Chapter 32: Public Transit and the Built Environment

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1 ABSTRACT

This chapter explores the association between the characteristics of the built environment and public transit ridership. The chapter contrasts the built environment determinants of public transit ridership in urban centres with significant transit ridership with those where transit mode share has been stagnant or falling. The past few decades have witnessed a growing awareness of the correlation between land use (built environment) and travel behaviour (e.g., transit mode share). Some proxies of the built environment, namely density, design, and diversity, have been the subject of intellectual curiosity in North America and Europe. A synthesis of the classic literature on the built environment and public transit serves as the launching pad for a review of the recent empirical evidence highlighting some nuanced findings. The chapter concludes with suggestions for a fresh look at the built environment determinants of public transit ridership in large and small, and old and young cities.

2 INTRODUCTION

The economic, cultural, and social success of large and small cities, to an extent, depends upon the ease residents can acces desired destinations. Modern metropolises are also known for their advanced transport systems enabling accessibility and mobility. A glance of the populace and economically vibrant cities in Southeast Asia, Europe, and North America would reveal several common factors that contribute to their success. One of those factors is an efficient public transit system that provides comprehensive coverage throughout the urban landscape. Densely populated cities like New York and Hong Kong cannot function without the elaborate public transit networks that provide access to employment hubs during peak periods of travel.

Whereas comprehensive and efficient public transit systems have contributed to the economic and social success of cities across the globe, the presence of transit-based mobility continues to be concentrated in a small number of large cities. In North America, despite the significant contribution of transit-based mobility to enhance economic and social outcomes in populous cities, transit use is somewhat limited in mid- to small-sized cities. Meanwhile, the experience in mid to small-sized European cities is different from the one in

America such that commutes by public transit continue to account for a sizable proportion of all trips made.

Public transit use is more pronounced in cities of varying sizes in Europe but not as much in North America. Researchers have pointed out several reasons for the differences. The most cited difference between cities in Europe and North America is their respective built environments. European cities are known for their high-density, compact, mixed land uses, which researchers believe have enabled more extensive adoption of public transit. In comparison, except for large, more populous, yet a limited number of North American cities, urban land use in North American cities is characterized by mid- to low-density, sprawling, and single-purpose land uses. Researchers pointed out that vintage matters for land use. The land use in European cities, most of which were predominantly built before the emergence of the private automobile or rail-based public transit, reflects the prevalent transport technology of their times. In *Edge Cities*, Joel Garreue argues that the maximum desirable commute throughout human history, irrespective of the transportation technology, has been 45 minutes. This implies that the land use and the physical extent of the city from ancient Rome (when the mode of transportation was predominantly walking) to the modern mixed-mode transportation cities, the desirable (average) commute times have been less than 45 minutes.

Other research has shown that in addition to vintage, the scarcity of developable land is more pronounced in European cities than their North American counterparts, which made post-war development transpiring at much higher densities in Europe. At the same time, comparatively higher gasoline taxes, parking charges, and other levies in Europe make mobility by private automobile significantly more expensive than it is in North America.

This chapter focuses on the relationship between the built environment and mobility by public transit in some North American cities. Though cities in Southeast and South Asia provide exciting perspectives on the use of public transit, yet the significant differences in the underlying demographic and political structures would make weak cross-jurisdictional comparisons with North America. However, similar culture, demographics, and legal frameworks between Europe and North America make for better comparative constructs.

The goal of this chapter is not solely to focus on how one can increase mobility by public transit in urban settings where travel by transit has taken a backseat. Instead, this inquiry also focuses on the circumstances that make public transit not the preferred alternative for travellers. Whereas public transit is by far the preferred alternative for climate change and sustainability concerns, trips by public transit are, on average, much longer in duration than the comparable trips by private automobile. It is assumed that individuals continue to be utility maximizers, and the desire to optimize their utility often overshadows the desire to have better societal outcomes.

This chapter comprises of two parts. First, the chapter undertakes a systematic literature review to determine how research in the past has addressed the relationship between the built environment, as is proxied by the intensity of development, diversity of land uses nearby, and availability of land, among others. In the second part, the chapter relies on empirical evidence, mostly in the form of spatially disaggregated demographic data complemented with spatial measures of accessibility and travel behaviour to answer the more nuanced questions. For instance, is the public transit use in the newly built parts of the traditionally transit-dominated cities significantly higher than neighbourhoods of similar vintage in other cities not known for higher public transit use. We conclude the chapter by identifying the enabling factors for better public transit outcomes.

3 WHAT WE KNOW FROM THE LITERATURE

One can imagine a symbiotic relationship between the built environment and public transit use. Transit supportive built form, the specifics of which we will discuss later, can promote transit use. Consequently, and over time, newly built higher-order public transit, as the theory suggests, could influence the built environment in proximity of transit stations. Hence, a bi-directional model of the built environment and transit use emerges. The literature presented here, though not exhaustive, presents the essential themes that have come to define the prevalent "conventional wisdom" as it relates to how the built environment and transit use are connected. We also present slightly divergent views from the literature where the conventional beliefs about the assumed dependencies between the built environment and transit use, when put to empirical tests, reveal weak or no association between the two.

A quick scan of academic and professional literature suggests that the contemporaneous correlation between proxies of the built environment and travel behaviour has been the most frequent output of studies exploring the determinants of transit use. A shortlist of built environment attributes, namely population or employment densities measured as persons or jobs per unit area at the neighbourhood, city, regional or national level; housing density, intersection density, road-length or side-walks per unit area, land use mix, and prevalence of non-residential land uses, such as retail in the walking distance have served as proxies to describe built environment at varying spatial scales. Others have broadened the list by including some transit supply attributes, namely transit service frequency and proximity to transit stations, among others. Research has mostly documented that a compact built environment discourages travel by the private automobile and encourages travel by public transit (Ewing and Cervero, 2017).

Cervero and Kockelman (1997) analyzed the travel mode choices for non-work trips for the residents in the San Francisco Bay Area and concluded that the built environment attributes, clustered as density, land-use diversity, and design (3Ds) are correlated with travel behaviour. They observed that "that [high] density, land-use diversity, and pedestrian-oriented designs generally reduce trip rates and encourage non-auto travel in statistically significant ways." The strength of the relationships they uncovered was weak as they concluded that the influence of the 3Ds on travel behaviour "appear[s] to be fairly marginal." While acknowledging the "modest to moderate" magnitude of the built environment-travel demand relationship, they concluded that "creating more compact, diverse, and pedestrian-orientated neighborhoods, in combination, can meaningfully influence how Americans travel."

The 3Ds highlighted as a bundled set of attributes have, either individually or collectively, dominated the discourse on the determinants of travel behaviour. Earlier, Newman and Kenworthy (1989) highlighted the need to reduce automobile dependence by focussing on factors that help reduce automobile and gasoline use. Compact urban form or density emerged as the central theme since then and was later reiterated in a series of subsequent publications that demonstrated lower automobile use in jurisdictions with higher population densities (Kenworthy and Laube, 1999).

Bivariate comparisons of population densities and automobile use were instrumental in framing policies on how to increase public transit ridership while reducing dependence on the private automobile. However, as was demonstrated by others later (Handy et al., 2006), comparing a proxy of the built environment and one for travel behaviour in isolation ignores the other mitigating factors that influence the evolution of the built environment and associated human behaviour. Often, high-density cities are older than low-density cities such that the higher density neighbourhoods were primarily built earlier before the use of automobiles became ubiquitous. Controlling for the age of a place is likely to demonstrate the inherent limitations in bivariate correlations, which ignore the structural differences amongst jurisdictions. We will return to the vintage argument later in the chapter.

Essentially, the transit-supportive built environment is also considered supportive of travel by non-motorized modes such that those who reside in “walkable areas” are found more likely to walk (as expected) but also rely more on public transit and are “significantly less likely to drive or own a vehicle compared with those living in less walkable areas” (Glazier et al., 2014). The authors examined “the individual and combined associations of residential density and the presence of walkable destinations” on their impact on mobility, obesity, and diabetes.

Neighbourhood design attributes that influence connectivity are also associated with travel behaviour, especially the use of non-motorized modes. At the same time, the built environment attributes that promote walk or bicycle modes might be associated with lower transit mode share, thus exposing the trade-off between non-motorized modes and transit. A study from Beijing demonstrated that “[h]igher destination accessibility, a higher number of exclusive bicycle lanes, a mixed environment and greater connectivity between local streets tend to increase the use of the bicycle.” Two additional findings were equally relevant. One that residential density had “no significant effects on the use of a bicycle for commuting.” Second, an increase in the supply of public transit was associated with a “decrease rather than increase [in] bicycle commuting.” The author found that “drastic changes in the built environment are a major reason for the demise of ‘the kingdom of bicycles’ in China.” This implies that a very walkable built environment might not necessarily be equally supportive, or facilitating, of travel by public transit. In fact, at extremely high population densities, one sees diminishing returns to density for public transit as the mode of travel switches in favour of walking and cycling (Haider, 2019).

The correlation between the walkability of a place and greater use of public transit has been reported independently by many in different jurisdictions (Frank et al., 2006). However, such a line of inquiry often makes certain assumptions implicitly or explicitly and, at times, ignore factors that may influence the statistical significance and magnitude of the association between attributes of the built environment and travel behaviour. Glazier et al. (2014), for instance, assumes that the presence of walkable destinations and residential density are “potentially modifiable components of walkability measures.” The authors assume that, as an outcome of public policy interventions, modifying the built environment by changing its density or land-use is doable. However, transforming existing land uses in the short-term requires political and financial capital, a changing demographics, and the resulting change in cultural preferences, all of which cannot be readily accomplished through by recommending “for use by policy-makers, planners and public health officials.”

The other associated challenge is with self-selection where those who are more likely to have opted for non-motorized modes of travel or public transit would self select themselves in such locations that permit the desired travel behaviour (Handy et al. (2006); Cervero and Duncan (2008)). After one accounts for self-selection, the strength of the relationship between built environment attributes and travel behaviour might be weaker than expected. When it comes to travel mode choice decisions, Cervero and Duncan (2008) show “that residential self-selection accounts for approximately 40 percent of the rail-commute decision.”

3.1 The Built Environment, Physical Activity, and Health

A large body of literature continues to explore the linkages between the built environment and the wellness and health of residents. Research shows that the built environment influences health outcomes not directly but through the impact of the built environment on travel behaviour. In a two-step process, the built environment is believed to influence how people travel, and travel behaviour, in turn, impacts the health and well-being of the individuals. For instance, research has shown that when the built environment promotes or facilitates travel by active modes of transportation, i.e. bicycling and walking, residents report a lesser incidence of obesity and other related illnesses including diabetes and high blood pressure (Frank et al. (2006); Rundle et al. (2007); Li et al. (2008)). The underlying assumption is that attributes of neighbourhood design that facilitate travel by non-motorized modes, such as connectivity of the road network and accessibility to nearby destinations including parks and public transit, promote walking and biking, which are associated with improved health outcomes.

Often, research that establishes a link between neighbourhood design and health outcomes also finds a positive correlation between the walkability of a place and the use of public transit (Frank et al., 2006). Thus, in addition to the positive correlation between travel by non-motorized modes and better health outcomes, a positive correlation is also observed between higher public transit use and improved health and fitness of the residents.

Despite the abundance of research demonstrating the linkage between the built environment and health and wellness, other researchers have found this relationship to be weak or tenuous. Research has shown that once demographic factors and lifestyle choices are considered, the link between obesity and the built environment becomes weaker or disappears (Eid et al., 2008). Often self-selection is the ignored confounder that might reveal that those who are likely to be obese choose to live in sprawling neighbourhoods. Eid et al. (2008) categorically rejected earlier prognosis of design-related obesity and concluded that “current interest in changing the built environment to counter the rise in obesity is misguided.”

3.2 Meta-Analysis of the Literature

Much can be learnt from research that presents a synthesis of the literature, including meta-analysis, to summarize the diverse findings exploring the linkages between the built environment and travel behaviour. Not surprisingly, definitive answers are hard to find. For instance, the relationship between urban density, neighbourhood design, land-use mix and travel behaviour is established in some research, whereas others “find the impact of such variables to be at best marginal” (Badoe and Miller, 2000).

A meta-analysis of the built environment and travel revealed that “[t]ravel variables are generally inelastic with respect to change in measures of the built environment” (Ewing and Cervero, 2010). An interesting finding from the meta-analysis was that the typical approach of measuring the impact of individual built environment measures on travel behaviour might not account for much. However, taken together, built environment proxies could have a significant impact on travel behaviour. The meta-analysis revealed that whereas vehicle miles travelled (VMT) were impacted more by accessibility to destinations, walking was impacted mostly by the diversity of nearby land uses. Interestingly, public transit use was influenced by, as expected, proximity to public transit, as well as street network design. Finally, Ewing and Cervero (2010) noted that population and employment densities had a week association with travel behaviour after other variables were accounted for.

An earlier review of almost 50 studies by Ewing and Cervero (2001) exploring the linkages between built environment and travel behaviour outcomes, such as trip frequency, trip length, travel mode choice, and transportation effort measured as either VMT or vehicle hours travelled informed that such associations were influenced more by the socioeconomic characteristics of travellers and less by the attributes of the built environment.

Often, public policy interventions regulating the built environment in new establishments rely on population density as the preferred intervention. However, research has shown population density alone, though required, not be a sufficient enabler of influencing travel behaviour. When it comes to density, “it is unclear whether it is the density or the variables that go long with density that affect people’s travel behavior” (Chen et al., 2008). Ignoring the presence of such factors (self-selection for one) could lead to hasty conclusions. An analysis of mode choice of residents in the New York Metropolitan Area revealed that employment density and not population density at home had a more significant impact on mode choice decisions.

3.3 Impact of Transport Infrastructure on Built Environment

Newly built transit or highway infrastructure influences nearby land development. The impact could be in the form of type of development, concentration, intensity, and diversity of land uses, and pace of development. New transit infrastructure, for example, rail-based transit with the dedicated right-of-way, is believed to have a more substantial impact on the nearby land than other surface-based modes.

Despite the promise, carefully conducted studies have shown a moderated impact of transit on land developments. Bay Area Rapid Transit (BART) in San Francisco is an interesting example of the expansion of sizeable suburban rail projects in the United States. BART started operations in September 1972. A critical review of BART's impact on land development after being in service for 20 years revealed that "land-use changes associated with BART have been largely localized, limited to downtown San Francisco and Oakland and a handful of suburban stations," (Cervero and Landis, 1997). While BART had a modest impact in select areas with multi-family housing built near subway stations, the authors found BART did "little to stem the tide of freeway-oriented suburban employment growth" as the floorspace added to non-BART freeway corridors was much higher than the office development in the vicinity of BART stations. Mostly, the authors observed that the availability of developable land was a more significant predictor of the potential land use development.

For new developments, urban planning professionals identified a series of developmental paradigms that were labelled as 'smart growth.' Smart growth promised a compact built environment that is less automobile-dependent (Burchell, 2000). However, critical reviews of smart growth claims have been less than convincing. Handy (2005), for instance, examined four commonly stated claims about smart growth, namely:

1. "building more highways will contribute to more sprawl,
2. building more highways will lead to more driving,
3. investing in light rail transit systems will increase densities, and
4. adopting new urbanism design strategies will reduce automobile use."

The author concluded that "the four propositions have not yet been fully resolved: researchers have made more progress on some of these propositions than others, but even in the best cases, our ability to predict the impact of smart growth policies remains limited."

3.4 THE GEOGRAPHY OF INTELLECTUAL CURIOSITY

While reviewing research on the linkages between the built environment and transit use, one cannot ignore a small number of usual-suspect cities that have served as the experimental laboratories. Influential research from the small number of cities has been instrumental in devising policies linking the built environment and public transit. A question emerges about the relevance of these studies for other cities with distinct demographics, topology, climate, and economy. A large number of highly influential studies for instances are based on data from Bay Area in San Francisco (Cervero and Landis), Portland, Oregon (Li et al., 2008; Dong and Zhu, 2015), New York (Chen et al., 2008), King County (Frank et al., 2006), and recently Beijing (Zhao, 2014).

Furthermore, few international comparisons of built environment-transit use nexus could be found in the literature. Also, how sampled cities were selected and what was done to account for the order of magnitude difference between the sampled cities is not known. A comparative study of the built environment of 15 cities located in 12 countries found considerable differences in the built form (Adams, 2014). The authors found “a 38-fold difference in median residential densities, a 5-fold difference in median intersection densities and an 18-fold difference in median park densities.” Hence the question that emerges is whether one can generalize findings from a relatively high or very high-density place, such as Hong Kong, to North Shore, New Zealand, which depicts much lower development densities.

At the same time, few if any studies consider the relationship between the built environment and transit for European cities. The relative scarcity of research exploring the linkages between the built environment and public transit use from European cities needs some reflection. Perhaps, similarities in the built environment among European cities, the similar vintage of their construction and development over the past few centuries, and much higher use of public transit throughout the European continent are the reasons why need for such exploration was perhaps not felt. Also, the sociopolitical frameworks commonly found in Europe, for instance, acceptance of higher levels of taxation in return for higher levels of public services and social security nets, are inherently different from those prevalent in the United States and Canada. Hence, intercity comparisons of jurisdictions across the Atlantic would ignore not just the fact that most North American urban centres, unlike the European counterparts, developed primarily in the past 100 years, but also that sociodemographic and economic frameworks across the continents differ considerably.

3.4.1 Old versus new cities

Comparative studies of built environment and transportation often control for the systematic differences between and among cities. For instance, empirical analysis controls for household demographics, income levels, automobile ownership, price of gasoline, and the like. What is often not controlled for is vintage. The built environment, to a large extent, is a product of the prevalent transportation technology. Since human beings started living in formal settlements, the shape and size of the settlements have been influenced by transportation technology. The spatial extent of the mostly pedestrian communities in ancient Rome and Egypt was defined, to a large extent, but the distances covered comfortably by foot. As transportation technology improved first with domesticated animals and later with motorized transportation, the spatial extent and structure of communities changed considerably. Hence, Joel Garreau (1991) argued in *Edge City* that throughout human history, and irrespective of transport technology, the longest desirable commute had been no more than 45 minutes.

The built environment seen in the modern European metropolises with narrow streets, tree-lined boulevards, low-rise multi-residential buildings supporting very high population densities was a reflection of the modes of transportation available when these places were first built and settled over the past few hundred years. In comparison, the North American metropolises were mostly developed when the private automobile and rail-based, higher-order public transit were readily available. The resulting built form in North America is thus a reflection of the automobility of its time.

Neighbourhood vintage, we argue, influences the built environment, which in turn influences transit use. For comparative research, one must, therefore, attempt to control for vintage. Comparing cities built mostly in the 19th century or before with those developed primarily in the 20th century must include explicit controls for vintage to tease out the nuanced relationship between the built environment and public transit. Even comparing areas of different vintage within the same cities must not ignore the timing of development. For instance, Dong and Zhu (2015), in a study of smart growth developments in Portland and Los Angeles, observed that older neighbourhoods, when compared with newer builds, tend to be more advanced on smart growth metrics.

The next section presents empirical (stylized) findings of the relationship between the built environment and public transit. The analysis is informed by the discussion presented in the literature review. We intend to understand why transit use is higher in some jurisdictions and not in others. The literature reviewed in this chapter demonstrates the environmental, health, and social benefits of higher transit use. Still, at least in North America, public transit use pales in comparison with that of the private automobile. Of course, efficient, and reliable public transit is a prerequisite for mass adoption of public transit. In places where transit service is unreliable, not efficient, or comprehensive in its coverage, people will likely use other modes for mobility. However, in many large North American cities that are characterized by the transit-supportive built environment, transit use still lags travel by the private automobile. The analysis presented here explores the barriers to higher transit use by exploring some factors that have not attracted sufficient attention in the past.

4 ANALYSIS OF THE BUILT ENVIRONMENT – TRANSIT NEXUS

The empirical analysis presented here is based mainly on Census-based data from Canada and the United States. Also, we use a new database of the built environment and transit proximity indicators for almost 480,000 neighbourhoods across Canada to explore the relationship between the built environment and public transit use.

4.1 'PUBLIC TRANSIT IS BETTER, BUT CARS ARE FASTER'

Statistics Canada, Canada's official statistical agency, the first time in 2011included a question about the duration of daily commutes in the National Household Survey (NHS) that replaced the long-form census. The respondents, employed individuals and 15 years of age or older, were asked the following question: "How many minutes did it usually take this person to get from home to work?"[1] The public-use microdata file was subsequently released in 2013, which prompted an op-ed in Canada's national newspaper, the Globe and Mail. The op-ed revealed that commutes by public transit, irrespective of the local demographics, were significantly longer than commutes by the private automobile. On average, across Canada, transit commutes were 81% longer in duration than those by car (Haider, 2013). Even for cities known for high transit use, transit fared poorly for travel time. The commute to work

[1] https://www23.statcan.gc.ca/imdb-bmdi/instrument/5178_Q2_V1-eng.pdf

data, released as part of the NHS, showed that in a transit-friendly city like Montréal, travel to work by car on average took 26.5 minutes. However, travel by public transit on average took 42 minutes. Thus, even in cities known for transit use and infrastructure, commute by transit was 58% longer.

The op-ed revealed nothing new to the transportation planning fraternity. However, for the transit enthusiasts, and the broader public, transit times being considerably slower was a revelation. Four days after the op-ed was published, the newspaper dedicated a section to publish feedback from readers who had reacted with hundreds of messages and comments. The exercise revealed that many who advocate for transit earnestly believed that transit commutes were faster than those by the private automobile and that if urban workers were moved in large numbers from using cars to transit, the system-wide travel times would improve. Nevertheless, Haider (2013) noted that "commute to work data challenges the notion that building more public transit will save travel time by shifting commuters from cars to public transit. How is it possible that transferring commuters from a faster mode of travel to a slower one will shorten travel times? Simple arithmetic and common sense suggests that system-wide travel times will instead be longer when more people commute by the slower mode, i.e., public transit."

The more pertinent question to ask is even if transit service is available and travel costs are not the deciding factor, why would one opt to commute by a slower mode to and from work. Urban commuters, especially those who are time-poor, are likely to prefer the mode of travel that is faster. Hence, public transit does not have to be just cheaper or reliable; it must also offer travel times that are competitive with those by cars.

In 2016, the long-form census in Canada reconfirmed what was observed five years earlier in the NHS. Transit commutes on average were significantly longer by public transit than by cars in Canada's eight most populous Census Metropolitan Areas (CMAs), which are collectively home to 18 million people, about 50% of Canada's population. Commutes by public transit were, for example, 70% longer in Calgary than by car (Figure 1). On the lower end, transit commutes were 58% longer by transit in Winnipeg. Despite transit commutes being significantly longer than those by cars, Canada's most populous urban regions reported high transit use with Toronto reporting a public transit mode split of 25.3%. Quebec City was at the lower end with 12.6% (Statistics Canada, 2016).

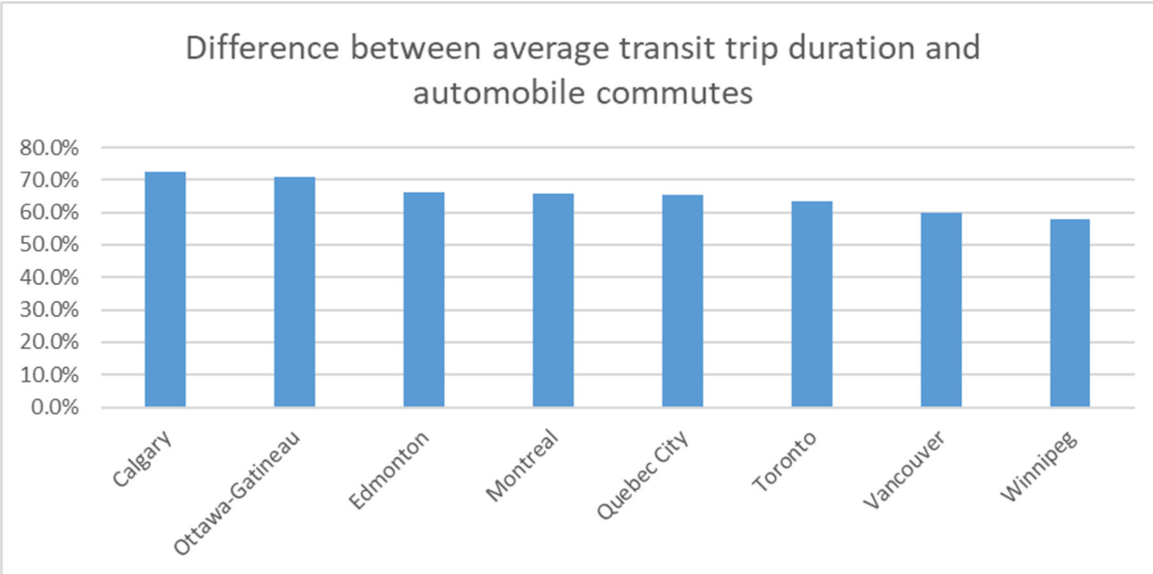

Figure 1: The difference in average commute times by transit and car (percentage)

A similar relationship is observed for urban regions in the U.S. Higher transit use is associated with longer commute times. We compare the three-dimensional association between population density (a proxy for the built environment), commute times, and transit mode share for the Core-based Statistical Areas (CBSA). CBSA is described as follows:

> A core-based statistical area (CBSA) is a U.S. geographic area defined by the Office of Management and Budget (OMB) that consists of one or more counties (or equivalents) anchored by an urban center of at least 10,000 people plus adjacent counties that are socioeconomically tied to the urban center by commuting. Areas defined on the basis of these standards applied to Census 2000 data were announced by OMB in June 2003. These standards are used to replace the definitions of metropolitan areas that were defined in 1990. The OMB released new standards based on the 2010 Census on July 15, 2015.[2]

The 31 CBSAs are necessarily conurbations that stretch beyond the State boundaries. The most populous CBSA with a population of 14.3 million is linked with New York City and includes areas in New Jersey and White Plain. The least populous in the data set is San Rafael, CA, with a population of 259,358 individuals. We illustrate the results in the next two charts. First, we present evidence in support of the oft-cited observation about the built environment and public transit mode share. Figure 2 illustrates that higher density regions are associated with higher public transit mode share.

[2] https://en.wikipedia.org/wiki/Core-based_statistical_area.

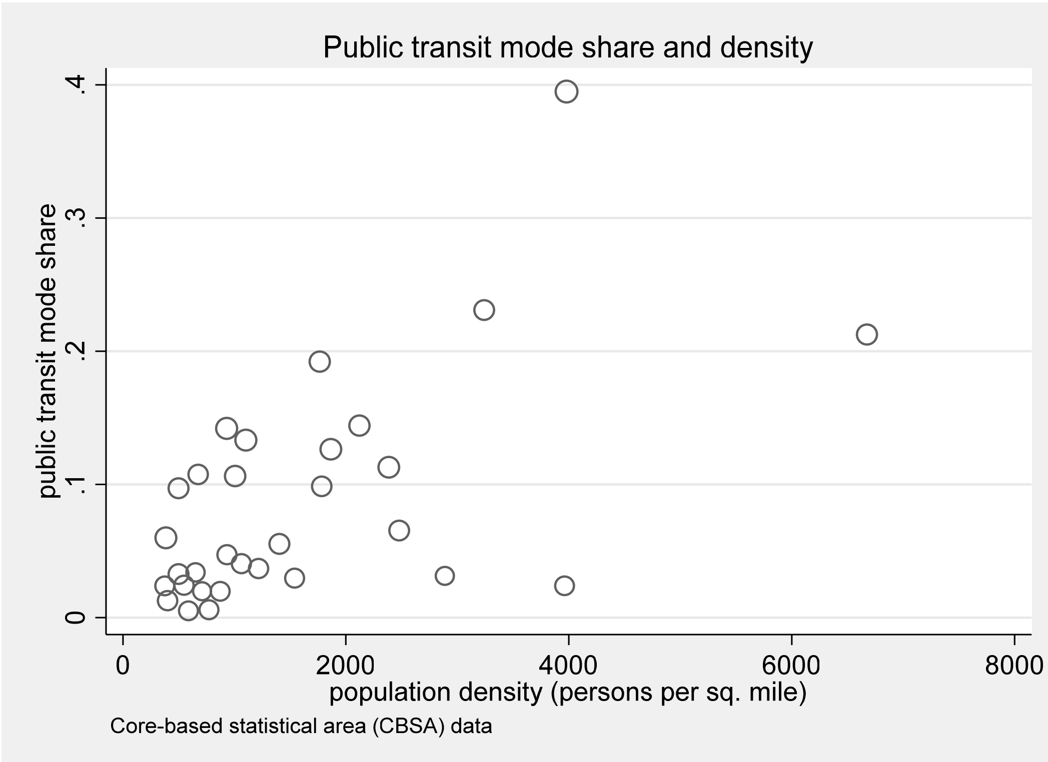

Figure 2: Population density and public transit mode share across CBSA in the U.S.

Figure 3 illustrates the argument being made here that higher public transit use is associated with longer average commute times. CBSAs with transit mode share of greater than 10% are associated with average commute times of 30 minutes or higher. The size of circles in Figure 3 depicts the population densities. What is interesting is that some high-density CBSAs, characterized by large circles, report lower transit mode share of 5% or less and commute times of less than 30 minutes. On the other hand, one sees some high-density CBSAs associated with higher public transit mode share, and consequently longer average commute times. Thus, one could infer from Figure 3 that population density does not automatically associate with higher transit mode share. This observation has also been made in the literature that higher density is a prerequisite but not a sufficient condition for higher transit use. However, the primary inference remains the same as was observed for the Canadian data, i.e., higher public transit mode share correlates with longer commute times.

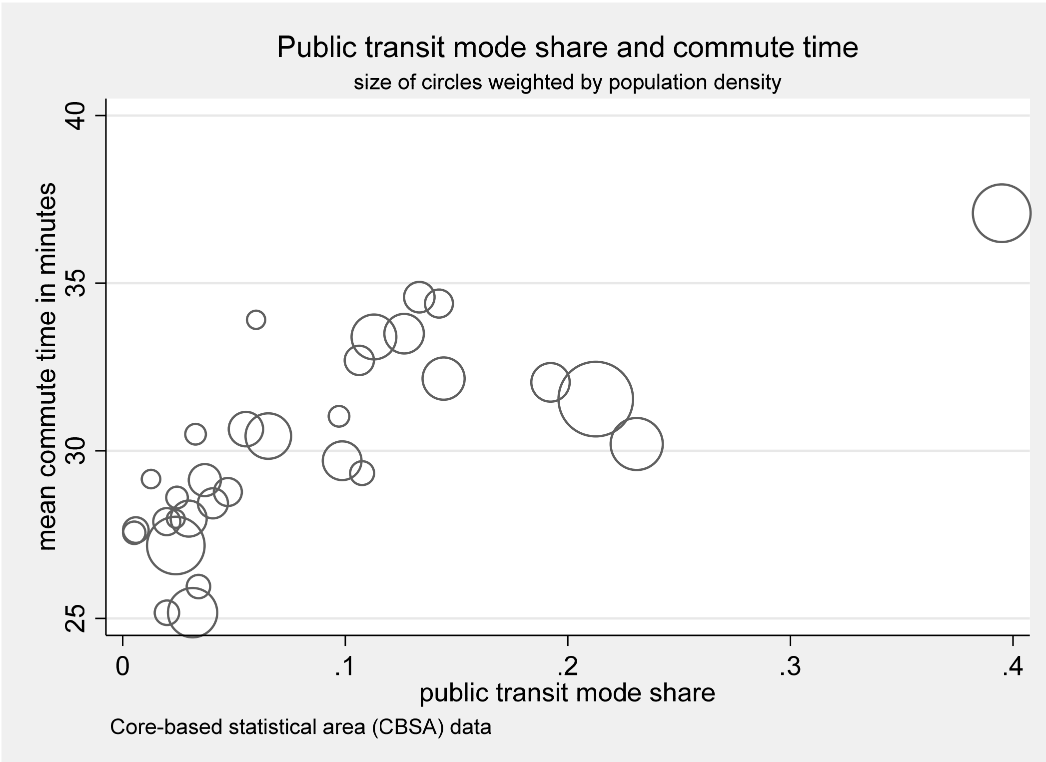

Figure 3: Population density and public transit mode share across CBSA in the US

CBSAs are agglomerations of urban areas with significant diversity in demographics where the most populous regions such as New York and Los Angeles have populations over 10 million, while smaller areas such as Gary, Indiana, have populations of 0.7 million. Similarly, the spatial footprint of these areas varies significantly, such that Washington-Arlington-Alexandria covers an area scratched for 5,000 square miles, whereas Boston, Massachusetts, is stretched over 1,160 square miles. One can argue that comparing CBSAs with such diversity in demographics and spatial extent could suffer from aggregation bias that may hide the nuanced local differences within and across CBSAs.

To address this limitation, we present a similar analysis performed at the census tract (C.T.) level for the New York region using data from the 2000 census. Mainly, we have divided the 5000-plus C.T.s constituting the New York region into six discrete regions based on distance from downtown Manhattan. Figure 4, therefore, contains six panels, each representing a unique subset of C.T.s based on their distance from downtown Manhattan. The panel labelled nearest covers only those C.T.s that are nearest to downtown Manhattan and are situated within 10 km of the Central Business District (CBD). Other panels accordingly present data for C.T.s that are located at greater distances from downtown Manhattan. A breakdown of the C.T.s distances is presented in Table 1. The discretization of space allows one to explore any change in the relationship based on the location of the C.T.s.

The x-axis for the six panels represents public transit mode share, whereas the Y-axis represents the average commute time in minutes. Also, the markers are colour-coded to categorize each C.T. into low- (red), medium- (blue), or high-income (green) neighbourhood by the three income levels.

Table 1: Distance thresholds for the six neighbourhood categories

Distance from Manhattan CBD (km)	mean	min	max
Nearest	6.59	0.28	10.04
Nearer	12.63	10.05	15.55
Medium near	18.70	15.57	22.40
Medium far	30.01	22.44	40.16
Farther	54.28	40.17	71.36
Farthest	97.35	71.79	179.80

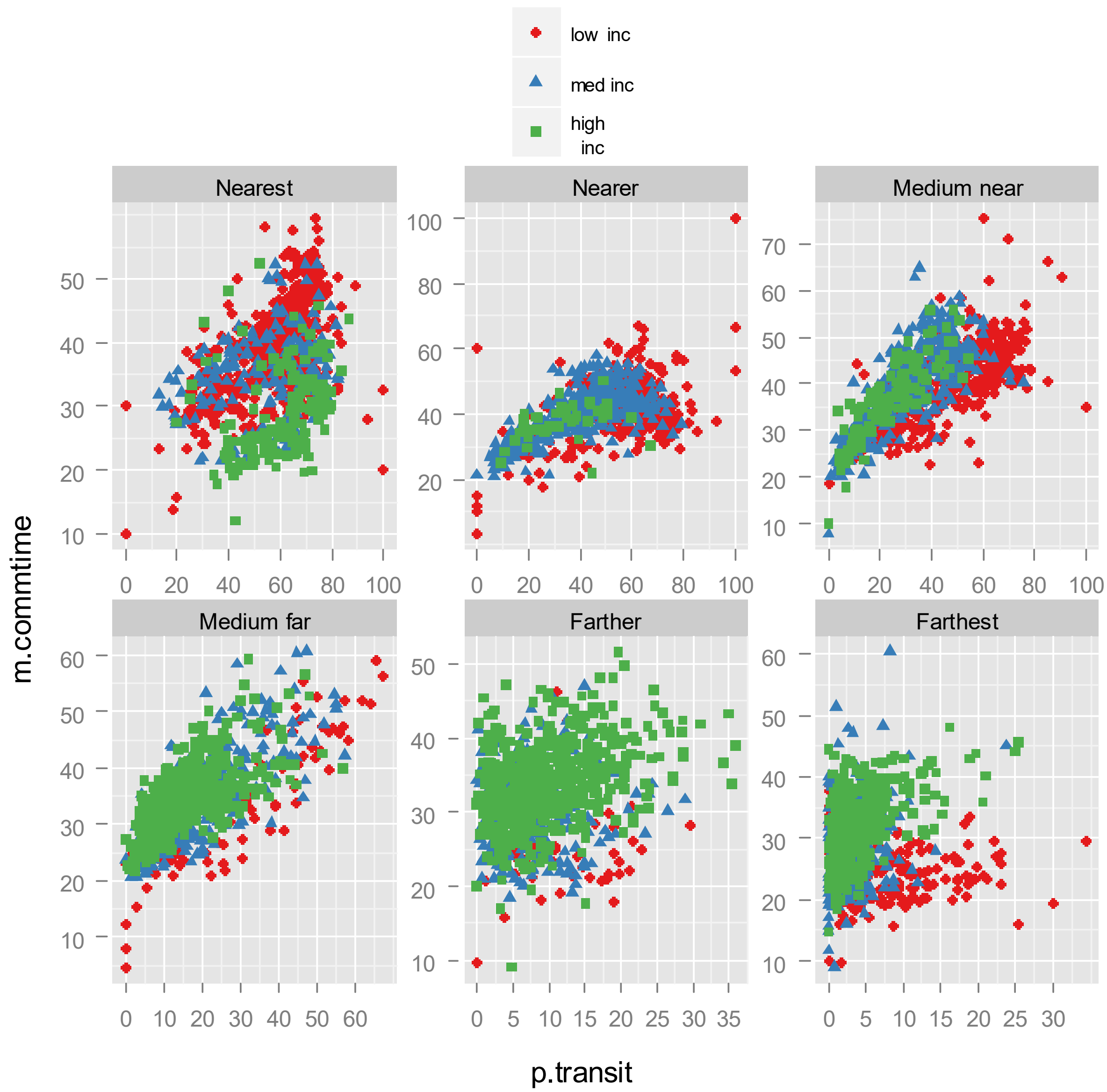

Figure 4: Population density, household income, and public transit mode share in the New York region

The panel labelled Nearest presents a scatter plot between transit mode share and median commute times for C.T.s situated within 10-km of the Manhattan CBD. One sees a positive correlation between public transit mode share and median commute times. Even for the neighbourhoods that are closest to downtown Manhattan, which is served by fast-moving subways on dedicated rights-of-way, commute times on average are higher for the neighbourhoods with higher transit use. The positive correlation persists for C.T.s that are depicted in panels labelled as Nearer, Medium Near, Medium Far, or Farther from the CBD. The correlation weakens for only those neighbourhoods that are located at least 70-km away from downtown Manhattan.

The colour of markers in the scatter plot, which accounts for the neighbourhood income level, reveals that low-income C.T.s (red) often report higher levels of public transit mode share and longer commute times. This is more evident for C.T.s located nearest or nearer to the CBD, but not for remotely located suburban C.T.s.

A key takeaway from Figure 4 is the following. A higher level of transit mode share is associated with a longer commute time. The relationship holds for both: a comparative analysis of spatially aggregated data for CBSAs and also the spatially disaggregate data at the neighbourhood level (C.T.) for the New York region. This exposes a key challenge for increasing public transit use in North America. Even in places where the built environment is conducive for higher-order transit systems, and places with an ample supply of diverse transit modes offering efficient transit service, transit commute times are longer. To compete with the private automobile, transit must offer competitive travel times.

4.2 DOES VINTAGE MATTER?

In the literature review section earlier, we discussed the relevance of vintage for the built environment and associated public transit use. We argued that cities built before automobile use became ubiquitous were designed to facilitate mobility by non-motorized modes of travel. Specifically, such cities were known for higher population densities, mixed land uses, and the destinations were closely placed. Pre-auto era cities portrayed a compact urban form that was devoid of sprawl, which is characteristic of automobile-dependent communities.

In this section, we intend to compare the relationship between vintage, specifically the age of a neighbourhood, the associated built environment and its association with public transit use. We present data from the 2016 Census in Canada for two urban regions, Montreal and Calgary. We use data for respective Census Metropolitan Areas (CMA). A CMA consists of "one or more neighbouring municipalities situated around a core. A census metropolitan area must have a total population of at least 100,000 of which 50,000 or more live in the core."[3]

We have adopted a spatially disaggregate approach where Calgary and Montreal CMAs are analyzed at the census tract (C.T.) level. C.T.s are "are small, relatively stable geographic areas that usually have a population between 2,500 and 8,000 persons. They are located in census metropolitan areas and in census agglomerations that had a core population of 50,000 or more in the previous census.[4] The purpose of this analysis is to compare population densities, a proxy for the built environment, and public transit mode share in similar vintage neighbourhoods. Montreal is known as a transit city and famous for its European-styled urban design. On the other hand, Calgary reports much lower population density and public transit use. Competitive analysis of public transit mode share across Canada often highlights the apparent fact that places like Montréal, because of their compact built form, have been able to achieve much higher public transit use than places like Calgary, whose built environment is categorized as sprawling.

Such intercity comparisons, as we have argued earlier, often ignore vintage. Calgary, unlike Montréal, is a newer city where a majority of the dwelling units enumerated in 2016 was

[3] https://www150.statcan.gc.ca/n1/pub/92-195-x/2011001/geo/cma-rmr/cma-rmr-eng.htm.
[4] https://www150.statcan.gc.ca/n1/pub/92-195-x/2011001/geo/ct-sr/def-eng.htm

constructed after 1980. In comparison, Montréal was settled much earlier in the 18th century and grew in space and population over the past 200 years. Using Calgary and Montréal as opposite poles of the built environment, we investigate the role, if any, vintage may have played in their respective built environments and consequent public transit mode share.

However, instead of comparing the entire urban landscape in one metropolis with that in the other, we compare public transit mode share and built environment for respective neighbourhoods that are differentiated by age. We categorize a C.T. as new if most of the dwellings in the C.T. were constructed after 1980. Similarly, we categorize a C.T. as old if most dwellings were built before 1981. Hence, the comparative analysis presented here contrasts population densities and public transit mode shares for older neighbourhoods in Montréal with older counterparts in Calgary and vice versa.

The results are presented in the following table.

Table 2: A comparison of age differentiated neighbourhoods in Calgary and Montreal

				New if at least 50% dwellings built since 1981 (%)			Population	
CMA	**Dwellings in 2016**	**Bult since 1981**	**Bult since 1981 (%)**	**Old neighbour-hoods**	**New neighbour-hoods**	**Total**	**Old neighbour-hoods**	**New neighbour-hoods**
Montreal	1,727,215	731,225	42.3%	66.5	33.5	100	2,471,730	1,627,197
Calgary	519,775	328,880	63.3%	44.3	55.7	100	515,399	877,210

			Public transit mode split (%)		**Population Density (persons / sq. km)**	
CMA	**Employed 15-plus (commuters)**	**Public transit mode split (%)**	**Old neighbour-hoods**	**New neighbour-hoods**	**Old neighbour-hoods**	**New neighbour-hoods**
Montreal	1,883,920	25.0	30.2	13.9	7,125	2,352
Calgary	684,260	14.5	16.6	12.8	2,777	2,605

Montreal CMA has a population of four million, with 1.73 million dwellings. Calgary, on the other hand, is a smaller urban region with a population of 1.4 million inhabitants and 520,000 dwellings. Apart from the differences in size, the two cities are inherently different in age of the constituting neighbourhoods such that 63% of the dwellings in Calgary were constructed after 1980. In Montreal, post-1980 dwellings represented 42% of the dwellings. Whereas one in three neighbourhoods were predominantly built since 1981 in Montreal, 56% of the neighbourhoods were of post-1980 vintage in Calgary.

The public transit mode split in Montréal at 25% for commute trips is 72% higher than the one in Calgary. However, the difference in public transit mode splits when compared for the entire urban areas ignores the vintage of the constituting neighbourhoods. To address this limitation, we compare public transit mode splits between Montréal and Calgary by dissecting the cities into old and new neighbourhoods. As expected, parts of Montréal characterized as old neighbourhoods reported a much higher public transit mode split of 30.2% compared to older parts of Calgary with the corresponding statistic at 16.6%.

Unlike older neighbourhoods, a comparison of newer neighbourhoods between the two cities revealed that Montréal, with a 13.9% public transit mode split, was marginally better than 12.8% observed for Calgary. Interestingly, the significant difference in public transit mode splits observed for older neighbourhoods between the two cities almost disappears for newer neighbourhoods. A comparison of the means test revealed that the difference in mode splits for newer neighbourhoods was not statistically significant (p = 0.2870, Figure 5). The difference in average transit ridership for older parts of the two cities was statistically significant ($p < 0.000$).

```
Two-sample t test with equal variances

   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
Montreal |     306    13.88549    .6118413    10.70285    12.68152    15.08945
 Calgary |     141    12.84501    .5508865    6.541415    11.75588    13.93414
---------+--------------------------------------------------------------------
combined |     447    13.55728    .4536766      9.5918    12.66567    14.44889
---------+--------------------------------------------------------------------
    diff |            1.040476    .9761517               -.8779645    2.958916
------------------------------------------------------------------------------
    diff = mean(Montreal) - mean(Calgary)                         t =   1.0659
Ho: diff = 0                                     degrees of freedom =      445

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.8565         Pr(|T| > |t|) = 0.2870          Pr(T > t) = 0.1435
```

Figure 5: Comparison of means test for transit mode share in new neighbourhoods in Calgary and Montreal

To a large extent, the above-mentioned results can be explained by the differences and similarities in the built environment between the two cities. Working with population density as a proxy for the built environment, one sees a large difference in population densities of old neighbourhoods in Montréal and Calgary. However, that difference disappears, in fact, reverses, for newer neighbourhoods. Consider that the average population density in the older neighbourhoods of Montréal was recorded at 7,100 persons per square kilometres compared to 2,777 persons per square kilometres for older neighbourhoods in Calgary. However, when neighbourhoods built predominantly after 1980 in Montréal are compared with similar vintage neighbourhoods in Calgary, one realizes that at 2,605 persons per square kilometres, newer neighbourhoods in Calgary reported higher density than their newer counterparts in Montréal.

These results present an interesting story. Public transit mode share is higher for a transit-supportive built environment characterized by higher development densities, compact built form, and mixed land uses, to name a few. When differences in the built environment exist between cities, one also sees a difference in public transit mode shares. However, the differences in the built environment are more pronounced in parts of the cities built earlier. Recently developed neighbourhoods, even in transit-friendly cities, have similar built environments as the ones found in newer neighbourhoods in cities not known for public transit use. As the difference in the built environments reduces or disappears over time, public transit mode shares also become similar across jurisdictions. Regrettably, the trend one sees here is of lesser reliance on public transit in newly built parts of cities, irrespective of the transit use prevalent in the well-established, older parts of the city.

4.3 A NATIONAL DATABASE OF TRANSIT ACCESSIBILITY

Comparative analysis of the built environment and public transit use requires identical, or at least similar, data or metrics to explore the association between the built environment and transit use. Developing such metrics is resource and time-intensive. Therefore, often studies are limited to a single jurisdiction or involve a comparison of two or several jurisdictions. Comprehensive multi-jurisdictional studies of the built environment across countries or continents are few and often involve a handful of jurisdictions. The financial and resource constraints in data gathering and metric development are the reason why built environment studies are confined to a select few cities in North America where there has been a tradition of collecting such data sets.

Large-scale development of proximity metrics and other indicators of the built environment to cover the entire national landscape will be prohibitive for individual researchers or small teams. However, national-level public sector agencies have the capacity and the resources to develop such data sets. An example of a national initiative to develop cross-country metrics for proximity, built environment, and transit-supportive land uses is the recently released (April 2020) Proximity Measure Database (PMD) by Statistics Canada.[5] In collaboration with the Canada Mortgage and Housing Corporation, Statistics Canada developed a nationwide database of 10 proximity/build environment-related metrics at the spatially disaggregated scale of dissemination blocks such that the database comprises half a million (mutually exclusive and almost exhaustive) observations. Statistics Canada defines the dissemination block (D.B.) as follows:

A dissemination block (D.B.) is an area bounded on all sides by roads and/or boundaries of standard geographic areas. The dissemination block is the smallest geographic area for which population and dwelling counts are disseminated. Dissemination blocks cover all the territory of Canada.[6]

This extensive database makes it possible to answer questions about the relationship between the built environment and public transit at the national level. As was pointed out earlier, most previous research has focused mainly on local urban markets from which inferences were drawn for policymaking at the national, provincial, or regional levels that might not be relevant beyond the study areas.

In the following paragraphs, we present a brief discussion of some of the relevant metrics from PMD to determine the extent of transit-supportive built environment at the national level and to compare relevant metrics amongst nine populous urban centres in Canada accounting for more than 50% of Canada's population. Canada's capital, Ottawa, spreads

[5] https://www150.statcan.gc.ca/n1/pub/17-26-0002/172600022020001-eng.htm
[6] https://www12.statcan.gc.ca/census-recensement/2016/ref/dict/geo014-eng.cfm

across two provinces, Ontario and Quebec, and therefore the metrics are presented separately for the two parts.

Public transit mode split for commutes is highest in the Toronto Census Metropolitan Area (CMA) followed by Montréal and Vancouver such that the three most populous Urban regions report at least one in five work-related trips being made by public transit respectively. The transit mode share declines to a low of under 10% for Hamilton, a neighbouring CMA to Toronto and part of the Toronto commuter shed. The public transit mode splits differ across the urban regions in the same way their demographics differ. Toronto, Montréal and Vancouver are more populous and their respective built environments, proxied by population and employment densities, compactness of urban form, diversity in land uses, and the like, are more likely to facilitate commuting by public transit.

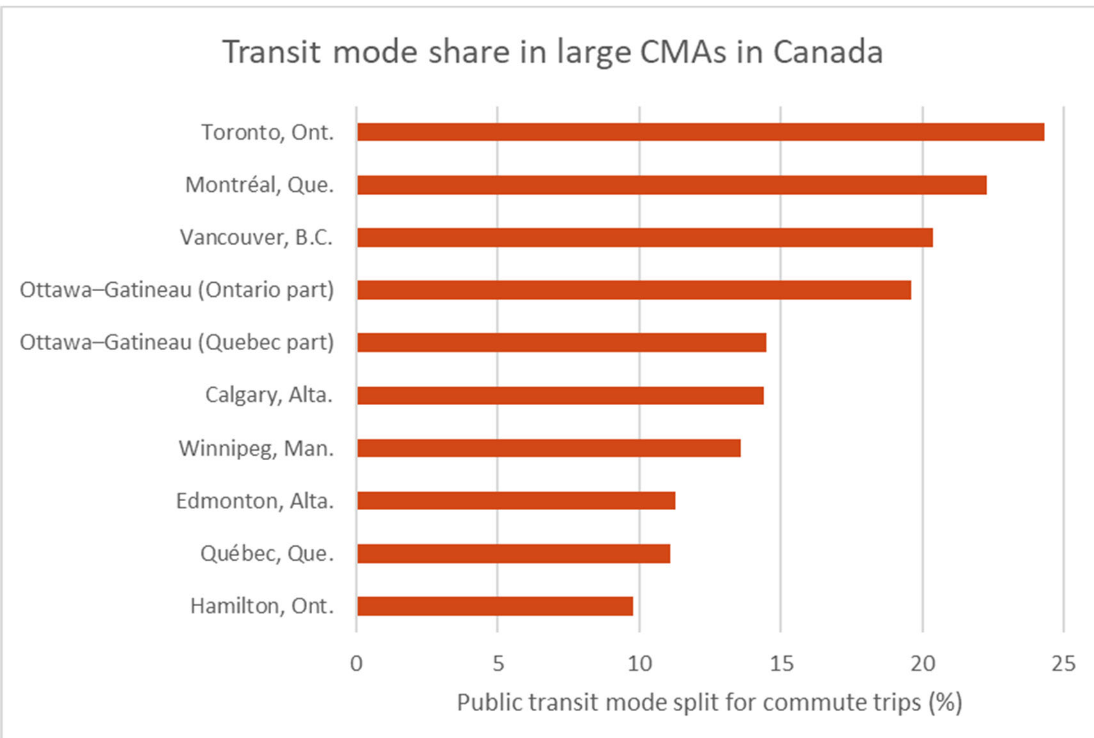

Figure 6: Public transit mode share in Canada's most populous Census Metropolitan Areas, 2016

Source: Statistics Canada, Census (2016)

Proximity to public transit infrastructure offering reliable and regular transit service is a prerequisite for higher levels of transit use. Often, proximity to public transit use is measured as the network or straight-line distance from trip origins to the nearest transit station or stop. However, the transit proximity measure developed by Statistics Canada not only accounts for spatial proximity to transit infrastructure but also normalizes proximity by the aggregate trip making activity in the morning peak period and transit operating frequencies derived from the General Transit Fleet Specification. The measure is defined as follows:

> Proximity to public transit measures the closeness of a dissemination block to any source of public transportation within a 1 km walking distance. This measure is derived from the number of all trips between 7:00 a.m. - 10:00 a.m. from a conglomeration of 95 General Transit Feed Specification (GTFS) data sources. (Statistics Canada, 2020)

Figure 7 presents the distribution of proximity to transit index. A quick comparison of Figure 6 and Figure 7 will reveal a lack of one-to-one correspondence between higher transit proximity and higher transit mode shares. Whereas Toronto CMA reported the highest public transit mode split, the highest proximity to public transit infrastructure is reported for Winnipeg, which reported a much lower transit mode split. Similarly, whereas Edmonton and Calgary, the two most populous cities in Alberta, have ranked lower in transit proximity, their corresponding transit mode shares are higher than other regions that reported better proximity to public transit infrastructure. The above suggests that whereas proximity to public transit matters, it is not a sufficient condition for higher public transit use.

Another point to realize is that not all public transit is created equal. Accessibility to higher-order public transit, either rail or bus, but having a dedicated right-of-way, could be an essential factor in determining the extent of public transit mode share. Consider that the highest public transit mode shares are reported for Toronto, Montréal, and Vancouver, which are the three cities with rail-based public transit operating on dedicated rights-of-way. Montréal and Toronto are served by underground rail in their core municipalities, whereas Vancouver is served by surface rail operating on the dedicated right-of-way. Following these three cities in transit mode share is Ottawa, which until recently operated one of the most successful bus rapid transit systems in North America with an overall transit mode split for commute trips of about 19%. Recently, Ottawa has replaced its bus rapid transit system with a rail-based system. Following Ottawa is Calgary, which also operates a well-subscribed surface rail transit system that serves part of the urban core.

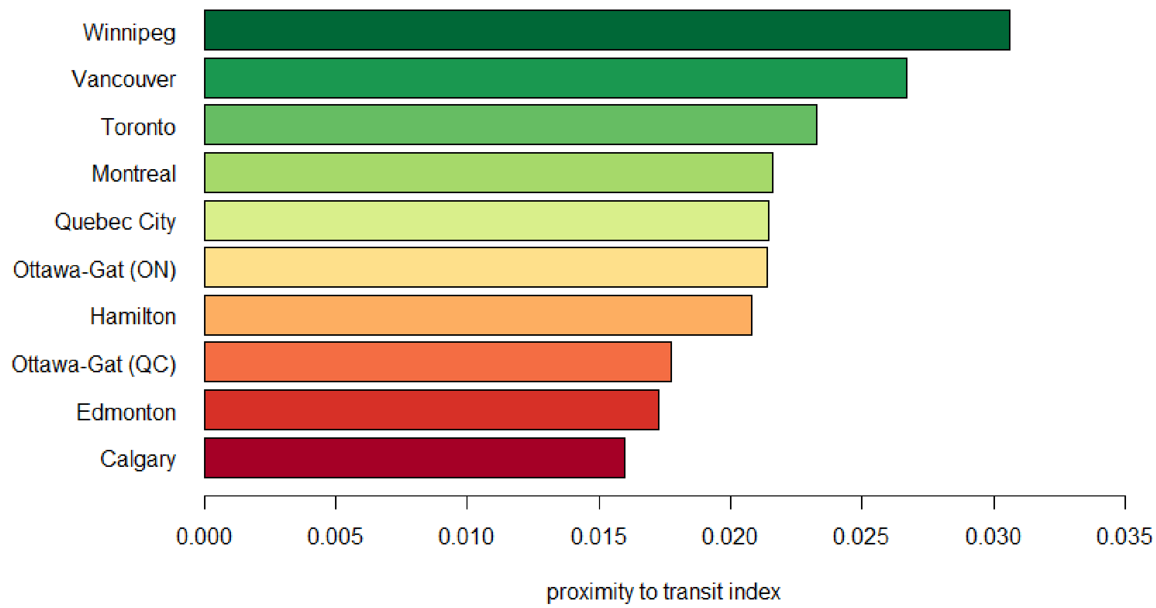

Figure 7: Proximity to public transit infrastructure in large CMAs in Canada

That Winnipeg reports the highest accessibility to public transit but is not among the cities with higher transit mode points to the fact that accessibility to any type of transit is not sufficient. Instead, proximity to higher-order transit, that offers competitive or near competitive travel times to automobile is seen to have a higher payoff for transit mode share.

Since the transit mode share reported here is for work trips only, one would expect that higher accessibility to employment destinations should correlate with higher transit use. Figure 8 offers corroborative evidence. Cities with higher accessibility to employment are also the ones with the highest public transit mode shares. However, this relationship does not hold for all cities where Calgary and Winnipeg report higher accessibility to employment, yet higher-order transit facilities in Ottawa are partly responsible for higher transit mode split.

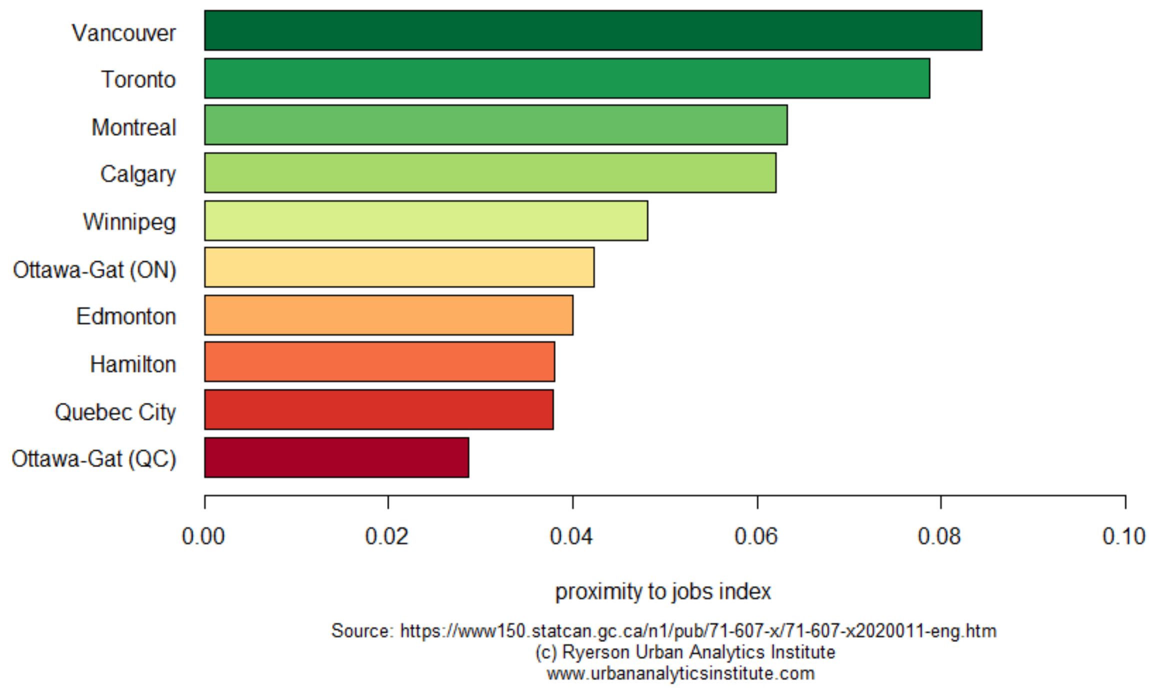

Figure 8: Proximity to employment in large CMAs in Canada

The numerous proxies for the built environment, including measures of compactness, diversity, and accessibility, may be collapsed into one aggregate measure to classify places. As mentioned earlier, Statistics Canada developed eight distinct metrics to capture proximity to destinations, including employment, public transit neighbourhood parts, educational facilities, grocery stores and pharmacies. In addition, Statistics Canada combined these disaggregate metrics into one aggregate measure "to indicate neighbourhoods that have access to basic needs for family with minors." Thus, for every dissemination block in the data set that comprised half a million dissemination blocks, an aggregate measure was developed as an ordinal variable categorizing each neighbourhood as being high, low, or medium amenity dense neighbourhood. "Dissemination block with access to at least one grocery store, pharmacy, healthcare facility, childcare facility, primary school, library, public transit stop, and employment" was referred to as an amenity dense neighbourhood. Specifically, a "high amenity density neighbourhood is defined as an amenity dense neighbourhood that has proximity measure values in the top third of the distribution for each of the eight proximity measures."

Figure 9 presents the map for Vancouver, where each dissemination block has been colour-coded as high amenity (green), medium amenity (blue), and low amenity density (grey). Of the vast area that comprises Vancouver, only a small segment of neighbourhoods are categorized as high amenity (green) dense neighbourhoods. Most neighbourhoods are categorized for medium (blue) or low (grey) amenity density. If a transit-friendly city like Vancouver can boast only a small minority of its neighbourhoods as high amenity density, what can one say of large and small towns whose built environment is not compact and transit mode share is considerably small.

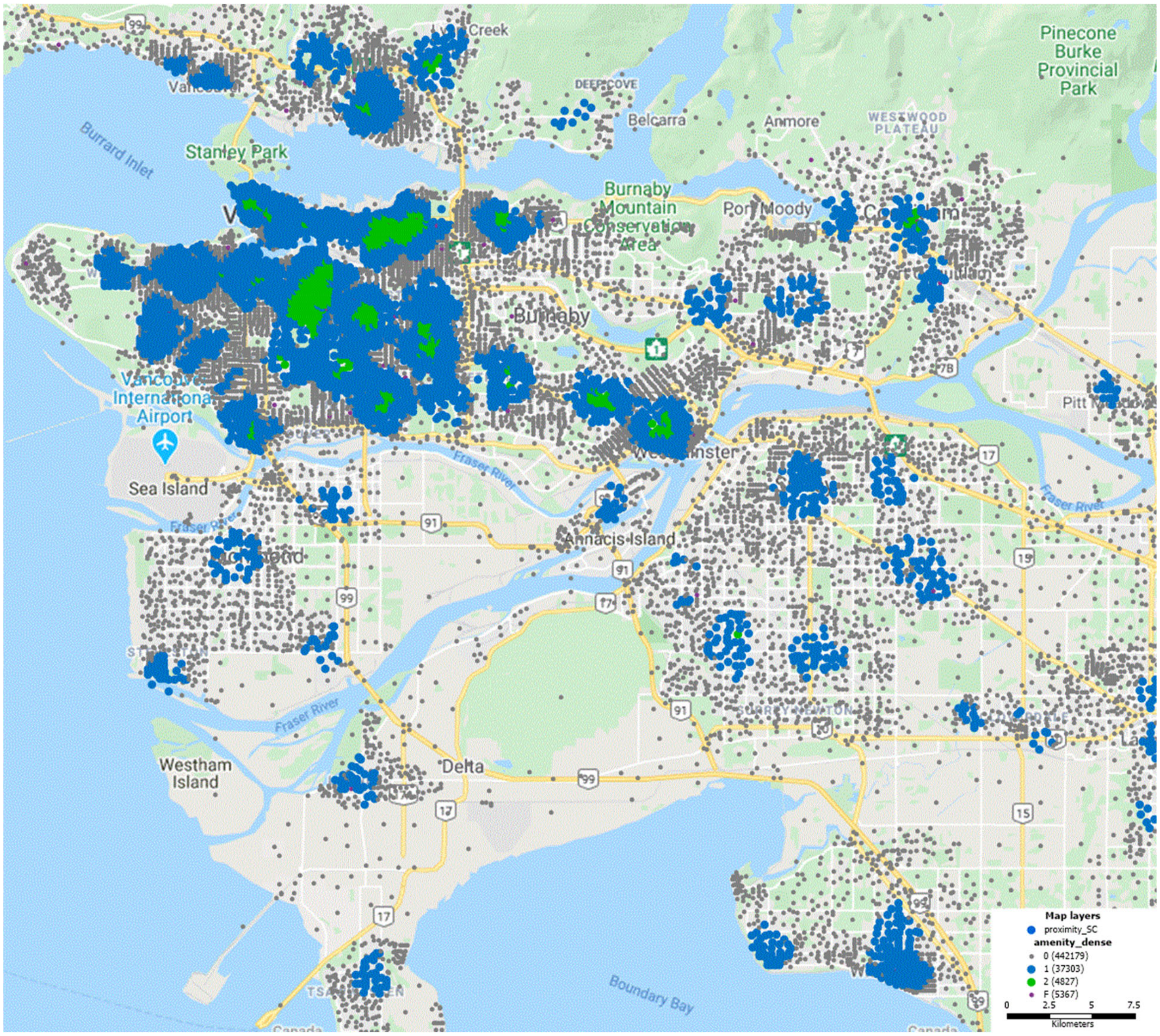

Figure 9: Ordinal depiction of neighbourhoods being of high (green), medium (blue), or low (grey) amenity density.

Another relevant question to pose is what segment of the population lives in high amenity density neighbourhoods. Since the Proximity Measures Database covers all dissemination blocks across Canada, one may try to answer this question by aggregating the population for dissemination blocks as per their categorization for amenity density. The results are presented in Figure 10.

Primarily, across Canada, fewer than 3% of Canadians live in areas that could be categorized as amenity dense neighbourhoods. An overwhelming majority of Canadians comprising more than 80% of the population reside in neighbourhoods that are categorized as lower amenity density. One can infer from these results the potential for public transit use across Canada. The current built environment of neighbourhoods across Canada such that more than 80% of the population resides in places where the built environment does not meet the prescribed standards for supporting reliable and efficient public transit. Fewer than 20% Canadians who live in medium amenity density neighbourhoods are the ones who could be targeted for improvement in transit mode share.

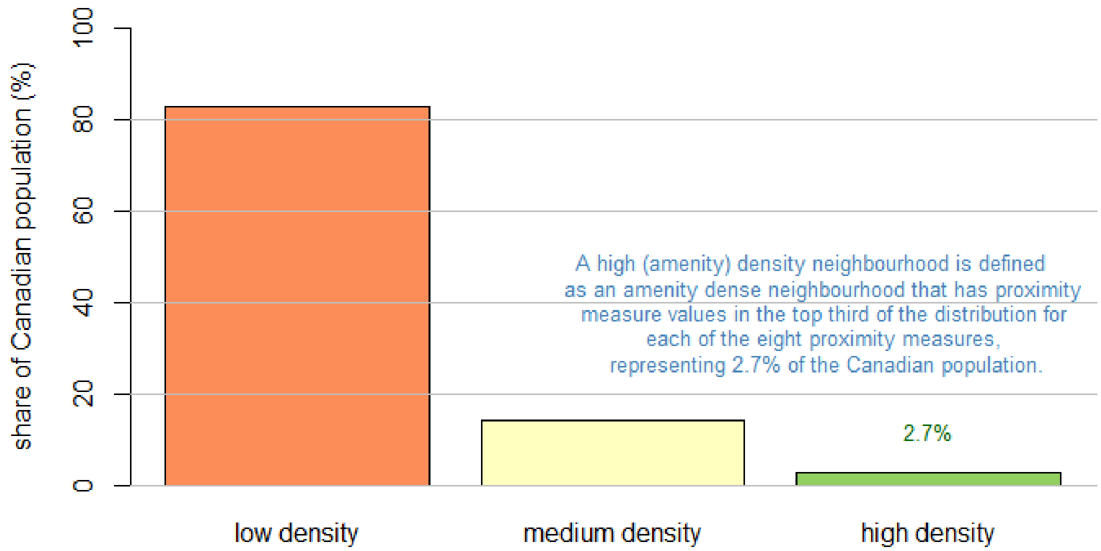

Figure 10: Comparison of means test for transit mode share in new neighbourhoods in Calgary and Montreal

5 CONCLUSIONS

This chapter explored the relationship between the built environment and public transit use. The chapter comprised of two parts. The first part presented a review of the relevant literature exploring the linkages between the built environment and public transit. The second part used data from select few jurisdictions to explore linkages between the built environment and public transit after controlling for factors that have not been discussed widely in the past.

The literature review identified several proxies for the built environment. The most frequently cited measures are indicators of activity concentration. Hence, population and employment densities along with road or intersection densities are frequently cited metrics of the built environment. Other indicators measure the diversity in the built environment (quantified as different types of nearby land uses) and access to amenities, including public transit, central business direct, employment, retail and others.

The near-consensus in the reviewed literature is that higher density, diversity, and other urban design dimensions of the built environment are associated with higher use of public transit. However, no one factor, may that be population or employment density, is a sufficient determinant of higher public transit use. At the same time, built environment metrics are correlated with each other such that any association observed between a built environment metric and public transit use might ignore how other indicators, not controlled for explicitly in the analysis, may also be influential, yet are missing from the analysis. For instance, higher population density neighbourhoods share several other built environment traits, such as higher intersection or road densities, and demographic traits, such as smaller housing units and small-sized households. Thus, population density, if used as an indicator of the built environment in isolation, might reveal a more pronounced impact on public transit usage. In contrast, other supporting built environment attributes, not explicitly control following the analysis, may also be influential on the outcome and when are included in the analysis, might reduce the estimated impact of population density

The primary focus of this chapter has been on the impact of the built environment on transit use. However, others have researched this topic in reverse by exploring the impact of transit infrastructure on nearby land. It has been argued that higher-order public transit is likely to increase the intensity of development on nearby land and may also contribute to accelerated development of undeveloped parcels. Though, some research has shown that transit service changes on their own are not sufficient to influence the neighbouring built form.

The empirical part of the chapter explores the question of why, even when public transit service is available, a large number of commuters, at times the majority, travels by non-transit modes. This chapter identifies the average travel time differences between public transit and automobile as a reason for the lower use of public transit. Data from Canada's most populous cities shows that even for cities where higher-order public transit operating on a dedicated right-of-way exists, average travel times by public transit are considerably longer than those by the private automobile. Data from New York City revealed that neighbourhoods with higher public transit mode split also reported higher average commute times. For urban commuters, who are often time-poor, travel by a slower mode is often not the preferred option. Hence, public policy interventions designed to "take people out of their cars" and moved to public transit ignore the apparent lack of competitive advantage for public transit. Also, any assumption that moving a large number of commuters from a faster mode of travel to a slower one will improve average travel times defies logic.

The empirical analysis presented in the chapter shows that neighbourhood vintage is a critical determinant of the built environment that consequently influences public transit mode share. A comparison of public transit use in Montréal, Canada's second-most populous urban centre, also known for high higher transit mode split for commutes, and Calgary, which is not known as a transit-oriented city, showed significant differences in their built environment and public transit use. Such comparisons, though, ignore the differences in vintage between the two cities. Montréal was developed over the past 300 years or more. In contrast, Calgary's urban development has been a recent phenomenon occurring over the past 50 years when mobility by automobile had become ubiquitous. A comparison of built environment indicators and transit use of similar vintage neighbourhoods between Calgary and Montréal suggested little difference. Future comparisons of cross-jurisdictional differences in built environment attributes and public transit use must also be informed by the differences in the vintage of neighbourhoods and cities.

Public policy recommendations emerging from research on the linkages between the built environment and transit use often assume that the existing built environment characteristics, if not supportive of higher transit use, could be modified. For instance, when researchers find higher densities to be correlated with higher public transit use, their findings imply that population densities be increased in low-density areas above the minimum threshold needed for operating frequent transit service. Such recommendations are based on the assumption that the built environment of existing neighbourhoods could be modified. However, such interventions are costly for political and financial reasons. Hence, examples of changes in the built environment of existing neighbourhoods are quite rare. Hence, recommendations for a higher population density or compact built form to support mobility by public transit will be more useful for planned developments.

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