 5,905.71 km^2 and a population density of 945.40/km^2. Montreal is the second largest metropolitan area in Canada and is located in Southwest Quebec about 542 km away from Toronto. In 2011, Montreal had a population of 3,824,221 living in 1,696,210 dwellings. Also, the regional district has a land area of 4,258.31 km^2 and a population density of 898.10/km^2 (Statistics Canada, 2011). Ottawa is the capital city of Canada and the 4th largest CMA across the country. It occupies the eastern portion of Southern Ontario, and housed 1,236,324 people who lived in 526,627 dwellings according to the 2011 Census. Also, the regional district has a land area of 6,287.03 km^2 and a population density of 196.60/km^2. Finally, Vancouver, which is the 3rd largest CMA of Canada, occupies the Southwest corner of British Columbia and in 2011 it had a population of 2,313,328 living in 949,565 dwellings. Also, the regional district has a land area of 2,882.55 km^2 and a population density of 802.5/km^2 (Statistics Canada, 2011).

In terms of public transit market share, the four CMAs rank as the top four in the country. Toronto is in the lead with a transit share of 23% for work trips in 2011. This is followed by Montreal with a share of 22%, and then both Ottawa and Vancouver with transit mode shares of 20% each (Statistics Canada, 2011). Figure 1 summarizes the mode split shares for work trips for the study areas and Canada. Compared to the nationwide mode distributions, auto drive and public transit mode shares decrease and increase by 6% respectively in the study areas. Figure 2 presents the spatial distribution of transit trip production in the four study areas. It is obvious that these trips are mostly concentrated in the core and surrounding areas.

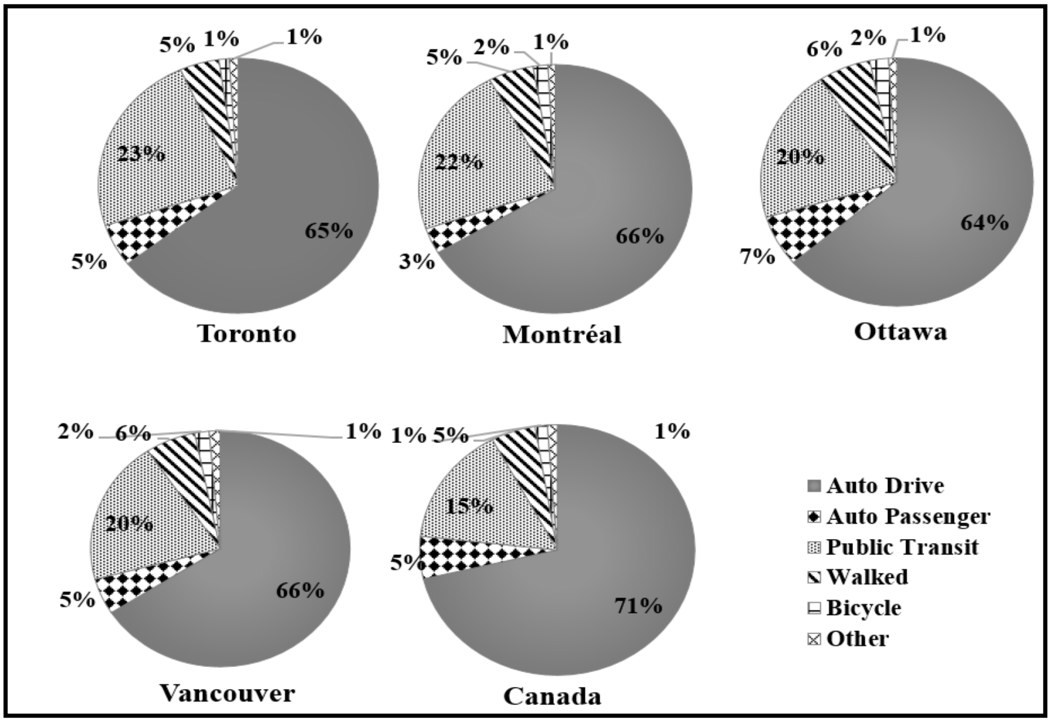

Figure 1. Share of travel modes for journey-to-work in 2011

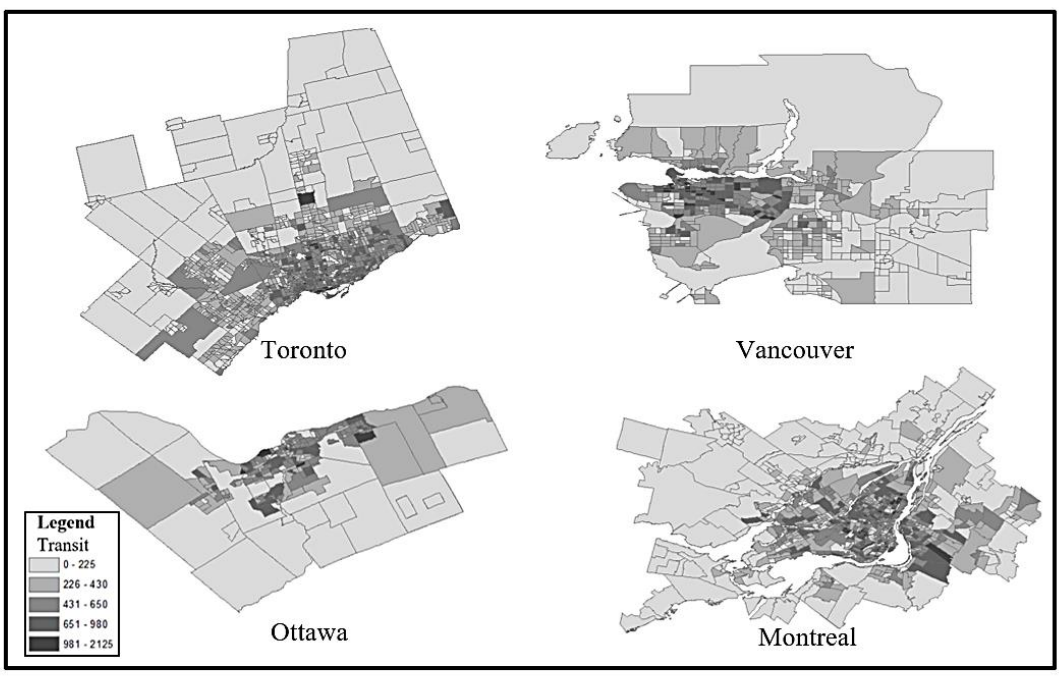

Figure 2. Spatial distribution of transit trip productions in 2011

Data

Several databases were merged in order to carry put the analysis. 2011 shapefiles for the four study areas were obtained from DMTI Spatial and used as the basis of the analysis. Also, socio-economic characteristics from Statistics Canada were obtained. These files were joined using ArcMap 10.1 Geographic Information System (GIS). In addition, a number of variables were created using the joined shapefiles such as population density. Finally, CanMap Route Logistics 2011 was acquired from DMTI to help quantify the nature of the road network (i.e. gridded vs. curvilinear) in each census tract.

Model Formulation

Table 1 lists the variables used in the analysis. These variables were inspired by the information found in the literature on the factors affecting transit ridership in urban areas. Starting with socio-economic variables, older people are expected to use the transit system more than other population groups. Therefore, we use the Pop55+ to represent this group of people in our modeling work. Households with five or more family members are expected to have a negative impact on public transit. The reason is that these households are more likely to live in suburban areas and own more than one car. Hence, they are more likely to drive to work. On the contrary, minorities usually travel less distance to work and are more likely to have a positive effect on transit as they are more prone to live in central locations that are usually accessible by transit. This group includes low income population and immigrants who are recent movers to Canada. Population density (population per km^2) is expected to have a positive impact on transit ridership since the higher the population in an area, the more likely it is to use public transportation.

Table 1. List of variables used analysis

Variable	Description	Expectation
Pop55+	The population of 55 years or older in a census tract	+
Family 5+	The number of families with 5 or more people living in the household in a census tract	-
Minority	The percentage of the minorities in the total population per census tract	+
PD	The population density per kilometer squared per census tract	+
*EI**	The entropy index calculated per census tract: $EI = -(1/L) \sum_c (p_c \ln(p_c))$	+
*MDI***	The mixed density index calculated per census tract: $MDI = (PD \times ED) / (PD + ED)$	+
Net. Design	1 if the road network in gridded in the census tract; 0 otherwise	+
Outlier	1 if observation on transit ridership pertains to a residual greater than 500; 0 otherwise	N/A

* L is total number of land use classes in the census tract; p_c is proportion of land use type c in the tract
** *PD* = Population Density; *ED* = Employment Density

With regards to land use variables, the entropy index "*EI*" is used as it is expected to have a positive influence on transit. That is, higher entropy values (i.e. closer to 1) suggest the presence of mixed land uses, which in turn is associated with easier access to public transit. Meanwhile, the mixed density index "MDI" is also expected to have positive effect since the higher the MDI value, the higher the level of population and shorter commuting distances making transit more appealing to travelers. As discussed in the background section, gridded road networks are more likely to be associated with presence of transit service. Hence, areas with dominance of gridded networks (as oppose to curvilinear) are more likely to increase transit usage. An example of the gridded and curvilinear network designs for the CMA of Toronto is shown in Figure 3. Finally, the *"Outlier"* variable is used to account for outliers since certain census tracts are expected to have disproportional higher and lower transit trips when compared to the majority of the zones producing transit trips.

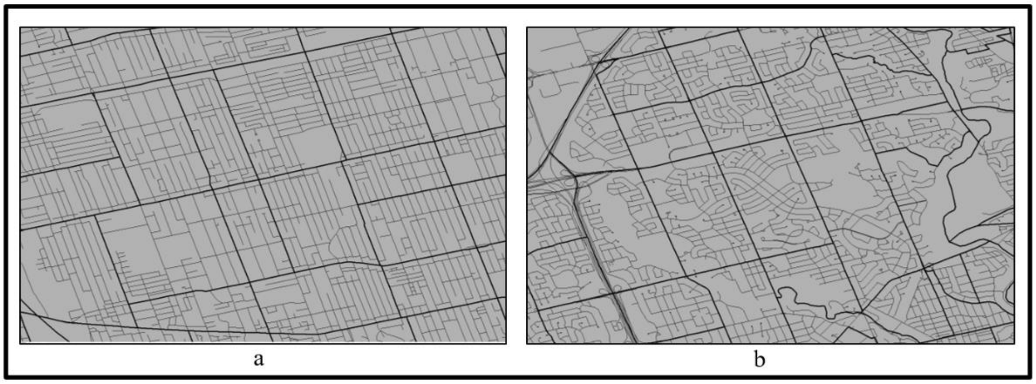

Figure 3. Road network designs within Toronto CMA: (a) Gridded and (b) Curvilinear

While the majority of studies modeling trip generation use the ordinary least square (OLS) multivariate regression, we opted for a Simultaneous Auto-Regression (SAR) model. This was necessary to account for the presence of spatial autocorrelation in the modeled trips. The SAR model used in the analysis takes the following form:

$$T = \beta_O + \sum_{k=1}^{N} \beta_k X_k + \sum_{k=1}^{N} \rho W(T - \beta X_k) + \varepsilon$$

where T is the dependent variable representing number of transit work trips origination from a given census tract in a specific metropolitan area. β_O is the constant parameters while β_k is the beta coefficient pertaining to variable X_k, N is the total number of variables, and ε is the error term capturing unknown random variables. Also, ρ is a spatial lag parameter that account for the presence of spatial autocorrelation while W is a weight matrix representing the spatial affinity between the census tracts. In the estimated models, a first order rook structure was used to design matrix *W*.

Results and Discussion

The urban form of the four Canadian urban centers was explored and quantified following the approach presented in Tsai (2005). *Moran's I* statistic for population and employment densities was calculated using the GeoDa spatial analysis software and the results are presented in Table 2. Toronto has the lowest value for *Moran's I* for population density and the second lowest for employment density. These results indicate that Toronto's urban form is somewhat discontinuous and multinucleated. Thus, it can be classified as a polycentric metropolitan area. Ottawa has similar results to Toronto. On the other hand, Vancouver has the highest value of *Moran's I* for population density and the second highest for employment density. As a result, this CMA exhibits a compact multinucleated urban form. In the same fashion, Montreal can also be considered to have a compact multinucleated urban form.

Table 2. Moran's I Statistic for population and employment densities

Variable	Toronto	Vancouver	Montreal	Ottawa
Population	0.4325	0.6198	0.5720	0.5048
Employment	0.4647	0.5411	0.5904	0.4006

Note: All variables are significant at the 99.9% level based on 999 random permutation

The SAR estimation results concur that spatial autocorrelation effects are highly significant among the generated transit work trips as the spatial lag parameter (*ρ*) is positive and highly significant in all four models (see Table 3). When considering the four models, all the estimated parameters of the socio-economic variables are significant and show intuitive signs except for "*Family 5+*". The older population variable showed a positive and significant effect on transit ridership. However, the negative effect reported elsewhere in the literature on the size of the households with respect to transit rider ship is not supported in any of the four models. Instead, the *"FAMILY 5+"* parameter is positive and significant in all the models. This might be the case since the study considered the largest four metropolitan areas in Canada. Also, since these areas, for the most part, have reliable public transport systems, one can expect that using transit may be more time effective and less costly among larger Canadian families. As suggested in literature, the percentage of minority populations "*Minority*" have a positive and significant impact on transit trips except for Vancouver where the parameter is not significant. By comparison, the results pertaining to minority population had strongest affinity, by far, in Ottawa. Population density, "*Pop. Density*", has a positive influence on transit ridership and the estimated parameters are consistent in all four models. As the population density increases in a census tract, more transit trips are expected to originate from the tract.

Table 3. Estimation results of the SAR models

Variables	Toronto		Montreal		Vancouver		Ottawa	
	Beta	t-stats	Beta	t-stats	Beta	t-stats	Beta	t-stats
ρ	0.41	14.37	0.48	16.42	0.53	13.54	0.30	4.20
Constant	-338.97	-11.09	-203.60	-9.16	-240.30	-6.77	-256.90	-4.72
Pop55+	0.25	16.36	0.12	11.57	0.13	7.40	0.20	7.13
Family 5+	0.10	1.77	0.69	7.38	0.35	3.76	0.90	4.03
Minority	202.34	5.79	2.29	5.06	52.17	1.17	607.15	4.84
PD	0.02	10.72	0.01	6.97	0.02	5.60	0.03	3.38
EI	389.37	3.47	170.60	1.95	379.63	3.10	230.05	1.12
MDI	-	-	0.02	3.18	0.00	0.06	0.04	1.94
Net. Design	187.66	9.75	66.39	4.72	92.47	4.70	-34.64	1.17
Outlier	351.76	13.57	450.89	11.63	441.75	11.97	346.31	4.27
R^2	0.68		0.67		0.73		0.63	

On the land use side, the entropy index "*EI*" met our a priori expectation with a positive and significant affinity to transit ridership. Other things being equal, areas with heterogeneous land uses are more likely to increase the number of transit trips. On the other hand, the mixed density index "*MDI*" exhibits a positive and significant influence on transit in the case of Montreal and Ottawa. However, it was negative and insignificant for Vancouver and was not considered in the Toronto model since it clashed with the remaining variables. The models verified that areas with predominant gridded network design are more likely to utilize transit trips compared to areas where curvilinear network design are more present. Such relationship holds in the three largest CMAs except for Ottawa. Finally, the consideration of the outlier variables (*Outlier*) in the models had a significant influence on the overall fit. As it stands, the estimated SAR models are able predict reasonable transit ridership for the four metropolitan areas. However, the Vancouver model showed fairly better predictions as the estimated SAR model is able to explain 73% in the variability of generated transit work trips at the census tract level.

Conclusion

This study examines the degree at which the built environment affects transit ridership for the 2011 Journey-to-Work while controlling for socio-economic variables in the four largest Canadian metropolitan areas. The analysis utilized the Simultaneous Auto-Regressive modeling technique since spatial autocorrelation exists in the generated transit trips at the census tract level. While "*Family 5+*" variable was not in line with previous findings, the results could still be explained given the nature of the studied regions. Also, the results from the other variables are in line with findings from past studies. In addition, for the most part, the results showed systematic effects between the four models and emphasize the important role that land use (namely mixed land uses and network design) has on transit ridership. As such, this research makes a meaningful contribution to the existing body of transportation literature.

The work presented in this paper will allow planners to better understand the relationship between urban form and transit ridership in large metropolitan areas. This study supports several new planning techniques that encourage compact, diverse, and pedestrian oriented urban forms. The later is very important as it can positively influence Canada's environment and transportation systems. Models were estimated for only four urban cities in Canada (Toronto, Vancouver, Montreal, and Ottawa). Therefore, future research will focus on performing additional analysis in a number of other Canadian cities to better understand urban form and its relation to public transportation in the Canadian context.

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