Impact of minimum parking requirements for multi-family residential buildings on housing affordability and sustainability

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URBAN ANALYTCS INSTITUTE

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EXECUTIVE SUMMARY

This study investigates the effects of minimum parking requirements on multi-family residential buildings in Canada, focusing on enhancing housing affordability and reducing the environmental impact of residential construction. Historically, Canadian municipalities mandated builders to provide a specific number of parking spaces, often proportional to the number of dwelling units. However, societal shifts leading to decreased car ownership suggest that these mandatory parking norms may no longer align with the present and future parking needs. This research examines whether reducing or abolishing these requirements could lower construction costs, potentially improving affordability for end-users and lessening environmental burdens due to fewer underground parking constructions.

The research context is the growing housing affordability crisis, affecting many Canadians. Renters and first-time homebuyers, especially young individuals lacking equity from prior homeownership, face increasing challenges. This study focuses on multi-family residential dwellings, which are typically more affordable than ground-oriented housing (i.e., single-family detached homes, semi-detached or duplex homes) and are a popular choice among low to middle-income families. Given that parking requirements add to the construction and maintenance expenses of these dwellings, their reduction could enhance affordability.

A Scan of Municipal Parking Regulations in Canada

This report offers a structured analysis of minimum parking requirements in selected Canadian jurisdictions, assessing their influence on housing affordability and environmental sustainability. It includes a detailed review of parking regulations in Edmonton, Montréal, and Toronto, based on municipal bylaws.[1] The findings show variability in parking requirements across and within these cities and a trend towards decreasing these mandates over time. Notably, two of these municipalities have shifted from minimum to maximum parking requirements, reflecting a change towards accommodating current and future trends in automobile use and parking demand.

Current and Future Demand for Parking

The study undertook a detailed review of societal and technological changes that may contribute to the declining demand for automobile ownership and parking. The report identified shared mobility alternatives, including car sharing where households pool resources to own or have access to a fleet of shared vehicles made available to automobile cooperative members. Whether collectively or individually owned, a large scale adoption of autonomous

[1] The three cities were chosen to capture the diversity in housing market sizes, regional influences, and urban planning frameworks.

vehicles in the future will profoundly impact the amount of parking space required and the location of parking facilities. The autonomous vehicles will be able to pack compactly in parking lots, requiring much less space than regular vehicles. Furthermore, fully autonomous vehicles will be able to travel to inexpensive parking locations, thus shifting the demand for parking spatially. While the impact of autonomous vehicles will realize in the long run, shared mobility and other innovations are having an immediate impact.

At the same time, unlike their baby-boomer parents, millennials have shown a lesser affinity for owning automobiles and have relied on newer modes of transportation, such as Uber and other ride-hailing alternatives, which advances in information and communication technologies have enabled.

While the trends above have been in play for years, the sudden outbreak of COVID-19 further affected mobility patterns and travel demand. Teleworking, or working from home, has fundamentally altered the demand for mobility, directly impacting parking demand. The persistently high office vacancy rates across employment hubs in Canada are suggestive of the long-lasting impact of teleworking. The continued infusion of communication and information technologies has resulted in mobility advances where Mobility is seen as a service (MaaS) rather than a product, merging private and public modes for urban journeys, which are likely to alter parking demand.

These trends suggest that the demand for parking is likely to decline overall and will gravitate to cheaper locations. Hence, minimum parking requirements in multi-family buildings will have to respond to the changes in automobile ownership and parking demand trends.

Imputed and Explicit Value of Parking

The study undertook an econometric analysis to estimate the cost of parking embedded in the transaction price of condominiums in multi-family residential buildings in Toronto[2]. The study found that condominiums bundled with a parking spot cost five to seven percent more than the ones without dedicated parking. An analysis of rental dwellings also suggested that the rents for units with dedicated parking spots were higher than those without parking.

The study also looked at differences in the value of parking geographically. An analysis of the listings for standalone parking spots on the Multiple Listing Service found that parking spots in Toronto were listed on average 34 percent higher than in the suburbs. This finding aligns with the higher land value in urban versus suburban areas. When attached to a multi-family residential unit, the value of parking as a proportion of the overall property value did not differ between urban and suburban locations. While we may have expected suburban buyers and

[2] Due to data limitations, the econometric analysis was only conducted for the City of Toronto.

renters to spend more of their housing budgets on parking given their greater reliance on personal vehicles, the greater availability of parking in the suburbs may also be driving the value of parking down compared to urban areas where parking is scarcer.

Looking at the value of parking attached to residential units that are near transit versus those that are less accessible to transit, the study found that the value of parking as a proportion of overall property value was higher for buildings located farther away from higher-order transit, such as subways compared to those that were within 800 m of a transit stop. These findings taken together with the theory of supply and demand suggest that reducing availability may increase the price of parking and, consequently, of housing. However, when viable alternatives to driving are available, parking prices seem to decrease along with the demand for parking and personal vehicles overall.

Developing Construction Cost Scenarios for Parking Infrastructure

Using industry-relevant cost estimation models, the study developed construction cost scenarios for multi-family residential buildings in Edmonton, Montréal, and Toronto. The proforma-based analysis of construction costs for multi-family residential buildings included a business-as-usual scenario representing a typical building for each city. Construction costs for lower parking requirements were also developed and compared to the Business as Usual scenario to determine the impact of reducing parking on construction costs. As expected, lower parking requirements reduced construction costs, which were proportional to the reduction in parking provision. The study found that lowering the minimum parking requirements by 40 percent compared to the status quo resulted in a decline of up to 9 percent in hard construction costs. It is expected that some construction cost savings will be passed on to the end user of space in multi-family residential buildings, as determined by the level of supply elasticity in the local housing market.

Rehabilitation and Maintenance Costs of Underground Parking Infrastructure

Maintenance costs of parking infrastructure in multi-family residential buildings were explored to determine their impact on the cost of ownership or rents. This research found that the use of concrete is pervasive in underground garages. While concrete is a durable material, it deteriorates based on exposure to elements, resulting in spalled concrete, delamination, leaking cracks and more. The rehabilitation of concrete structures is expensive and adds to the long-term maintenance costs of buildings, resulting in higher costs of ownership or rents.

The review of published research confirmed that periodic maintenance increases the service life of parking infrastructure. In comparison, deferred maintenance increases rehabilitation costs because infrastructure deteriorates faster, requiring more extensive repairs. The repair costs of parking infrastructure for condominiums and purpose-built rental buildings depicted a wide range, again depending upon the extent of wear and tear that differed across buildings. The review confirmed that maintenance costs are higher for buildings with more parking spots than those with fewer spots.

The study estimates the annual maintenance cost for parking at $575 per spot, which is a significant amount cost to tenants and owners. These costs can be reduced by managing the amount of parking required and by ensuring timely maintenance of the parking that is developed.

Construction Management Implications of Underground Parking Construction

The cost of providing underground parking is significantly higher than above-ground parking. According to Altus Group (2022), it takes around $5 – 27 per sq. ft to construct surface-level parking, $75 – 160 per sq. ft to build an above-ground garage and $115 – 265 per sq. ft to construct below-ground parking. Research examined some of the engineering challenges and drivers of these higher costs associated with deep excavation for underground parking infrastructure construction.

Underground parking infrastructure is increasingly susceptible to flooding. The surface runoff is intended to be handled by storm sewers in urban areas. However, given the extensive construction in urban centres, runoff absorption capacity is compromised in places where open green spaces are limited or nonexistent. At the same time, backflow from an existing storm or sewer system can also lead to flooding in an underground parking facility. This implies that underground parking lots are more susceptible to flood-related damage than surface or above-grade parking facilities, meaning higher long-term maintenance costs in cases where flood damage occurs and higher initial construction costs because of the expensive measures required to limit flood water damage.

Deep excavation usually exacerbates the risk of unwanted settlement and different types of slope instability. Settlements that are beyond acceptable thresholds can create cracks in neighbouring buildings. Slope instability or failure could be even more damaging. To stabilize the soil, a retaining wall is built to withstand lateral loads such as soil and hydrostatic pressure. Nevertheless, the hydrostatic pressure increases with the excavated depth, leading to additional concerns about leaking water that require expensive remedial measures at the design and construction stage, contributing to increased construction costs. Hence, construction costs increase because of safety provisions to mitigate risks from deep excavation.

Environmental Implications of Underground Parking

Minimum parking requirements have the environmental implications. Deep excavation displaces soil and creates the need for soil disposal. Estimates by the Ontario Society of

Professional Engineers revealed in 2016 that handling and disposing of excess soil may account for 14 percent of the total project cost. Trucks carrying excess soil from construction sites for disposal travel hundreds of kilometres and contribute to congestion and greenhouse gas emissions.

Environmental regulations require the excavated soil to be reused rather than wasted. However, this might not be cost-effective in urban areas where the excavated soil might require extensive remediation, thus contributing to the overall construction costs. Furthermore, space constraints for soil disposal are a growing concern in Canada.

When soil with impurities is relocated, there's a risk of spreading microorganisms through the soil and water systems. Particularly concerning are E. coli and similar coliform bacteria. These can be found in urban soils, often moving through sewage networks. The level of contamination in soil isn't solely linked to the depth of excavation but is more related to how close it is to the pollution source. These bacteria could originate from the fecal matter of humans, birds, and domestic and wild animals. There's a safety concern, particularly if contaminants infiltrate drinking water sources in rural settings. This risk increases in cases where surplus soil is placed beneath the water table, like during the restoration of pits or quarries.

Transporting excess soil over long distances can lead to problems with invasive species. Different jurisdictions have varying regulations for exotic and invasive species. Human activities introduce alien species to areas where they don't naturally occur. Not all exotic species are intrusive; they become invasive if they harm native land, water, or species, causing ecological or economic issues.

The construction of underground parking facilities is a significant source of greenhouse gas (GHG) emissions. These emissions arise from various activities, including excavation, construction of retaining walls, building walls and floors, waterproofing, and facility operation. Notably, excavation and the construction of retaining walls are critical differentiators between underground and above-ground parking, contributing heavily to GHG emissions. While underground parking might offer microclimate benefits, such as reducing the urban heat island effect, its environmental friendliness is debated. Excavation is particularly impactful as it releases trapped carbon dioxide from the soil, where its concentration is higher than in the atmosphere. The construction process, especially the deep excavation involving heavy equipment, also produces significant CO_2 emissions.

The environmental impacts of constructing underground parking infrastructure are extensive and broad-ranging. By revising minimum parking requirements for multi-family residential buildings, cities can contribute to lowering the adverse environmental impact of the construction industry.

Policy Implications

This study underscores the transformative potential of reducing or eliminating minimum parking requirements in multi-family residential buildings across Canada. The findings strongly suggest that such a policy shift could significantly enhance housing affordability while concurrently addressing environmental concerns.

The analysis reveals that reduced parking provisions can lead to considerable savings in construction costs, potentially lowering prices for end-users. This aspect is especially vital in urban areas where housing affordability is a pressing issue. The cost implications extend beyond construction, as evidenced by the substantial maintenance and rehabilitation expenses associated with underground parking. The study's findings on the explicit and imputed value of parking further underscore the economic and societal shifts affecting automobile ownership and usage, highlighting the growing misalignment between current parking norms, and evolving urban lifestyles.

The study demonstrates the extensive ecological footprint of constructing and maintaining underground parking facilities, ranging from soil displacement and potential contamination issues to significant greenhouse gas emissions. By revising parking requirements, cities can reduce these environmental impacts, aligning urban development more closely with sustainable practices.

Overall, the evidence presented in this report argues persuasively for reevaluating parking policies in the context of multi-family residential developments. The findings suggest that such a policy shift would be responsive to changing societal norms and serve broader objectives of affordability and environmental stewardship. As Canadian cities grapple with the dual challenges of housing affordability and environmental sustainability, the insights from this study offer a compelling roadmap for policy innovation and urban development strategies.

RÉSUMÉ

La présente étude examine les effets des exigences minimales de stationnement sur les immeubles collectifs résidentiels au Canada. Elle met l’accent sur l’amélioration de l’abordabilité du logement et la réduction de l’incidence environnementale de la construction résidentielle. Par le passé, les municipalités canadiennes exigeaient que les constructeurs fournissent un nombre précis de places de stationnement, souvent proportionnel au nombre de logements. Cependant, des changements dans la société ont mené à la réduction du nombre de propriétaires de voitures. Ils donnent à penser que ces normes d’espaces de stationnement obligatoires pourraient ne plus correspondre aux besoins actuels et futurs en la matière. La présente étude cherche à déterminer si la réduction ou la suppression de ces exigences pourrait faire baisser les coûts de construction. Ainsi, on pourrait potentiellement améliorer l’abordabilité pour les utilisateurs finaux et réduire les pressions sur l’environnement en diminuant le nombre de stationnements souterrains construits.

La recherche s’inscrit dans le contexte de la crise croissante de l’abordabilité du logement, qui touche de nombreuses personnes au Canada. Les locataires et les accédants à la propriété, en particulier les jeunes sans avoir net d’une propriété précédente, sont confrontés à des difficultés croissantes. La présente étude porte sur les logements collectifs, qui sont généralement plus abordables que les logements avec entrée privée (maisons individuelles, jumelés ou duplex) et constituent un choix populaire parmi les familles à revenu faible ou moyen. Étant donné que les exigences en matière de stationnement augmentent les dépenses de construction et d’entretien de ces logements, leur réduction pourrait améliorer l’abordabilité.

Examen de la réglementation municipale sur le stationnement au Canada

Le présent rapport expose une analyse structurée des exigences minimales en matière de stationnement dans certaines municipalités canadiennes. Il présente une évaluation de leur influence sur l’abordabilité du logement et la durabilité environnementale. Il comprend un examen détaillé de la réglementation du stationnement à Edmonton, Montréal et Toronto fondé sur les règlements municipaux[3]. Les constatations montrent que les exigences de stationnement varient entre les différentes villes et au sein de celles-ci. On observe aussi une tendance à la réduction de ces exigences au fil du temps. Fait à souligner, deux de ces municipalités sont passées d’exigences minimales à des exigences maximales de stationnement. Cette situation témoigne d’un changement visant à tenir compte des tendances actuelles et futures en matière d’utilisation de l’automobile et de demande de stationnement.

[3] Les trois villes ont été choisies pour tenir compte de la diversité dans la taille des marchés de l’habitation, des influences régionales et des cadres d’urbanisme.

Demande actuelle et future de places de stationnement

L’équipe de recherche a entrepris un examen détaillé des changements sociétaux et technologiques qui pourraient contribuer à la baisse de la demande en ce qui a trait à la propriété d’automobiles et aux espaces de stationnement. Des solutions de mobilité partagée ont été recensées dans le rapport, notamment le partage de véhicule. Des ménages pourraient ainsi mettre en commun leurs ressources pour accéder à un parc de véhicules partagés ou autrement mis à la disposition des membres d’une coopérative automobile. L’adoption à grande échelle de véhicules autonomes, qu'ils appartiennent à une seule personne ou à plusieurs, aura une incidence importante sur la superficie de stationnement requise et l’emplacement des aires de stationnement. Les véhicules autonomes pourront être stationnés de manière beaucoup plus compacte dans les espaces de stationnement par rapport aux véhicules ordinaires. De plus, les véhicules entièrement autonomes pourront être déplacés vers des places de stationnement peu coûteuses. Ainsi, la demande en matière de stationnement sera déplacée dans l’espace. L’incidence des véhicules autonomes se concrétisera sur le long terme, mais l’effet de la mobilité partagée et d’autres types d’innovations est déjà concret.

Parallèlement, au contraire de leurs parents baby-boomers, les membres de la génération Y ont montré moins d’affinité pour la propriété d’automobiles. Ils sont plus enclins à utiliser les modes de transport plus récents, comme Uber et d’autres options de service de hélage électronique, permis par les progrès des technologies de l’information et des communications.

Les tendances décrites ci-dessus se dessinent depuis plusieurs années, mais l’éclosion soudaine de la COVID-19 a eu une incidence supplémentaire sur la mobilité et la demande de déplacements. Le télétravail (ou le travail à domicile) a profondément modifié la demande de mobilité, ce qui a eu une incidence directe sur la demande de stationnement. Les taux d’inoccupation qui demeurent élevés dans les bureaux et les pôles d’emploi au Canada laissent entrevoir les effets à long terme du télétravail. L’influence continue des technologies de communication et d’information a mené à des avancées dans le domaine de la mobilité. Aujourd’hui, la mobilité est conçue comme un service (mobilité-service) plutôt que comme un produit. La fusion des modes privés et publics dans les trajets urbains qui en découle est susceptible de modifier la demande de stationnement.

Ces tendances donnent à penser que la demande de stationnement est susceptible de diminuer globalement et se déplacera vers des endroits moins chers. Par conséquent, les exigences minimales de stationnement dans les immeubles collectifs devront tenir compte de l’évolution des tendances liées à la propriété d’une automobile et à la demande de places de stationnement.

Valeur imputée et explicite du stationnement

L'équipe de recherche a effectué une analyse économétrique pour estimer le coût du stationnement intégré dans le prix des transactions de copropriétés au sein d'immeubles collectifs résidentiels à Toronto[4]. L'étude a révélé que les copropriétés comprenant une place de stationnement coûtent de 5 à 7 % plus cher que celles sans stationnement. Une analyse des logements locatifs a également indiqué que les loyers des logements ayant des places de stationnement réservées étaient plus élevés que ceux des logements sans stationnement.

L'équipe de recherche a également examiné les différences dans la valeur du stationnement entre différents endroits. Une analyse des inscriptions de places de stationnement autonomes au Multiple Listing Service® a révélé que les prix demandés pour les places de stationnement à Toronto étaient en moyenne 34 % plus élevés que dans les banlieues. Cette constatation est cohérente avec le fait que la valeur des terrains est plus élevée en ville qu'en banlieue. Lorsqu'un stationnement est associé à un logement collectif, il n'y a pas de différence entre les villes et les banlieues en ce qui a trait à la valeur du stationnement en proportion de la valeur globale de la propriété. On aurait pu s'attendre à ce que les acheteurs et les locataires des banlieues consacrent une plus grande partie de leur budget de logement au stationnement étant donné leur dépendance plus élevée aux véhicules personnels. Toutefois, la plus grande disponibilité du stationnement en banlieue pourrait aussi faire diminuer la valeur du stationnement par rapport aux zones urbaines où le stationnement est plus rare.

L'équipe de recherche a examiné la valeur des stationnements associés à des logements situés à proximité des transports en commun par rapport à ceux qui sont plus loin. L'étude a révélé que la valeur des stationnements en proportion de la valeur globale de la propriété était plus élevée pour les immeubles situés plus loin des transports en commun de haut niveau, comme les métros, par rapport aux immeubles qui se trouvaient à moins de 800 mètres d'un arrêt de transport en commun. Ces constatations, combinées à la théorie de l'offre et de la demande, donnent à penser que la réduction de la disponibilité des espaces de stationnement pourrait faire augmenter leur prix et, par conséquent, celui du logement. Cependant, lorsque des solutions de rechange viables à la conduite sont accessibles, les prix des espaces de stationnement semblent diminuer, tout comme la demande globale de stationnement et de véhicules personnels.

Élaboration de scénarios de coûts de construction pour l'infrastructure du stationnement

[4] En raison des limites en matière de données, l'analyse économétrique n'a été effectuée que pour la ville de Toronto.

À l’aide de modèles d’estimation des coûts pertinents pour le secteur, l’équipe de recherche a élaboré des scénarios de coûts de construction pour des immeubles collectifs résidentiels à Edmonton, Montréal et Toronto. L’analyse basée sur les prévisions financières des coûts de construction des immeubles collectifs résidentiels comprenait un scénario de maintien du statu quo représentant un immeuble typique pour chaque ville. Les coûts de construction selon un scénario de réduction des exigences de stationnement ont également été établis et comparés au scénario de maintien du statu quo. Le but était de déterminer l’incidence de la réduction du stationnement sur les coûts de construction. Comme prévu, la réduction des exigences de stationnement fait diminuer les coûts de construction. La baisse des coûts est proportionnelle à la réduction des espaces de stationnement. L’étude a révélé que la réduction de 40 % des exigences minimales de stationnement par rapport au statu quo entraînerait une baisse pouvant atteindre 9 % des coûts de construction de base. On s’attend à ce que certaines économies liées aux coûts de construction soient répercutées sur l’utilisateur final des espaces dans les immeubles collectifs résidentiels, selon le niveau d’élasticité de l’offre sur le marché local de l’habitation.

Coûts de remise en état et d’entretien des infrastructures des stationnements souterrains

Les coûts d’entretien des infrastructures de stationnement dans les immeubles collectifs résidentiels ont été examinés afin de déterminer leur incidence sur les coûts de la possession ou de la location d'un logement. Selon les résultats de la recherche, l’utilisation du béton est répandue dans les garages souterrains. Le béton est un matériau durable, mais il se détériore avec l’exposition aux éléments. Il produit ainsi des éclats, des décollements et des fissures provoquant des fuites. La remise en état des ouvrages en béton coûte cher et fait augmenter les coûts d’entretien à long terme des bâtiments, ce qui fait monter les coûts de la possession et de la location des logements.

L’examen des recherches publiées a confirmé que l’entretien périodique prolonge la durée de vie des infrastructures de stationnement. À titre comparatif, l’entretien différé fait augmenter les coûts de remise en état, car les infrastructures se détériorent ainsi plus rapidement. Par la suite, des réparations plus importantes s’imposent. Les coûts de réparation des infrastructures de stationnement pour les copropriétés et les immeubles de logements destinés à la location variaient beaucoup, dans ce cas également, en fonction de l’importance de l’usure du stationnement de l’immeuble. L’examen a confirmé que les coûts d’entretien sont plus élevés dans les immeubles où il y a plus de places de stationnement que dans ceux où il y en a moins.

Selon l’étude, le coût annuel d’entretien du stationnement estimé est de 575 $ par place, ce qui représente un coût important pour les locataires et les propriétaires. Ces coûts peuvent être réduits en gérant la quantité de places de stationnement requises et en assurant l’entretien régulier du parc de stationnement aménagé.

Incidences de la construction de stationnements souterrains sur la gestion de la construction

Les coûts de construction des stationnements souterrains sont nettement plus élevés que ceux des stationnements hors sol. Selon le Groupe Altus (2022), il en coûte environ de 5 à 27 $ par pied carré pour construire un stationnement de surface, de 75 à 160 $ par pied carré pour construire un garage en surface et de 115 à 265 $ par pied carré pour construire un stationnement souterrain. Les recherches ont porté sur certains des défis d'ingénierie et des facteurs expliquant ces coûts plus élevés associés à l'excavation en profondeur pour la construction d'infrastructures de stationnement souterrain.

Les infrastructures des stationnements souterrains sont de plus en plus exposées aux inondations. Les eaux de ruissellement de surface sont en principes traitées par des égouts pluviaux en milieu urbain. Cependant, compte tenu de l'ampleur de la construction dans les centres urbains, la capacité d'absorption des eaux de ruissellement est compromise dans les endroits où les espaces verts ouverts sont limités ou inexistants. Parallèlement, le refoulement d'une installation existante de traitement des eaux ménagères ou des égouts pluviaux peut aussi entraîner des inondations dans un parc de stationnement souterrain. Les stationnements souterrains seraient donc plus vulnérables aux dommages causés par les inondations que les aires de stationnement de surface ou au-dessus du niveau du sol. Ainsi, ils nécessiteraient des coûts d'entretien à long terme plus élevés en cas de dommages causés par des inondations. Ils entraînent aussi des coûts de construction initiaux plus élevés, attribuables aux mesures coûteuses nécessaires pour limiter les dommages causés par les inondations.

Les excavations en profondeur aggravent généralement le risque de tassement indésirable et de différents types d'instabilité des pentes. Les tassements qui dépassent les seuils acceptables peuvent créer des fissures dans les immeubles avoisinants. L'instabilité des pentes ou leur défaillance pourrait être encore plus dommageable. Afin de stabiliser le sol, un mur de soutènement est construit pour résister à des charges latérales comme la pression du sol et la pression hydrostatique. Néanmoins, la pression hydrostatique augmente avec la profondeur de l'excavation, ce qui suscite des préoccupations supplémentaires au sujet des fuites d'eau. Des mesures correctives coûteuses seraient nécessaires aux étapes de la conception et de la construction, ce qui entraînerait une augmentation des coûts de construction. Par conséquent, les coûts de construction augmentent en raison des dispositions de sécurité visant à atténuer les risques liés aux travaux d'excavation en profondeur.

Répercussions environnementales du stationnement souterrain

Les exigences minimales en matière de stationnement ont des répercussions environnementales. Les travaux d'excavation en profondeur entraînent des déplacements des sols et créent un besoin d’élimination des sols. Selon les estimations de l’Ontario Society of Professional Engineers, le traitement et l’élimination des sols excédentaires pourraient représenter 14 % du coût total des projets d’aménagement. Les camions qui transportent le sol excédentaire des chantiers de construction pour élimination parcourent des centaines de kilomètres. Ils contribuent à la congestion routière et aux émissions de gaz à effet de serre.

Les règlements environnementaux exigent que le sol excavé soit réutilisé plutôt que gaspillé. Toutefois, cette exigence pourrait ne pas être rentable dans les régions urbaines où il pourrait être nécessaire d’entreprendre des travaux d’assainissement importants du sol excavé. Cette exigence fait augmenter les coûts de construction globaux. De plus, les contraintes d'espace liées à l’élimination du sol sont une préoccupation croissante au Canada.

Lorsque le sol contenant des impuretés est déplacé, il y a un risque que des microorganismes se propagent à travers le sol et le réseau d’eau. Les bactéries E. coli et les bactéries coliformes semblables sont particulièrement préoccupantes. Elles peuvent se trouver dans les sols urbains et se déplacent souvent dans les réseaux d’eaux usées. Le niveau de contamination du sol n’est pas seulement lié à la profondeur des travaux d’excavation. Il est davantage lié à la proximité de la source de pollution. Ces bactéries peuvent provenir des matières fécales des humains, des oiseaux, ainsi que des animaux domestiques et sauvages. Il s’agit d’une préoccupation en matière de sécurité, surtout si des contaminants s’infiltrent dans les sources d’eau potable en milieu rural. Ce risque augmente lorsque du sol excédentaire est placé sous la nappe phréatique, comme lors de la restauration de fosses ou de carrières.

Le transport de sols excédentaires sur de longues distances peut être problématique sur le plan des espèces envahissantes. Différentes municipalités appliquent diverses réglementations pour les espèces exotiques et envahissantes. Les activités humaines permettent d’introduire des espèces étrangères dans des zones où celles-ci ne se trouveraient pas naturellement. Les espèces exotiques ne sont pas toutes intrusives. Elles deviennent envahissantes si elles nuisent aux terres ancestrales, aux milieux aquatiques naturels ou aux espèces indigènes et causent des problèmes écologiques ou économiques.

La construction de places de stationnement souterraines est une source importante d’émissions de gaz à effet de serre. Ces émissions proviennent de diverses activités, notamment l’excavation, la construction de murs de soutènement, des murs et des planchers, ainsi que l’imperméabilisation et l’exploitation des installations. Il convient de noter que les travaux d’excavation et la construction de murs de soutènement sont des facteurs déterminants qui distinguent les stationnements souterrains des stationnements hors sol. Ces facteurs contribuent beaucoup aux émissions de gaz à effet de serre. Les stationnements souterrains pourraient présenter des avantages en matière de microclimat, comme la réduction de l’effet des îlots de chaleur urbains. Toutefois, leur caractère écologique est matière à débat. Les travaux d'excavation ont une incidence particulièrement importante, car ils libèrent du CO_2 emprisonné dans le sol, dont la concentration est plus élevée que dans l'atmosphère. Le processus de construction, en particulier les travaux d'excavation en profondeur à l'aide d'équipement lourd, produit également d'importantes émissions de CO_2.

La construction d'infrastructures de stationnement souterrain a de vastes répercussions environnementales. En révisant les exigences minimales de stationnement pour les immeubles collectifs résidentiels, les villes peuvent contribuer à réduire l'incidence environnementale négative du secteur de la construction.

Répercussion sur les politiques
La présente étude souligne le potentiel de transformation qu'offre la réduction ou l'élimination des exigences minimales de stationnement dans les immeubles collectifs résidentiels partout au Canada. Les constatations indiquent fortement qu'un tel changement de politiques pourrait améliorer considérablement l'abordabilité du logement tout en tenant compte des préoccupations environnementales.

L'analyse révèle que la réduction des espaces de stationnement peut se traduire par des économies considérables en coûts de construction, ce qui pourrait faire baisser les prix pour les utilisateurs finaux. Cet aspect est particulièrement crucial dans les régions urbaines où l'abordabilité du logement est un enjeu urgent. Les répercussions financières s'étendent au-delà de la construction, comme en témoignent les importantes dépenses d'entretien et de remise en état associées aux espaces de stationnement souterrain. Les résultats de l'étude sur la valeur explicite et imputée du stationnement mettent davantage en relief les changements économiques et sociaux qui touchent la propriété et l'utilisation des automobiles. Ils soulignent l'écart grandissant entre les normes actuelles en matière de stationnement et l'évolution des modes de vie urbains.

Dans l'étude, on démontre la vaste empreinte écologique de la construction et de l'entretien des aires de stationnement souterraines. Le déplacement du sol, les problèmes de contamination potentiels et les fortes émissions de gaz à effet de serre en font partie. En révisant les exigences de stationnement, les Villes pourraient réduire ces répercussions environnementales et aligner davantage l'aménagement urbain sur les pratiques durables.

Dans l'ensemble, les éléments probants exposés dans le présent rapport fournissent des arguments convaincants en faveur d'une réévaluation des politiques de stationnement dans le contexte des ensembles de logements collectifs. Les constatations indiquent qu'un tel changement de politique serait adapté à l'évolution des normes sociétales et répondrait aux objectifs plus généraux en matière d'abordabilité et de la gérance de l'environnement. Pour les villes canadiennes aux prises avec le double défi de l'abordabilité du logement et de la durabilité environnementale, les renseignements tirés de cette étude offrent une feuille de route convaincante pour l'innovation en matière de politiques et les stratégies d'aménagement urbain.

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1 A SCAN OF MUNICIPAL PARKING REGULATIONS IN CANADA

1.1 INTRODUCTION

This section reviews parking regulations in three municipalities: Edmonton, Montreal, and Toronto. This report aims to help understand how parking regulations may impact how multi-family residential buildings are constructed and how parking requirements would affect the design, construction, cost, and ultimately prices of multi-family residential dwellings. Hence, this review focuses on parking regulations for new construction of residential and mixed-use residential buildings. The scope of the inquiry is further limited to off-street parking.

The review explores two dimensions of off-street parking regulations in multi-family residential buildings. First, it documents parking stall space requirements by reviewing the height, length, and width dimensions. Second, it reviews parking space provision requirements for multi-family residential buildings. The relevant regulations for each of the three cities are documented throughout the report as footnotes and summarized in tables for fast scanning.

The review observed similar requirements for standard parking space dimensions, with an averageparking slot being 2.5 meters (m) wide, 5.5 to 6 m in length, and 1.8 to 2 m in height. A parking spot next to an obstruction, such as a pillar or wall, carried larger parking dimensions. Only Toronto specified minimum and maximum parking space (i.e., length, width) dimensions.

The parking space requirements presented a greater variety in regulations. For instance, Toronto and Edmonton had city-wide regulations with exceptions for special zones where a variance from minimum or maximum parking space requirements was suggested. Montreal comprises several boroughs that differ in parking regulations. Also, the smaller independent municipality of Westmount on the island of Montreal differed in regulations. Hence, Montreal's parking regulations review comprises four diverse boroughs and the Cityof Westmount.

In 2020, Edmonton replaced the minimum parking requirements with maximum parking requirements. In similar suit, the City of Toronto adopted new parking standards in 2022 to replace minimum parking requirements with maximum parking requirements and changes to visitor parking requirements. The move is intended to reduce the parking burden on new residential construction. Montreal is unique because it specifies the parking requirements not necessarily per dwelling unit but by the built-up area of the unit. Hence, the specification would read as 1 spot per 50 m^2 rather than 1 spot per dwelling.

The regulations hold several similarities across the jurisdictions. For instance, the number of parking spots required (minimum or maximum) is a function of the number of dwelling units.

Parking requirements could also differ by the location of residential buildings relative to their proximity to a transit station. For example, in Montreal's Cote de Neiges neighbourhood, parking requirements specified one spot for 150 m^2 of space near public transit and a revised higher rate of one parking space for each 90 m^2 of space for buildings located farther away from the transit stations.

Furthermore, parking requirements differed by demographics and the intended end users. For example, parking requirements were higher for residents, such as one spot per one- bedroom unit, versus those for visitors at 0.2 spots per resident. Similarly, parking requirements differed by demographics, with cities having different requirements for general residential buildings versus housing for targeted groups such as the elderly or students.

Lastly, within Toronto and Edmonton, downtown areas are further categorized into zones (eight in Edmonton, and two parking zone areas in Toronto) to account for their location-specific needs based on the declared or intended use of the structure.

1.2 Toronto Parking Regulations

The parking regulations are largely uniform throughout the City of Toronto. City's parking space regulations are set out in Zoning By-law 569-2013, Chapter 200.

The City defines a parking space as '*an area used for the parking or storing of a vehicle*' anddefines a vehicle as '*a wheeled or tracked device, either self-propelled or capable of being pulled by a self-propelled device, for moving persons or objects, or used for construction or agriculture*'.[5]

1.2.1 Parking Space Dimensions

Chapter 200.5.1.10 of the Zoning By-law lists requirements for parking space dimensions within the city. According to the by-law, a parking space must have the following minimum dimensions:

(i) length of 5.6 metres;
(ii) width of 2.6 metres;
(iii) vertical clearance of 2.0 metres; and
(iv) the minimum width in (ii) must be increased by 0.3 metres for each side of the parking space that is obstructed such that any part of a fixed object such as a wall, column, bollard, fence or pipe is situated within 0.3 metres of theside of the parking

[5] City of Toronto, Zoning By-law Ch. 800.50

space, measured at right angles, and more than 1.0 metre from the front or rear of the parking space.[6]

For a parking space accessed by a drive aisle, which the Zoning By-law defines as '*a vehicle passageway located within an area used for the parking or storage of 3 or more vehicles*',[7] with a width of less than 6.0 metres, the minimum dimensions of a parking space are:

(i) length - 5.6 metres;
(ii) width - 2.9 metres;
(iii) vertical clearance - 2.0 metres;
(iv) the minimum width in (ii) must be increased by 0.3 metres if one or both sides of the parking space is obstructed such that any part of a fixed object such as a wall, column, bollard, fence or pipe is situated within 0.3 metres of the side of theparking space, measured at right angles, and more than 1.0 metre from the frontor rear of the parking space.[8]

In addition, the minimum dimensions of a parking space that is adjacent and parallel to a drive aisle from which vehicle access is provided are:

(i) length - 6.7 metres;
(ii) width - 2.6 metres;
(iii) vertical clearance - 2.0 metres;
(iv) the minimum width in (ii) must be increased by 0.3 metres if one or both sides of the parking space is obstructed such that any part of a fixed object such as a wall, column, bollard, fence or pipe is situated within 0.3 metres of the side of theparking space, measured at right angles, and more than 1.0 metre from the frontor rear of the parking space.[9]

Along with minimum parking space dimensions, Chapter 200.5.1.10 of the Zoning By-law provides regulations for the maximum parking space dimensions within the City of Toronto. According to the by-law, the maximum dimensions for a parking space are:

(i) length of 6.0 metres
(ii) width of 3.2 metres[10]

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6 City of Toronto, Zoning By-law Ch. 200.5.1.10

7 City of Toronto, Zoning By-law Ch. 800.50
8 City of Toronto, Zoning By-law Ch. 200.5.1.10
9 City of Toronto, Zoning By-law Ch. 200.5.1.10
10 City of Toronto, Zoning By-law Ch. 200.5.1.10

Regarding the vertical clearance of parking spaces, the Zoning By-law states that 'the minimum vertical clearance for a parking space extends over the entire length and width ofthe parking space, excluding a wheel stop with a height of less than 18.0 centimetres'.[11]

Chapter 200.15.1.1 of the Zoning By-law lists requirements for accessible parking space dimensions within the city. According to the by-law, an accessible parking space must have the following minimum dimensions:

(i) length of 5.6 metres;
(ii) width of 3.4 metres;
(iii) vertical clearance of 2.1 metres[12]

In addition, the minimum dimensions of an accessible parking space that is adjacent and parallel to a drive aisle from which vehicle access is provided are:

(i) length - 7.1 metres;
(ii) width - 2.6 metres;
(iii) vertical clearance - 2.1 metres[13]

1.2.2 Parking Space Requirements

Within the City of Toronto, off street parking spaces must be provided for every building or structure erected or enlarged in compliance with Chapter 200.5.10.1 of the Zoning By-law.

This bylaw was revised in early 2022, and the updates represent a significant change to Toronto's parking requirements. With this revised bylaw, the City of Toronto shifted from requiring a minimum to a maximum number of parking spaces in new development projects to enable efficient forms of development and support alternative modes of transportation.

Chapter 200.5.10.1 outlines the maximum allowable parking space and occupancy rates for different housing types, such as apartment buildings, mixed-use buildings and multiple dwelling unit buildings other than apartments. The bylaw also includes two parking zone areas: Zone A, which has more restrictive parking maximums and applies to lands generally within 400 m of higher-order transit stations, and Zone B, which has less restrictive maximums and applies to lands generally within 100 m of frequent surface transit. Residential developments

[11] City of Toronto, Zoning By-law Ch. 200.5.1.10

[12] At the time of writing, accessible parking space dimension is currently under appeal (By-law: 579-2017) City of Toronto, Zoning By-law Ch. 200.15.1.1

[13] City of Toronto, Zoning By-law Ch. 200.15.1.2

with four or fewer units are excluded from maximum parking requirements. A detailed map of the parking zones [14] is shown below in Figure 1-1. The map outlines the parking zone overlay for a portion of the city to demonstrate the variability of parking. As part of the bylaw revisions, the land use categories were grouped together to simplify the bylaw and reduce the number of parking rates.[15]

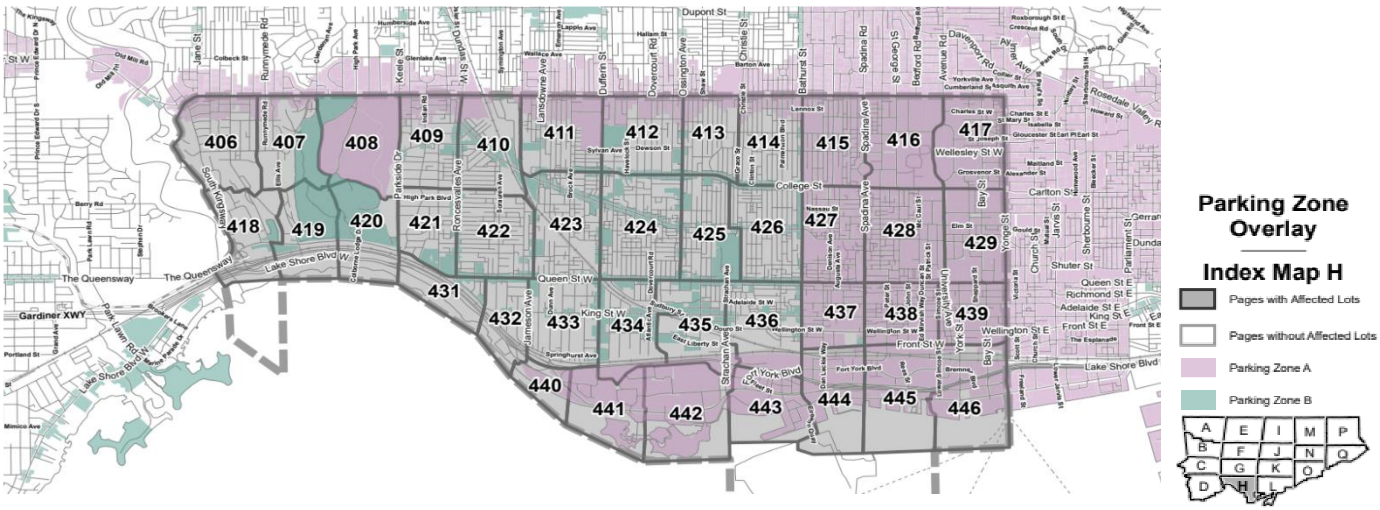

Figure 1-1: City of Toronto Zoning By-law Policy Zone Map[16]

According to the Zoning By-law, parking spaces provided for each use may not be less than the required minimum or greater than the permitted maximum.[17] Also, if there are multiple uses on a lot, the respective parking space rate for each use on the lot applies and the total number of required parking spaces is the cumulative total for all uses.[18]

In some instances, the Zoning By-law states that parking space rate is calculated as a ratio of parking space to the gross floor area, where gross floor area is defined as '*the sum of the total area of each floor level of a building, above and below the ground, measured from the exterior of the main wall of each floor level*'.[19] For example, a specific land use may require a minimum of 2 parking spaces for each 100 square metres of gross floor area.

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[15] https://www.toronto.ca/legdocs/mmis/2021/ph/bgrd/backgroundfile-173150.pdf
[16] https://www.toronto.ca/wp-content/uploads/2021/11/8e63-cityplanning-CWParkingKeyMap11082021.pdf
[17] City of Toronto, Zoning By-law Ch. 200.5.10.1
[18] City of Toronto, Zoning By-law Ch. 200.5.10.1
[19] City of Toronto, Zoning By-law Ch. 800.50

The following table (Table 1-1) lists parking space and occupancy rates for multi-family residential land uses in the City of Toronto.

Table 1-1: Parking Space and Occupancy Rates for Multi-Family Residential Land Uses in the City of Toronto[20]

Land Use Category	Parking Rate
Resident Requirement for a Dwelling unit in an: *Apartment Building*, *Assisted Housing* or a *Mixed Use Building*	Parking spaces must be provided: (A) in Parking Zone A (PZA) at a maximum rate of: (i) 0.3 for a bachelor dwelling unit up to 45 square metres and 1.0 for each bachelor dwelling unit greater than 45 square metres; (ii) 0.5 for a one bedroom dwelling unit; (iii) 0.8 for a two bedroom dwelling unit; and (iv) 1.0 for a three or more bedroom dwelling unit; and (B) in Parking Zone B (PZB) at a maximum rate of: (i) 0.7 for each bachelor dwelling unit up to 45 square meters and 1.0 for each bachelor unit greater than 45 square meters; and (ii) 0.8 for a one bedroom dwelling unit; and (iii) 0.9 for a two bedroom dwelling unit; and (iv) 1.1 for a three or more bedroom dwelling unit; and (C) in all other areas of the City, at a maximum rate of: (i) 0.8 for each bachelor dwelling unit up to 45 square meters and 1.0 for each bachelor unit greater than 45 square meters; and (ii) 0.9 for a one bedroom dwelling unit; and (iii) 1.0 for a two bedroom dwelling unit; and (iv) 1.2 for a three or more bedroom dwelling unit.
Dwelling Unit in a Multiple Dwelling Unit Buildings – Resident Parking Space	Parking spaces must be provided at a maximum rate of 1.0 for each dwelling unit.
Dwelling Unit in a Multiple Dwelling Unit, Apartment Building, a Mixed Use Building – Visitor Parking Space	Parking spaces must be provided: (A) in Parking Zone A (PZA) at a minimum rate of 2.0 plus 0.01 per dwelling unit; and (B) in Parking Zone B (PZB) and in all other areas of the City, at a minimum rate of 2.0 plus 0.05 per dwelling unit; and (C) at a maximum rate of 1.0 per dwelling unit for the first five dwelling units and 0.1 per dwelling unit for sixth and subsequent units.

[20] City of Toronto, Zoning By-law Ch. 200.5.10.1

Multi-Tenant (Rooming) Houses[21]	The parking requirements under the new zoning bylaw for multi-tenant houses are based on transit access. (A) For areas well-served by transit and the former city of Toronto, no parking spaces will be required for a multi-tenant house. For all other areas, a multi-tenant house with six rooms will require at least two parking spaces (the calculation is 0.34 spaces for each room).
Secondary Suite	(B) No parking requirements.

Chapter 200.15.10.10 outlines requirements for accessible parking space rates and states:

If the total parking space requirement is 5 or more, clearly identified off- street accessible parking spaces must be provided on the same lot as every building or structure erected or enlarged, as follows:

(A) if the number of required parking spaces is less than 13, a minimum of 1 parking space must comply with all regulations for an accessible parking space in Section 200.15;
(B) if the number of required parking spaces is 13 to 100, a minimum of 1 parking space for every 25 parking spaces or part thereof must comply with all regulations for an accessible parking space in Section 200.15; and
(C) if the number of required parking spaces is more than 100, a minimum of 5 parking spaces plus 1 parking space for every 50 parking spaces or part thereof more than 100 parking spaces, must comply with all regulations for an accessible parking space in Section 200.15.[22]

However, it should be noted that according to Chapter 200.15.10.5 there are no requirements for accessible parking spaces for dwellings in a detached house, semi-detached house, townhouse, duplex, triplex, fourplex, or secondary suite.[23]

1.3 Montreal Parking Regulations

The City of Montreal is divided into 19 boroughs, each with their own mayor and council. In addition, each Montreal borough has its own zoning bylaw which provide regulations governing parking requirements. Rather than list multi-family residential parking regulations for all 19 Montreal boroughs, this section will review parking regulations for four Montreal boroughs: Ville-Marie, Côte-des-Neiges–Notre-Dame-de-Grâce, Mercier– Hochelaga-Maisonneuve, and L'Île-Bizard–Sainte-Geneviève. Multi-family residential parking regulations

[21] The New Framework for Multi-Tenant (Rooming) Houses is not in Ch.200.5.10.1, but it will be in effect starting March 31st, 2024. This regulatory framework was adopted on December 14th, 2022.
[22] City of Toronto, Zoning By-law Ch. 200.15.10.1
[23] City of Toronto, Zoning By-law Ch. 200.15.10.5

are also be reviewed for Westmount, an independent municipality located on the Island of Montreal.

1.3.1 Vlle-Marie

The borough of Ville-Marie is located in central Montreal and includes the downtown area and Old Montreal. According to the 2016 Canadian Census,[24] Ville-Marie has a populationof 89,170 and a total area of 16.5 km². Figure 1-2 shows the location of Ville-Marie on the Island of Montreal.

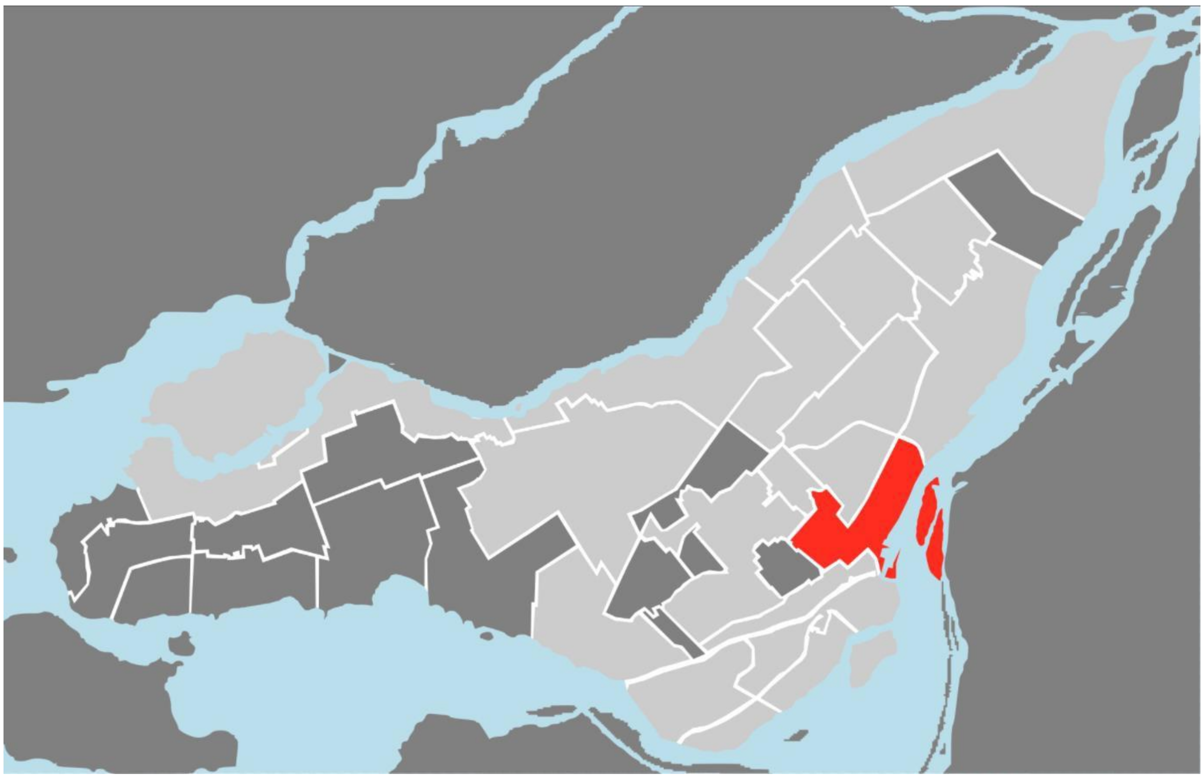

Figure 1-2: Location of Ville-Marie on the Island of Montreal

1.3.1.1 *Parking Space Dimensions*

Article 617 of the Urban Planning By-Law for the Borough of Ville-Marie 01-282 provides guidelines for parking space dimensions within Ville-Marie. The By-Law states that parking spaces must:

- be at least 2.50 m wide and 6.1 m long where it is parallel to a thoroughfare, alley or public road

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[24]http://ville.montreal.qc.ca/pls/portal/docs/page/mtl_stats_fr/media/documents/profil_sociod%c9mo_ville-marie%202016.pdf

- be at least 2.50 m wide and 5.5 m long in any other case
- have a clearance of at least 1.8 m in height[25]

Despite section 617, a parking area may include smaller parking units if:

- the parking unit must be at least 2.30 m wide and 4.6 m long
- the length and width of each parking unit shall be clearly indicated by means of visible signage
- each parking unit shall be identified by distinctive ground markings
- the number of smaller parking units shall not exceed 25% of the total number of parking units in the parking area[26]

1.3.1.2 *Parking Space Requirements*

Article 601 of the Urban Planning By-Law states that 'the floor surface area used to determine the number of required parking units equals the total floor area of a building, excluding spaces used for parking, loading and access roads'.[27] Article 602 states that 'the number of parking units authorized for a building comprising more than one use corresponds to the sum of the number of units authorized for each use'.[28] Article 603 statesthat 'when the number of authorized parking units corresponds to a fractional number, thenumber of units is rounded to the nearest whole number. A fractional number with a fraction equal to one half is rounded up to the nearest whole number'.[29]

Article 605 of the Urban Planning By-Law lists maximum parking provisions for residentialland uses in Ville-Marie which are summarized in Table 1-2.

Table 1-2: Maximum parking provisions for residential land uses in Ville-Marie[30]

Residential Land Use	Maximum Number of Parking Spaces Provided
Building with 3 dwellings or less	2 spaces per dwelling
Building with more than 3 dwellings	
(i) Dwelling with a floor area of up to 50 m²	1 space per dwelling
(ii) Dwelling with a floor area of more than 50 m²	1.5 spaces per dwelling
Rooming house or serviced dwelling	1 space for every 2 rooms

[25] Urban Planning By-Law for the Borough of Ville-Marie, Article 617
[26] Urban Planning By-Law for the Borough of Ville-Marie, Article 617
[27] Urban Planning By-Law for the Borough of Ville-Marie, Article 601
[28] Urban Planning By-Law for the Borough of Ville-Marie, Article 602
[29] Urban Planning By-Law for the Borough of Ville-Marie, Article 603
[30] Urban Planning By-Law for the Borough of Ville-Marie, Article 605

In addition, Article 606 states that 'a number of parking spaces greater than the maximum number is allowed for a use in category R.1 (comprised of 1 or 2 dwellings) when the excessunits are located inside the main building.[31]

1.3.2 Côte-des-Neiges-Notre-Dame-de-Grâce

The borough of Côte-des-Neiges–Notre-Dame-de-Grâce is located in central Montreal and isthe city's most populous borough. According to the 2016 Canadian Census,[32] Côte-des- Neiges–Notre-Dame-de-Grâce has a population of 166,520 and a total area of 21.4 km^2. Thefollowing map (Figure 1-3) shows the location of Côte-des-Neiges–Notre-Dame-de-Grâce on the Island of Montreal.

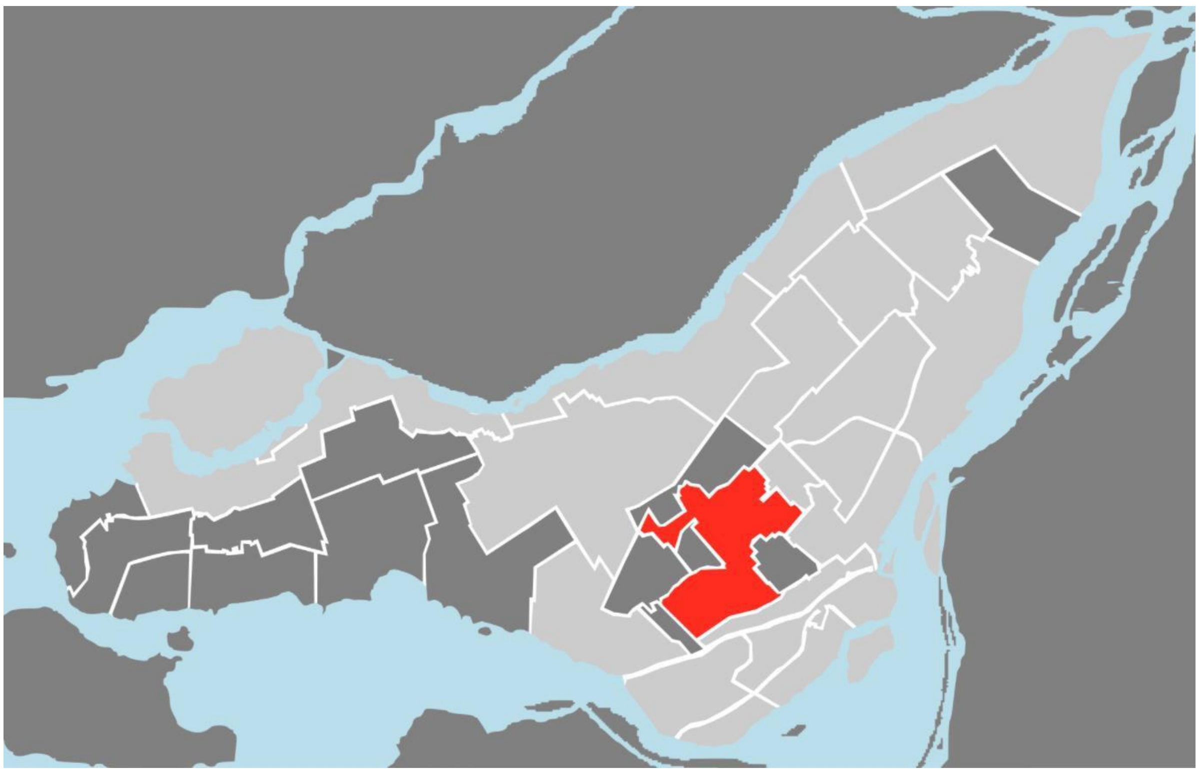

Figure 1-3: Location of Côte-des-Neiges–Notre-Dame-de-Grâce on the Island of Montreal

1.3.2.1 *Parking Space Dimensions*

Article 572 of the Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce 01-276 provides guidelines for parking space dimensions within the

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[31] Urban Planning By-Law for the Borough of Ville-Marie, Article 606

[32] http://ville.montreal.qc.ca/pls/portal/docs/PAGE/MTL_STATS_FR/MEDIA/DOCUMENTS/PROFIL_SOCIOD%C9MO_CDN-NDG%202016.PDF

borough. The By-Law states that parking spaces must:

- be at least 2.5 m wide and 6.1 m long when it is parallel to a thoroughfare, alley or public road;
- be at least 2.5 m wide and 5.5 m long in any other case[33]

Notwithstanding Article 572, the width of a parking unit, for a parking area provided within a building, may be reduced to 2.4 m if:

- the reduction in the width of the parking unit is required solely for the installationof columns or posts used to support the structure
- such columns or posts shall not be located more than 1 m from the beginning or endof the parking unit
- the placement of such columns or posts shall not encroach upon or diminish the width of the driveway and lane
- no other obstructions encroach on the parking unit, including walls, overhanging stairs with a clearance of less than 2.1 m, bollards, ventilation ducts, or any other equipment that would prevent the opening of doors[34]

1.3.2.2 *Parking Space Requirements*

Article 556 of the Urban Planning By-Law states that 'the floor area used to determine the number of parking units permitted is equal to the total floor area of a building, excluding spaces used for parking areas, loading areas and access roads. The calculation of floor area shall be on the exterior face of the walls'.[35] Article 558 states 'where the maximum number of parking units permitted is a fractional number, the number of units shall be rounded to the nearest whole number. A fractional number containing a fraction equal to one-half shallbe rounded up to the nearest whole number'.[36]

Article 560 of the Urban Planning By-Law lists maximum parking provisions for residentialland uses in Côte-des-Neiges–Notre-Dame-de-Grâce which are summarized in Table 1-3.

Table 1-3: Maximum parking provisions for residential land uses in Côte-des-Neiges–Notre-Dame-de-Grâce[37]

[33] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 572
[34] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 572
[35] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 556
[36] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 558
[37] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 560

Residential Land Use	Maximum Number of Parking Spaces Provided in a Zone Close to Public Transit	Maximum Number of Parking Spaces Provided in a Zone Far from Public Transit
All residential land uses	1 space per 150 m^2	1 space per 90 m^2

Article 563 of the Urban Planning By-Law states that 'a parking area may be located on alot other than that of the building it serves'.[38] Furthermore, Article 564 states that 'a parking area must be provided inside a building. However, a number of parking spaces equal to 10% of the maximum number of spaces allowed may be provided outside'.[39]

1.3.3 Mercier-Hochelaga-Maisonneuve

The borough of Mercier–Hochelaga-Maisonneuve is located in eastern Montreal. Accordingto the 2016 Canadian Census,[40] Mercier–Hochelaga-Maisonneuve has a population of 136,024 and a total area of 25.4 km^2. The following map, shown in Figure 1-4, displays the location of Mercier– Hochelaga-Maisonneuve on the Island of Montreal.

[38] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 563
[39] Urban Planning By-Law for the Borough of Côte-des-Neiges–Notre-Dame-de-Grâce, Article 564
[40]http://ville.montreal.qc.ca/pls/portal/docs/PAGE/MTL_STATS_FR/MEDIA/DOCUMENTS/PROFIL_SOCIOD%C9MO_MERCIER%20HOCHELAGA%20MAISONNEUVE%202016.PDF

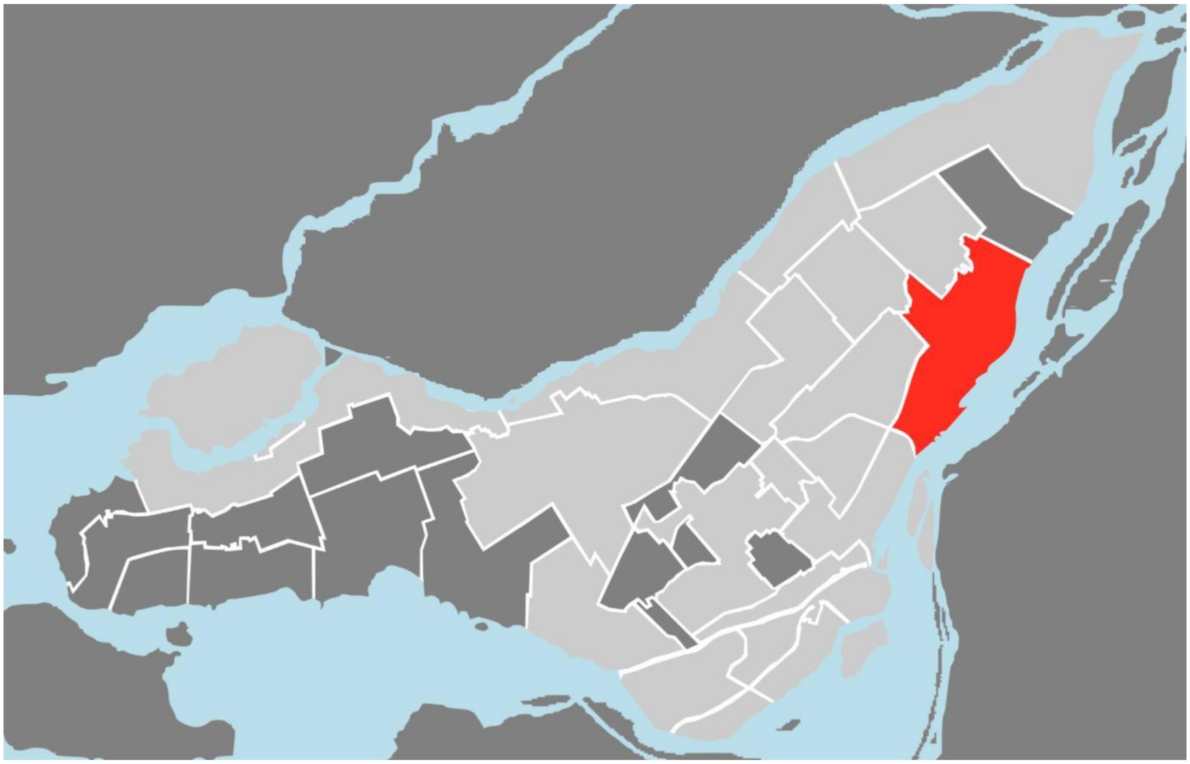

Figure 1-4: Location of Mercier–Hochelaga-Maisonneuve on the Island of Montreal

1.3.3.1 *Parking Space Dimensions*

Article 573 of the Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve 01-275 provides guidelines for parking space dimensions within the borough. The By-Law states that parking spaces must:

- be at least 2.5 m wide and 6.1 m long when it is parallel to a thoroughfare, alley or public road;
- be at least 2.5 m wide and 5.5 m long in any other case[41]

1.3.3.2 *Parking Space Requirements*

Article 561 of the Urban Planning By-Law lists minimum parking requirements and maximum parking provisions for residential land uses in Mercier–Hochelaga-Maisonneuvewhich are summarized in Table 1-4.

[41] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 573

Table 1-4: Minimum parking requirements and maximum parking provisions for residential land uses in Mercier–Hochelaga-Maisonneuve[42]

Residential Land Use	Minimum Number of Parking Spaces Required	Maximum Number of Parking Spaces Provided
Building of 1 to 2 units	None	1
Building of 3 to 4 units	None	2
Building of 5 to 6 units	None	3
Building of 7 to 8 units	None	4
Building of 9 to 35 units	None	1 space per dwelling unit
Building with 36 or more dwelling units, other than a building described in the following line	1 space per group of 2 dwellingunits	1 space per dwelling unit
Buildings with 36 or more dwelling units with a floor area of 50 m^2 or less for each unit	1 space per group of 4 dwelling units	1 space per dwelling unit
Rooming house, retirement home	None	1 space per group of 2 rooms

Article 563 of the Urban Planning By-Law states that 'the minimum number of parking spaces required is reduced by:

- 50% where a building is located within 500 m of a subway access
- 25% where a building occupied by a residential use is located within a radius of more than 500 m but equal to or less than 750 m from a subway access'[43]

Article 563 also states that 'the maximum number of parking units permitted is reduced by:

- 50% where a building occupied by a residential use is located within 500 m of a subway access
- 25% where a building occupied by a residential use is located within a radius of more than 500 m but equal to or less than 750 m from a subway access'[44]

In addition, Article 565 states that 'a parking area may be located inside or outside the building it serves. However, parking spaces that serve an H.6 or H.7 use shall be located only inside the building'.[45] An H.6 use is a residential building with 12 to 35 units and an H.7 use is a residential building with 36 or more units.[46]

[42] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 561
[43] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 563
[44] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 563
[45] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 565
[46] Urban Planning By-Law for the Borough of Mercier–Hochelaga-Maisonneuve, Article 133

1.3.4 L'île-Bizard–Sainte-Geneviève

The borough of L'Île-Bizard–Sainte-Geneviève is located in western Montreal and is the city's least populous borough. According to the 2016 Canadian Census,[47] L'Île-Bizard–Sainte-Geneviève has a population of 18,413 and a total area of 23.6 km². Figure *1-5* shows the location of L'Île-Bizard–Sainte-Geneviève on the Island of Montreal. L'Île-Bizard–Sainte-Geneviève consists mainly of a very low-density former village core and an island that is mainly agricultural and forested. As a result, it has very little public transit and its position compared to the rest of Montréal makes it an area less inclined to active transportation. Alternatives to the use of automobiles remain very limited. Low land use density in this borough still allows for above-ground parking units to be built rather than inside a building.

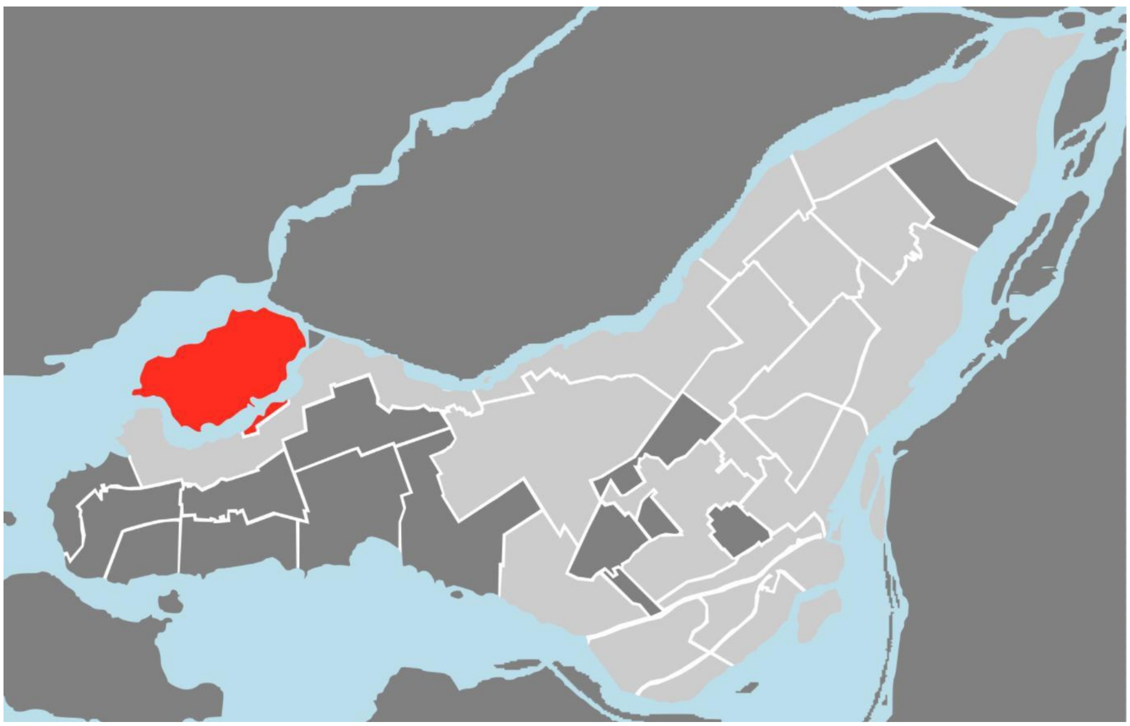

Figure 1-5: Location of L'Île-Bizard–Sainte-Geneviève on the Island of Montreal

1.3.4.1 *Parking Space Dimensions*

Article 250 of the Zoning By-Law for the Borough of L'Île-Bizard–Sainte-Geneviève CA280023 provides guidelines for parking space dimensions within the borough. As shown in Table 1-5, minimum parking space dimensions vary based on the angle of the parking space.

[47] http://ville.montreal.qc.ca/pls/portal/docs/PAGE/MTL_STATS_FR/MEDIA/DOCUMENTS/PROFIL_SOCIOD%C9MO_ILE-BIZARD%20STE-GENEVI%C8VE%202016.PDF

Table 1-5: Minimum parking space dimensions in L'Île-Bizard–Sainte-Geneviève[48]

	Angle of the Parking Space				
Dimension	**Parallel 0°**	**Diagonal 30°**	**Diagonal 45°**	**Diagonal 60°**	**Perpendicular 90°**
Minimal width of a parking space	2.25 m	2.25 m	2.25 m	2.5 m	2.5 m
Minimal length of a parking space	6.5 m	5.3 m	5.3 m	5.3 m	5 m

1.3.4.2 *Parking Space Requirements*

Article 245 of the Zoning By-Law lists minimum parking requirements for residential landuses in L'Île-Bizard–Sainte-Geneviève which are summarized in Table 1-6.

Table 1-6: Minimum parking requirements for residential land uses in L'Île-Bizard–Sainte-Geneviève[49]

Residential Land Use	**Minimum Number of Parking Spaces Required**
Single-family residence and mobile home	1
Two-, three- and multi-family dwellings	1.5 spaces per dwelling unit, except in zones R3-227, R2-229, C2-237, C1-344, R2-346 and R3-347, where it is reduced to 1 space per dwelling unit
Residence for the elderly	0.7 spaces per dwelling 0.5 spaces per room
Student housing	0.5 spaces per room

1.3.5 Westmount

Westmount is a small city located in the central portion of the Island of Montreal. The cityis an affluent enclave that is administratively separate from the City of Montreal.

According to the 2016 Canadian Census,[50] Westmount has a population of 20,312 and a total area of 4.04 km².. Figure 1-6 shows the location of Westmount on the Island of Montreal. Westmount is in fact an area that is already almost entirely built. There are few development opportunities, and it is an area of exceptional heritage value oriented toward preserving its existing built environment. The annual construction volume is relatively low.

[48] Zoning By-Law for the Borough of L'Île-Bizard–Sainte-Geneviève, Article 250
[49] Zoning By-Law for the Borough of L'Île-Bizard–Sainte-Geneviève, Article 245

[50] https://www12.statcan.gc.ca/census-recensement/2016/dppd/prof/details/page.cfm?Lang=E&Geo1=CSD&Code1=2466032&Geo2=POPC&Code2=0547&Data=Count&SearchText=Montreal&SearchType=Begins&SearchPR=01&B1=All

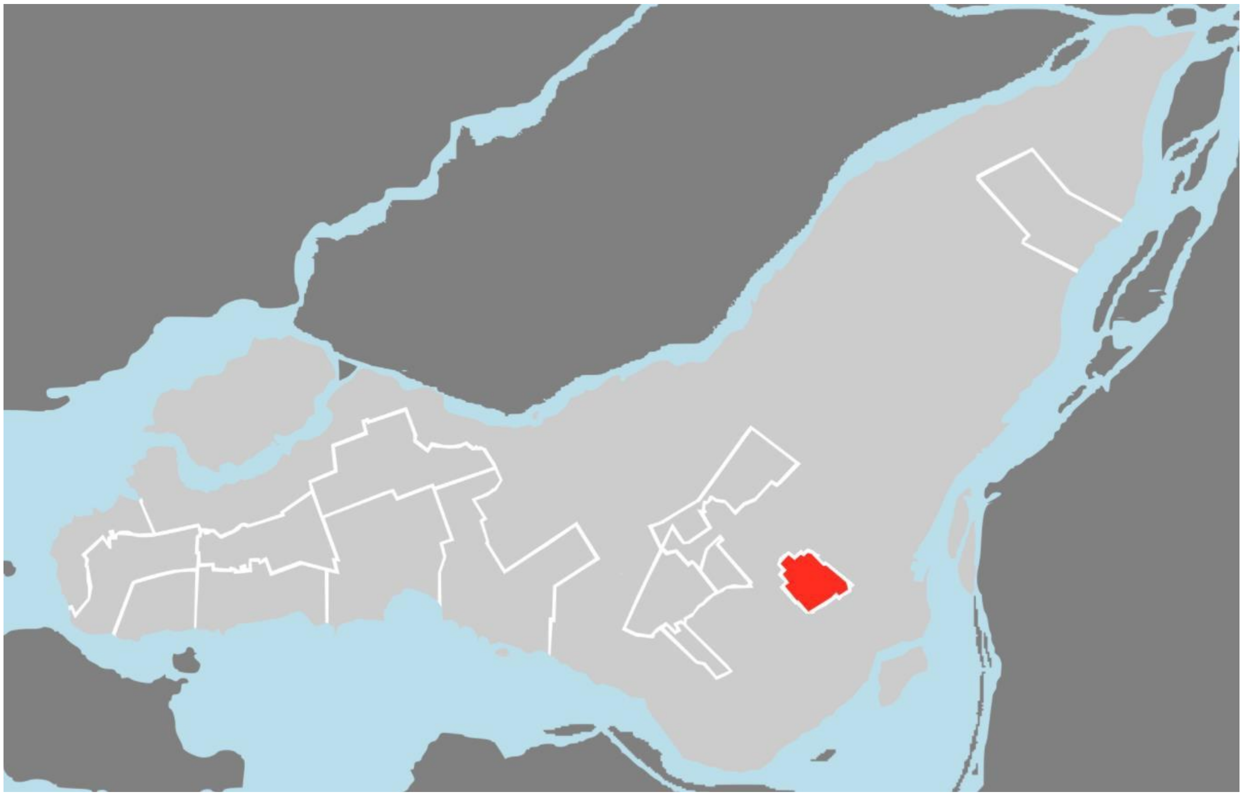

Figure 1-6: Location of Westmount on the Island of Montreal

1.3.5.1 *Parking Space Dimensions*

According to Section 5.5.3.1 of the Westmount Zoning By-Law, 'a parking space must be at least 8 feet (2.44 metres) wide and at least 18 feet (5.49 metres) long'.[51]

1.3.5.2 *Parking Space Requirements*

Sections 5.5.1 and 5.5.2 of the Zoning By-Law provides minimum parking requirements for residential buildings in the City of Westmount, which are summarized in Table 1-7.

Table 1-7: Minimum parking requirements for residential land uses in Westmount[52],[53]

Residential Land Use	**Minimum Number of Parking Spaces Required**
One-family building	1
Two-family building	2
Multi-family building	1 space per dwelling unit

51 Westmount Zoning By-Law, Section 5.5.3.1

52 Westmount Zoning By-Law, Sections 5.5.1

53 Westmount Zoning By-Law, Sections 5.5.2

Residence for senior citizens or institutional building (e.g. student housing)	1 space for every 10 persons (excluding students) 1 additional space per major fraction thereof (i.e., 5 persons or more) to be accommodated in the building

In addition, Section 5.5.7.1 of the Westmount Zoning By-Law states that 'exterior parkingmay not be provided for more than three vehicles on the site of a one or two-family building'.[54]

1.4 Edmonton Parking Regulations

City of Edmonton parking space regulations are set out in Zoning Bylaw No. 12800, Chapter 54. On June 23, 2020, Edmonton City Council voted to remove minimum on-site parking requirements (except for barrier free accessible parking) from the Zoning Bylaw with the change taking effect on July 2, 2020. Maximum parking provisions, however, wereretained in downtown Edmonton, Transit Oriented Development (TOD) areas, and main streets. Land uses without maximum parking provisions can exercise Open Option Parkingwhich allows developers, businesses, and homeowners to decide how much on-site parking to provide.[55]

1.4.1 Parking space dimensions

Chapter 54.1 of the Zoning Bylaw provides guidelines for parking space dimensions withinthe City of Edmonton. As shown in Table 1-8, the minimum parking space dimensions vary for different types of vehicle parking spaces. A maximum of 30% of provided parking spaces on a site may be small car spaces and such spaces shall be clearly signed.

Table 1-8: Edmonton Minimum Parking Space Dimensions[56]

Vehicle Parking Space Type	Length	Width (no obstructions)	Width (with obstruction on one side)	Width (with obstruction on both sides)	Vertical Clearance
Standard spaces and visitor parking spaces	5.5 m	2.6 m	2.7 m	3.0 m	2.1 m

54 Westmount Zoning By-Law, Section 5.5.7.1
55 https://www.edmonton.ca/city_government/urban_planning_and_design/comprehensive-parking-review
56 City of Edmonton, Zoning Bylaw Ch. 54.1

Small car spaces	4.6 m	2.6 m	2.7 m	3.0 m	1.9 m
Tandem spaces	11.0 m	2.6 m	2.7 m	3.0 m	2.1 m
Expanded/oversized spaces	6.2 m	2.9 m	3.1 m	3.3 m	2.4 m
Barrier free (accessible) spaces	5.5 m	2.4 m	Be located adjacent to a 2.4 m wide access aisle where no Vehicle Parking shall be allowed, and which shall be marked to indicate no Vehicle Parking is permitted		2.4 m
Parallel spaces	7.0 m	2.6 m	Drive aisle width is not required if adjacent to apublic right of way		2.1 m

1.4.2 Parking space requirements

Chapter 54.2 of the Zoning Bylaw lists maximum parking provisions for the City of Edmonton. Maximum parking provisions within the Downtown Special Area differ from therest of Edmonton. Within the Downtown Special Area there are eight Special Area Zones, each with their own separate maximum parking provisions. Special Area Zones and their abbreviations are listed in Table 1-9.

Table 1-9: Downtown Special Area Zones[57]

Special Area Zone	Abbreviation
Arena & Entertainment District	AED
Core Commercial Arts	CCA
Commercial Mixed Use	CMU
Heritage Area	HA
High Density Residential	HDR
Jasper Avenue Main Street Commercial	JAMSC
Residential Mixed-Use	RMU
Urban Warehouse	UW

Figure 1-7 illustrates where Special Area Zones are located within the Downtown Special Area.

[57] City of Edmonton, Zoning Bylaw Ch. 910

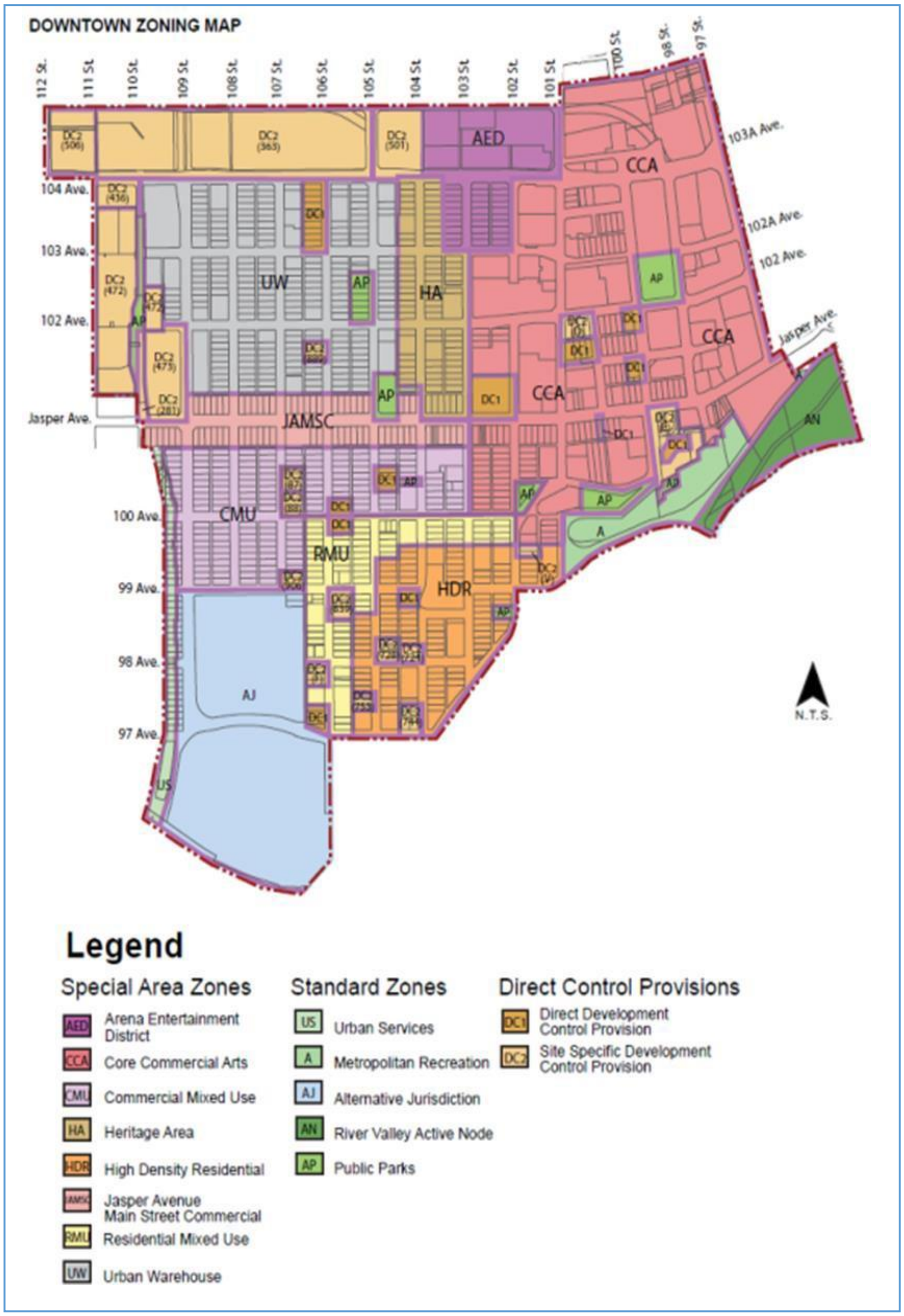

Figure 1-7: Downtown Special Area Zoning Map[58]

Maximum parking provisions for residential and residential-related uses within the Downtown Special Area are listed in Table 1-10, which use abbreviations for the eight Special Area Zones.

Table 1-10: Maximum parking provisions for residential and residential-related land uses in areas within the

[58] City of Edmonton, Zoning Bylaw Ch. 910

Downtown Special Area[59]

	Maximum Number of Parking Spaces Provided by Zone							
Area of Application	**AED**	**CCA**	**CMU**	**HA**	**HDR**	**JAMSC**	**RMU**	**UW**
Per Studio Dwelling	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Per 1 Bedroom Dwelling or Residential-Related Unit	1.25	0.75	0.75	0.75	1.0	0.75	1.0	0.75
Per 2 or more Bedroom Dwelling or Residential-Related Unit	1.25	1.25	1.25	1.25	1.5	1.25	1.5	1.25
Visitor Parking	10	10	10	10	10	10	10	10

Maximum parking provisions are also applicable for multi-unit housing sites outside the Downtown Special Area that are within:

- 600 metres of an existing LRT station, or a future LRT station
- 600 metres of an existing Transit Centre, or a future Transit Centre
- 150 metres of a Transit Avenue; or
- the boundaries shown in the Main Street Overlay map (Figure 1-8)

[59] City of Edmonton, Zoning Bylaw Ch. 54.2

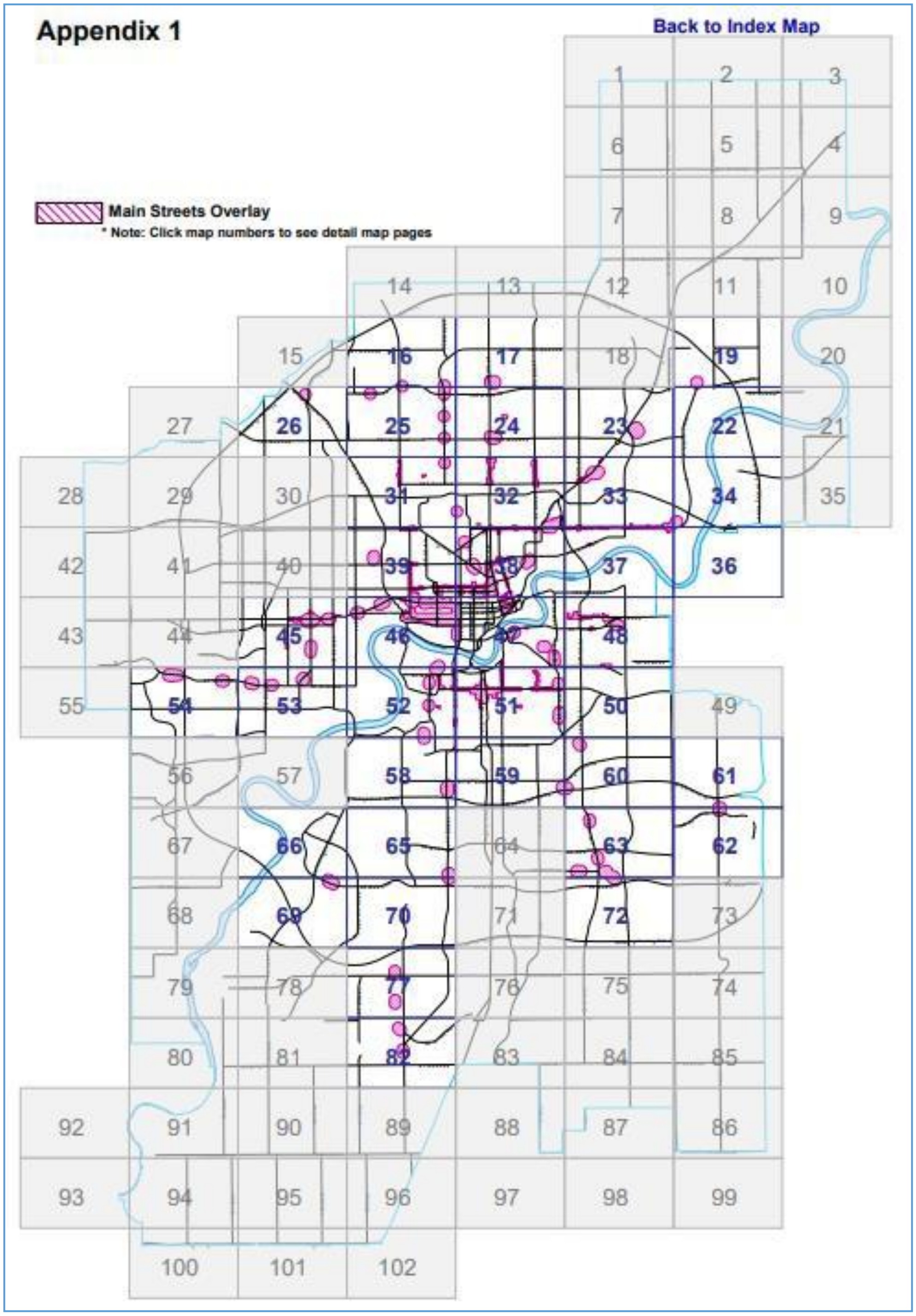

Figure 1-8: Edmonton Main Streets Overlay Map[60]

Maximum parking provisions for applicable multi-unit housing sites outside the Downtown Special Area are listed in Table 1-11.

[60] City of Edmonton, Zoning Bylaw Ch. 819

Table 1-11: Maximum parking provisions for applicable multi-unit housing outside the Downtown Special Area[61]

Area of Application	Maximum Number of Parking Spaces Provided
Per Studio Dwelling	1.0
Per 1 Bedroom Dwelling or Residential-Related Unit	1.0
Per 2 Bedroom Dwelling	1.5
Per 3 or more Bedroom Dwelling or Multi-Unit Housing in the form of Row Housing	1.75

Chapter 54.2 of the Zoning Bylaw also lists minimum barrier free parking requirements fordifferent land uses in the City of Edmonton. For multi-unit housing (5 or more dwellings), apartment hotels, fraternity and sorority housing, supportive housing, live work units, andlodging houses the minimum barrier free parking requirements are:

- 1 vehicle parking space per 0.8 Dwellings; or 1 vehicle parking space per 3 sleeping units which do not meet the definition for a dwelling. or;
- 1 vehicle parking space per 1.2 Dwellings; or 1 vehicle parking space per 5 rooms, suites, or sleeping units which do not meet the definition for a dwelling within the area of application of the Main Streets Overlay, Downtown Special Areas, or the Quarters Overlay.[62]

[61] City of Edmonton, Zoning Bylaw Ch. 54.2
[62] City of Edmonton, Zoning Bylaw Ch. 54.2

1.5 CONCLUSIONS

A scan of off-street parking regulations for residential developments in Toronto, Montreal,and Edmonton reveals that regulations differ both within and across municipalities (as seen in Table 1-12). Regarding parking space dimensions, Toronto has mostly minimum and maximum permissible dimensions (height, width, and length), while Edmonton and the five jurisdictions studied on the Island of Montreal have minimum parking space dimensions but no maximum dimensions.

Table 1-12: Provision of minimum or maximum parking dimensions in study jurisdictions

Jurisdiction	**Minimum Parking Dimensions**	**Maximum Parking Dimensions**
Toronto	✓	✓
Island of Montreal		
- Ville-Marie	✓	
- Côte-des-Neiges–Notre-Dame-de-Grâce	✓	
- Mercier–Hochelaga-Maisonneuve	✓	
- L'Île-Bizard–Sainte-Geneviève	✓	
- Westmount	✓	
Edmonton	✓	

Table 1-13 summarizes the use of off-street parking requirements for Edmonton, Montreal, and Toronto. The City of Toronto Zoning By-law lists maximum parking requirements for all residential land uses and both minimum and maximum parking provisions for visitor parking requirements. The City of Edmonton removed minimum off-street parking requirements on July 2, 2020, and now employs maximum parking provisions in the downtown area, Transit Oriented Development (TOD) areas, and main streets. Land uses in Edmonton without maximum parking provisions can exercise Open Option Parking, allowing property owners to decide how much on-site parking to provide. Parking requirements for residential land uses on the Island of Montreal differ by jurisdiction. L'Île-Bizard–Sainte-Geneviève and Westmount provide minimum parking requirements, Ville- Marie and Côte-des-Neiges–Notre-Dame-de-Grâce stipulate maximum parking provisions, and Mercier–Hochelaga-Maisonneuve employs both parking space minimums and maximums.

Table 1-13: Use of minimum parking requirements or maximum parking provisions in study jurisdictions

Jurisdiction	Minimum Parking Requirements	Maximum Parking Provisions
Toronto	✓	✓
Island of Montreal		
- Ville-Marie		✓
- Côte-des-Neiges–Notre-Dame-de-Grâce		✓
- Mercier–Hochelaga-Maisonneuve	✓	✓
- L'Île-Bizard–Sainte-Geneviève	✓	
- Westmount	✓	
Edmonton		✓

To illustrate how parking requirements differ in Toronto, Montreal, and Edmonton, Table 1-14 displays the number of spaces required for three typical multi-unit residential buildings: a fourplex, a 6-storey mid-rise, and a 20-storey high-rise. The fourplex in our calculation will have a 2-bedroom unit, two 1-bedroom units, and one bachelor unit. The 6-storey mid-rise will have 60 units with four 2-bedrooms, four 1-bedrooms, and two bachelors on each floor. The 20-storey high-rise will have 320 units with four 3-bedrooms, four 2-bedrooms, four 1-bedrooms, and four bachelors on each floor. For calculation purposes, all bachelor apartments are assumed to be under 50m^2 while all 1-bedroom, 2-bedroom, and 3-bedroom apartments are assumed to be over 50m^2. Parking requirements are calculated for Toronto, Edmonton, and all Island of Montreal jurisdictions in the study except for Côte-des-Neiges–Notre- Dame-de-Grâce as this borough calculates parking requirements based on total floor area of the building and not number or area of dwellings.

Table 1-14: Parking Requirements for Typical Multi-Family Residential Buildings

Jurisdiction	Fourplex	Mid-Rise (60 units)	High-Rise (320 units)
Toronto [63]	Maximum 4 spaces	Maximum 71 spaces	Maximum 357 spaces
Island of Montreal			
- Ville-Marie	Maximum 6 spaces	Maximum 84 spaces	Maximum 440 spaces
- Mercier–Hochelaga-Maisonneuve	Minimum 0 spaces Maximum 2 spaces	Minimum 30 spaces Maximum 60 spaces	Minimum 160 spaces Maximum 320 spaces
- L'Île-Bizard–Sainte-	Minimum 4 spaces	Minimum 60 spaces	Minimum 320 spaces

[63] The City council adopted new parking standards in 2022 (PH29.3), identifying that almost all minimum parking requirements have been eliminated for the majority of land uses. The new provisions suggest maximum requirements for new residential developments and changes to visitor parking requirements.

Geneviève			
- Westmount	Minimum 4 spaces	Minimum 60 spaces	Minimum 320 spaces
Edmonton	Maximum 5 spaces	Maximum 72 spaces	Maximum 420 spaces

L'Île-Bizard–Sainte- Geneviève and Westmount employ minimum parking requirements and have the same minimum parking requirements for all three building types. It should be noted that these calculations are illustrative and for comparison purposes only; in these areas in particular, higher-density new developments may not materialize particularly in the nearer term, given lower-density development patterns and limited available land in the two areas, respectively. This is because L'Île-Bizard–Sainte- Geneviève consists mainly of a very low-density former village core and is mainly agricultural and forested. Westmount is an area that is already built with development opportunities focusing on preserving its existing built environment. It should also be noted that while specific Toronto policy zones provide different maximum parking requirements (see Table 1-1) for most residential buildings, visitor parking requirements for most of the multi-family residential buildings in the city employ minimum parking requirements. The parking requirements identified for Toronto include the minimum requirements from the bylaw requirements in place prior to 2022 and the new maximum requirements that came into force in early 2022 . Costing for both the old and new requirements are included in Section 5 of this report. Edmonton and Ville-Marie employ maximum parking requirements, with Ville-Marie having higher maximum parking requirements for all three buildings than Edmonton, while the average Toronto mid-rise and high-rise have lower maximum parking requirements. Mercier-Hochelaga-Maisonneuve employs minimum and maximum parking requirements, but unlike Toronto, these requirements apply to every residential building in the borough. Mercier-Hochelaga-Maisonneuve has the lowest minimum and lowest maximum parking requirements for each type of residential building.

2 CURRENT AND FUTURE DEMAND FOR PARKING

2.1 INTRODUCTION

The future of parking demand is tied to the future of mobility. The modes people will use totravel, and the spatial distribution of trip origins and destinations will determine the demand for automobile ownership and the resulting demand for parking infrastructure. If the status quo prevails in the future and the current trends of automobile ownership and mobility persist, the demand for parking infrastructure may not subside. Hence, and at least for multi-family residential buildings, the cost of providing parking infrastructure willbe bundled with the overall cost of providing housing. When these costs to develop parking exceed imputed value, as is the case in relative terms with the less expensive dwellings in multi-family residential buildings, parking infrastructure costs can exacerbate the housing affordability challenges. However, a shift in mobility technology and culture in the future that lowers the demand for automobile ownership can reduce the demand for parking space and associated construction costs.

The scope of this section is confined to the analysis of innovations in mobility technology and culture, and the evolving trends of the same that are likely to influence the demand for parking space and infrastructure. First, we review recent innovations in mobility markets, such as car-sharing, ride-hailing, transport network companies (TNC), and the growing role of Artificial Intelligence (AI) in supporting the development of autonomous vehicles.

Recent developments in automobile technology are supplemented by cultural shifts in mobility patterns where the lure of owning automobiles for millennials, for instance, is not the same as was with baby boomers. Finally, COVID-19 has induced fundamental shifts in the way people live and work. The pandemic-driven sudden rise in teleworking (Working from Home) alone has caused a modest decline in mobility demand that is continuing post- pandemic, albeit not at the same level. Teleworking has also shifted the post-industrial era spatial equilibrium. The demand for parking space in and near the downtown employment hubs has experienced a gradual decline, accompanied by an increase in demand for space in suburban neighbourhoods offering spatial abodes at relatively affordable prices.

The advances in Information and Communication Technologies (ICTs) are the quintessential enablers of mobility culture and technology developments. Consider the shared mobility platforms that allow individuals to jointly own vehicles and use them if andwhen necessary. Such programs reduce the demand for automobile ownership, especially the demand for owning more than one vehicle. Households or individuals make bookings forvehicles from a dedicated fleet for future use. The real-time booking and fleet use is enabledby smart devices communicating on real-time digital networks where users and automobiles are matched using AI-based algorithms. Rather than owning one or more vehicles, where most of the time may be parked for over 80 percent of the time, one may opt for shared ownership that is likely to reduce the demand for automobiles. This implies that even though the shared mobility platforms will result in a smaller fleet of vehicles shared over a larger number of users, the average mileage over time could be higher for vehicles in the shared fleet than vehicles owned individually. Despite this caveat, the research presented here found overwhelming evidencesupporting the notion that car-sharing is associated with potential declines in vehicle ownership.

Car-sharing had its ups and downs, with some automobilemanufacturers first embracing the idea and operating similar services (during low demandfor new cars) but later exiting the market when the demand for new cars resumed, however, not for sedans but for larger vehicles. However there exists limitations with car-share vehicles. For example, car-share vehicles occupy space in public and private lots, where users have to go out of their way to access. Often, the lack of availability of different vehicles sizes influences the decision also.

A complimentary trend, ride-hailing, became even more popular during the same period. Operated by Transport Network Companies (TNCs), such as Uber and Lyft, ride-hailing emerged as the second incarnation of taxicabs where users could book and summon a ride using a smart communication device and an app that will match the rider with potential drivers who are in the vicinity and are willing to accept the fare. The automated matching algorithm, fixed predetermined fares, real-time monitoring of the vehicle during transit, automated card or cash-free digital payment are some of the reasons that popularized ride-hailing.

Ride-hailing ran into three significant challenges. First, the vehicles' drivers brought legal challenges to be treated as employees rather than independent contractors. Second, city administrations imposed compliance regulations for safety and licensing that increased thecost of operations and lowered the difference in the fares charged by the traditional cab services and TNCs. Lastly, the pandemic proved to be a considerable challenge where the demand for mobility declined considerably, forcing the TNCs to diversify their product offering by incorporating delivery services.

The car-less lifestyles were facilitated and enabled by ride-hailing services. Research reviewed in this section documents how younger cohorts might have skipped owning anautomobile or the older cohorts giving up one or more cars to rely on ride-hailing. The expected long-term trends suggest a resumption of ride-hailing services in the post- pandemic world that will continue to pressure automobile ownership downward.

The most significant expected impact on the demand for parking will likely come from autonomous vehicles. The detailed review presented in this section points to several expected innovations that will directly impact not only how vehicles will self-drive but, more importantly, how they will self-park. The fully autonomous vehicles, propelled likely by electric power, will have the ability to drop the passenger at the destination and then search for available and affordable parking that may or may not be close to the destinationof the last trip. Hence, parking locations will evolve, and large parking infrastructures willlikely relocate to locations where land and parking are inexpensive.

In summary, the advances in mobility technology and culture suggest that the future demand for automobile ownership is likely to decline. Consequently, and for other relatedfactors, the demand for parking space will decline as well. If these trends materialize, mandated parking space bundled with buildings might not be required to the same extent inthe future, therefore improving housing affordability.

2.2 CURRENT AND FUTURE DEMAND FOR PARKING

The twenty-first century has given rise to a wide array of mobility services, such as ride- hailing, carsharing, bike-sharing, and other mobile innovations. According to McKinsey &Company, the "The shared-mobility market accounted for approximately $130 billion to $140 billion in global consumer spending in 2019." (Heineke et al., 2021). With the abundance of mobility alternatives and the increasing developments in technologies, private automobile ownership is likely to change in the coming years. The rise of shared autonomous vehiclesmay also contribute to the reduction in private vehicle ownership. Since the start of COVID-19 (after March 11th, 2020), studies have found significant short-term behavioural and structural shifts to the urban planning and transportation industry (e.g., Anke et al., 2021; Christidis et al., 2021). Telecommuting and work from home practices have flourished ubiquitously and have hada significant impact on the mode of travel, spatial relocation, and travel demand (e.g., Zhu2013; Elldér, 2020).

As shared mobility and telecommuting increase, vehicle ownership may also change, though, the shift could vary from household to household and place to place. With the expected adoption of autonomous vehicles in the future, the spatial landscape of urban centres may evolve significantly as populous cities will need to build unique and innovativeinfrastructure to support the adoption of autonomous vehicles. Consequently, the adoption of autonomous vehicles is likely to modify the modern-day parking layouts (see Nourinejadet al., 2018) and ease parking constraints in densely populated urban settings while increasing parking efficiencies.

With the abundance of mobility alternatives witnessed recently worldwide, the question regarding the future of private auto ownership and the impact of autonomous vehicles onparking space is a matter of emerging interest among policy makers, business strategists,transport engineers, and urban planners. To imagine what future holds for mobility and parking, we reviewed transport planning literature to provide empirical and theoreticalperspectives on parking demand by evaluating the future of private vehicle ownership, shared mobility dependence, mobility services, and autonomous vehicle sharing capabilities.

2.3 SHARED MOBILITY

Shared mobility is defined as "the shared use of a vehicle, bicycle, or other low-speed mode that enables users to have short-term access to transportation modes on an as-needed basis" (Shaheen et al., 2015). The rise in the emergence of shared automobiles has created several economic and social benefits. Not only does shared automobile ownership mitigate carbon emissions (Zhao, 2018), but it reduces the financial burden of having to own a vehicle. Using the North American car-sharing membership survey, Martin, Shaheen, and Lidicker (2010) found that automobile ownership among the carsharing households declined by nearly 49 percent. The analysis suggested that one car-sharing vehicle on average may replace nine to 13 private vehicles. In a similar survey-based study, Cervero, Golub, and Nee (2007) found that after implementing the City Carshare program in the San Francisco area, about 29 percent of users got rid of one or more cars just two years after the launch of the program. Lane (2005) also finds that after a year of the launchof PhillyCarShare, the number of private vehicles on the road reduced.

The influx of new mobility alternatives, combined with the awareness of transportationcosts and environmental factors, has led to the rise of shared automobile ownership.

However, carsharing may be more complex than just the alternatives provided by shared mobility. The future of shared mobility is influenced by socioeconomic status, demographicbreakdown, and geographic context. When it comes to ride-sourcing and car-sharing, the evidence suggests that not all vehicle-owning households act the same (Dias et al., 2017). Dias et al., (2017) suggest that users of car-sharing mobility tend to be young, well-educated, higher-income, employed, and residing in higher density neighborhoods. Sweet and Scott (2021) claim that though adoption of mobility services expands to larger households, households with children are more likely to remain absent from this process. The evidence also indicates that the expansion of future shared mobility technologies like ride-hailing, car-sharing, and bike hailing can be explained through demographic (i.e., gender and income) and geographic variables (i.e., job density) (Sweet and Scott, 2021).

The COVID-19 pandemic has impacted the shared mobility paradigms. In essence, the recent pandemic has brought several behavioural and structural changes to the transportation industry. With the hesitancy to share space in vehicles with others during the pandemic, one would expect a decline in the demand for shared mobility services. For instance, Morshed, Khan, Tanvir, and Nur (2021) use real-time Twitter data to study the effects of COVID-19 on shared mobility and users' behavioural patterns.

The study reported an increase in negative sentiments and opinions towards ride-hailing services during the pandemic. Another pandemic-era study from Germany suggested the shift from public to private transportation modes (Anke et al., 2021). This belief aligned with a more comprehensive analysis of the EU member states, where the findings proved that the behavioural changes during the pandemic favoured increase in car ownership and use (Christidis et al., 2021).

Shaheen and Wong (2021) outline a scenario planning methodology to help answer the underlying questions of the short and long-term sustainability of public transport and shared mobility. The planning framework includes policy implementation plans for three-time horizons: within twelve months, one to three years, and four to six years. The time- sensitive breakdown allows for an in-depth economic stimulus proposal for public transportand shared mobility services. In summary, the report stresses the importance of short-term funding to help sustain the public transport and shared mobility industry (within twelve months). Once public transport and mobility services have stabilized over the next one to three years, policy and decision makers should emphasize systemic change (i.e., create new public transit business structures or employ customer-centric approach). In the long run, defined as from four to six years, public transportation and shared mobility will need to coexist to provide an innovative mobility ecosystem, which is done through investment in the private and public sectors.

2.4 Ride-hailing

Alongside ridesharing, ride-hailing services have flourished over the past decade, with Uber and Lyft as primary leaders in North America. Business wire estimates that the global market for ride-hailing is expected to reach $108.15 billion in 2025, with a compounded annual growth rate of 17 percent[64]. Moreover, the increase of on-demand ride-hailing services has been quite substantial. Didi Chuxing, Ola Cabs, Cabify, and others have joinedthe international marketplace alongside Uber and Lyft. Despite the increase of ride-hailing services, issues related to regulation, safety and environmental impact continue to spark controversies. While ride-hailing services might boast their role in alleviating traffic congestion, studies suggest that ride-hailing services take riders away from public transit systems (Schaller, 2017).

Young, wealthy, and those living in high-density areas tend to use ride-hailing services more (Dias et al., 2017; Conway, Salon, & King, 2018; Young & Farber, 2019). Others suggest the opposite and claim that ride-hailing caters more to low-income markets (Brown,2019). As environments differ, the need to use ride-hailing also varies. Brown (2019) also finds that the ride-hailing option is more popular when the parking is constrained or where parking restrictions are apparent. The effect of parking on ride- hailing is explored by Weinberger (2012) who reported a negative association between ride- hailing and parking availability. Henao and Marshall (2019b) find that, on average, passengers spend more money on ride-hailing services thanfinding parking and driving themselves. This evidence indicates that the correct pricing structure can help alleviate the disconnect between parking demand and supply.

With a diversity of previously existing transportation alternatives, public or private, researchers have wondered about the adverse impacts of ride-hailing on vehicle kilometrestravelled (VKTs). The question remains to be determined is whether shared mobility increases the average VKT per

[64] https://www.businesswire.com/news/home/20210610005383/en/Global-Ride-Hailing-Market-Report- 2021-COVID-19-Growth-and-Change-to-2030---ResearchAndMarkets.com

city or otherwise. For instance, Henao & Marshall (2019a) conducted a quasi-natural experiment to determine the impact of ride-hailing on the miles travelled in Denver. They found that for every 100 miles travelled with a passenger, an additional 69 deadheading miles are added without a passenger. Comparably, Clewlow andMishra (2017) observed that ride-hailing adds miles to the overall transportation system. In addition, converting car owners to occasional ride share users (those who use ride share services less than four times a month) appears to increase the total vehicle kilometres travelled, but taking them all the way to frequent user status (more than four times a month) leads to lower VKT generation. (Wu and MacKenzie, 2021).

In New York City, Schaller (2017) discovered that the growth of app-based ride-hailing services has contributed to an increase in trips, passengers, and mileage. On average, the ride-hailing services added 34,000 miles (55,000km) per year, which substantially increasedthe total traffic over three years. In San Francisco, from 2010 to 2016, ride-hailing increased Vehicle Miles travelled (VMTs) by 13% and vehicle hours travelled by 30%.

The same metrics would have increased by 7% and 12%, respectively, had ride-hailing not existed (Erhardt et al., 2019). On the other hand, a 2020 Vancouver Panel Survey[4] study found a 24% decrease in the VKT per vehicle over six years (2014-2020). Similarly, VKT percapita has experienced a decrease of 21% since 2014.

The findings suggest that individuals are taking shorter and fewer trips with their vehicles than before. However, one caveat to note of this study is that it accounts for data retrieved from 345 returning members from the panel survey conducted during the previous years.

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Wang et al. (2021) uses the 2017 National Household Travel Survey (NHTS) to examine household travel behaviour in the United States between 2016 and 2017. The paper studies the relationship between the usage of ride-hailing and possession of private vehicle ownership through a bivariate

[65] https://vancouver.ca/files/cov/2020-transportation-panel-survey.pdf

probit model. Based on the study, the authors find that being a regular user of ride hailing services is associated with a decrease of private vehicle ownership by 0.14 units. In other words, being a regular user of ride hailing services leads to a decrease of 8.23 percent of the average number of private owned vehicles. Using the same database, Wu and MacKenzie (2021) find that the number of household vehicles owned decreases by 0.065 units by occasional ride-hailing users compared to non-users. Additionally, the average number of vehicles owned by frequent ride-hailing users was 0.125 units less than occasional ride-hailing users.

2.5 TELECOMMUTING

O'Brien and Aliabadi (2020) define telecommuting as "a subset of teleworking, with the condition that there is a formal arrangement (e.g., policy or contract) between the employee and employer allowing or encouraging remote work at home" (O'Brien & Aliabadi, 1975, pp. 3). Telework, telecommuting, home-working or work from home (WFH) are synonymous when describing remote-working using Information and Communication Technologies. The emergence of teleworking has risen during the 21st century, especially over the past few years.

Technology advancements have allowed teleworking to be practiced and created scopes of employment opportunities for many individuals (Baruch and Nicholson, 1997). Teleworking provides ample benefits as well as costs to individuals, companies, and communities.

Initially, Nilles (1975) observed that teleworking would influence work-related travel behaviour to some degree. However, with the rise in factors like population density, the land value in central business districts, and the shift in commuting patterns, teleworkingnow helps ease traffic congestion.

Researchers have empirically studied the effects of telecommuting on travel behaviour and found that telecommuters on average reside further away from work than non- telecommuters (e.g., Mokhtarian, 1998; Zhu, 2013). For instance, Zhu (2013) discovers that telecommuters having higher income, children, and the access to private vehicles have a longer commute distance and duration. Choo, Mokhtarian, and Salomon (2005) analyzed the impact of telecommuting on vehicle miles travelled (VMT) through time seriesanalysis in the United States. The analysis concluded that telecommuting reduced VMT by 0.34 percent, though not 95 percent confident. Similarly, in Sweden, teleworking influenced mode choice, traffic congestion,and travel demand (Elldér, 2020). Previous research is suggesting that with the ability to work from home, the residential location choices for individuals who telework fully or partially will differ.

As Zhu (2013) explained, those who telecommute chose locations involving longer trip timesto and from work. Many who live and work in the downtown core of populous cities have been found to migrate to inner and outer suburbs. According to an Upwork report released in 2020[66], remote

[66] https://www.upwork.com/press/releases/economist-report-remote-workers-on-the-move

working is likely to lead to spatial redistribution of population in the United States where workers are expected to relocate residences farther away from their place of work. The resulting population growth in the surrounding suburbs may lead to increased traffic and housing demand that the current suburban transportation network and housing supply may not adequately meet. Stiles and Smart (2020) investigated remote working habits in several locations in the United States while analyzing the travel outcomes for all telework scenarios. From 2003 to 2017, full day working from home increased significantly compared to part-time teleworking. With the effects on travel demand and behaviour, the findings suggest that alternative locations for remote work help reduce travel time during peak periods under theassumption that teleworking can help ease traffic congestion by displacing the number of vehicles observed on the road during peak hours. Full-day homeworkers are more likely to avoid morning travel, evening travel or both times of a workday. With less individuals commuting to work, parking demand may change during peak travel hours as more spots are available.

The evolution of teleworking in Canada was relatively slow compared to other parts of the world. However, Canada was still seeing an increasing trend from 2000-2008 in the numberof employees working from home (Turcotte, 2010). Because of the diverse job market, those in managerial or professional roles typically worked from home. Time series data from Canada showed that when a person worked from home, the overall time spent travelling decreased, non-motorized transportation (e.g., walking) decreased, and the time spent in peak period travel also decreased (Lachapelle et al. 2018). Zhu et al. (2018) though reported contradictory findings relative to other researchers who have studied the impact of telecommuting and travel behaviour. The authors suggested that with an increase in telecommuting, individuals are likely to travel more, thus increasing the overall travel demand regardless of location. Those who live in locations farther away from their place of work are more likely to commute longer and farther to other destinations (i.e., grocery stores, gyms, or places of worship), which may increase the VKTs.

While teleworking in Canada showed relatively slower growth earlier (Turcotte, 2010), in recent years it has grown in practice and popularity due to COVID-19 stay-at-home and lockdown mandates. Statistics Canada reported that "at the beginning of 2021, 32% of Canadian employees aged 15 to 69 worked most of their hours from home, compared with only 4% in 2016" (Mehdi and Morissette, 2021). It is estimated that in the United States, approximately 37 percent of jobs can be performed from home, and if all occupations work the same number of hours, working from home can account for nearly 46 percent of allwages. Blumenberg, Paul, and Pierce (2021) use the 2017 U.S. National Household Travel Survey (NHTS) to understand level of vehicle ownership with respect to technology-facilitated services (i.e., remote work). The findings from the study indicates a positive association between working from home and the likelihood of having fewer household vehicles than adults. In addition, the authors suggest that new technology services can reduce, or eliminate, the dependency of privately-owned vehicles.

Using data spanning from 1999 to 2017, Schouten (2021) provides insightful findings from an exhaustive sample across the United States to evaluate the relationship between household relocation and vehicle ownership. Low-income households who make the changefrom the suburbs to urban neighbourhoods reduce vehicle ownership. Fifty-two percent of these movers are likely to become carless than households shifting locations between the suburbs. High-income households following the same shift are 58 percent more likely to transition into a carless lifestyle. Low-income households moving from urban to suburban neighbourhoods are 43 percent more likely to purchase a vehicle. However, for high-incomehouseholds who follow the same transition, the results find that they are 209% more likelyto obtain a vehicle than intra-urban movers. Intuitively, those who relocate from urban to suburban neighbourhoods will increase the vehicle ownership but providing a rich transit network may help alleviate the vehicle ownership burden for most.

2.6 MOBILITY AS A SERVICE (MAAS)

The definition of Mobility as a Service (MaaS) has evolved and changed over the past two decades. A concept that first arose in the late 90s, MaaS grew in recognition and received widespread interest after the implementation of the Whim app in Helsinki, Finland. Heikkilä introduced the first scholarly definition regarding MaaS. She described MaaS in her master's thesis as "a system, in which a comprehensive range of mobility services are provided to customers by mobility operators" (Heikkilä, 2014, pg. 8). Since then, the definition of MaaS has continually changed in conjunction with the technological advancements in the field. Researchers have stated that MaaS is still relatively new and lacks one wholesome definition to capture the MaaS ecosystem. For instance, Arias-Molinares and García-Palomares (2020) conduct a systematic review of the empirical and conceptual literature and argue that the definition of MaaS needs further refinement to account for the various components of the MaaS ecosystem. In addition, many scholars have included different attributes (Kamargianni & Matyas, 2017) and the role of societal ecosystems (Ghanbari et al., 2015) in their definitions and descriptions of MaaS. Despite the addition of elements, definitions of MaaS have generally revolved around three core elements: 1) offering a service, 2) offering mobility rather than transportation, and 3) offering integration of transportation services, information, payment, and ticketing (Sochor et al., 2018). In essence, MaaS is described as an exclusive single platform offering mobility services to complex personalized alternatives tailored to each individual.

Goodall and company (2017) suggest that urban density will continue to rise leading to more congestion in the future. Revamping existing infrastructure or changing the transit system to accommodate vehicle demand will be costly and timely. MaaS allows users to access various mobility options from one centralized domain. As a result, people, goods, and services can move more efficiently and are less expensive than the current possibilities. Goodall et al. (2017) further allude to the point that congestion issues will plague existing transportation networks, making it difficult for future cities to be more inclusive and livable for people. They argue that MaaS is the right move forward to combat urban conglomeration. MaaS has the opportunity to serve a larger cohort through different transportation alternatives, which can improve convenience and reduce vehicle traffic and environmental damage. Sochor et al. (2018) allude to these added value features as “integration of societal goals,” derived from their typology of MaaS. When cities and governments step up to mobility as a service, they can offer residents a range of mobility solutions. This way, neighbourhoods and communities can become more accessible, and vehicles can take up less parking space, reducing private ownership demand and lessening the environmental harm – serving both the needs of cities and citizens (Sochor et al., 2018).

The MaaS model takes the form in many ways; for example, one can access multiple transportation solutions through a single application (e.g., WHIM) or via a P2P provider (e.g., Uber). MaaS, at its total capacity, can increase mobility alternatives and simplify multimodality through integration, all while being sustainable (Preston, 2012). However, for MaaS to provide added value to communities, behavioural patterns towards private vehicle ownership must change. Empirical and qualitative studies examining MaaS user behaviour are rare due to the lack of limited implementation. However, one study used a six-month pilot test of UbiGo, a MaaS service in Gothenburg, Sweden, to examine MaaS users’ expectations and behaviour (Strömberg et al., 2018).

The findings revealed several promising results. Roughly 93 percent of the respondents were satisfied with the service, with many participants citing that it exceeded their expectations. Existing private automobile owners reduced their use of private vehicles and opted to use public transportation and active modes whenever possible. Those who did not have access to a private automobile but thought they required one discovered that they managed well without.

UbiGo endured much success because it catered to the mobility needs of participants (Strömberg et al., 2018). The authors cite suggest that a more ‘personable’ service can lead to both anticipated and unanticipated behavioural changes. Liljamo et al., (2021) studied public perception towards future car ownership with regards to MaaS and autonomous vehicles and found that approximately 58 percent of the respondents would not feel the need to own a private vehicle if there was a low-cost MaaS solution.

Another study focused on the relationship between private vehicle ownership and MaaS use, based on insight from a MaaS pilot study in Belgium (Storme et al., 2019). The study found that private vehicle use did reduce considerably for existing car owners, but not entirely. Nearly 73 percent of participants specified that during the pilot project they managed to have a car-free commute, while practically no one used their vehicles on a day-to-day basis. The results from the aforementioned studies provide more knowledge on the interrelationship between MaaS and private vehicle ownership. It suggests that MaaS can help lower private automobile dependency, increase the use of sustainable transport choices, and promote transportation policy change.

2.7 AUTONOMOUS VEHICLES

With the expected adoption of autonomous vehicles in the coming years, the underlying question then relates to whether society is ready for such a drastic cultural change. In a global survey nearly 58 percent of the participants said that they would ride in a fully functioning self-driving vehicle (Mitchell, 2015). Subsequently, a 2020 survey conducted by PAVE found that about 48 percent of Americans would not enter an autonomous ride-share vehicle. Furthermore, a third of the respondents suggested that the advantages of autonomous vehicles outweigh the disadvantages (PAVE, 2020). The public opinion research suggeststhat autonomous vehicles enjoy support and resistance.

If the adoption of autonomous vehicles overcomes the associated challenges, the future of urban transportation will also see a radical transformation. Factors we worry about – parking congestion, traffic, or pollution – will be resolved to a certain degree with the arrival of autonomous vehicles. Consequently, parking structures will be designed for spacemaximization and optimization. Nourinejad, Bahrami & Roorda (2018) investigated the impact of parking demand on identifying the optimal parking structure. When parking demand is low, parking layouts are traditional to what they are today (two-column islands).However, as parking demand increases, islands become larger with more columns to optimize the roadway space.

Statistically, optimal car-park layouts can decrease the need for parking space by an average of 62 percent and a maximum of 87 percent (Nourinejad et al., 2018). Zhang and Guhathakurta (2017) used simulation models to evaluate the effects of shared autonomousvehicles on the total parking demand in Atlanta. With just a 5 percent market penetrationlevel, the authors predicted a large decline in the demand for parking spaces. They estimated that one shared autonomous vehicle can remove up to 20 parking spaces by reducing vehicle ownership and maximizing vehicle occupancy rates. Therefore, one can expect that if dense urban populous cities adopt shared autonomous vehicles, similar results could be expected.

Parking patterns may potentially see a drastic change as autonomous vehicles can searchfor parking farther away at a cheaper rate (Fagnant and Kockelman, 2015). This implication stems from the assumption that autonomous vehicles can drop passengers offand find parking in other areas, far cheaper than the intended destination. Litman (2016)estimated that utilizing a comprehensive parking management strategy could reduce the cost of parking and the space needed. For example, remote parking reduces the parking requirements by upward of 30 percent, whereas increasing the capacity of the existing parking facilities only reduces parking by a maximum of 15 percent. Furthermore, autonomous vehicles do not necessarily have to park at commercial lots or side streets afterdropping their passengers. Zakharenko (2016) develops an endogenous model to analyze commuting by car and parking. The analysis predicts the emergence of a designated parking facility where most commuter autonomous vehicles will be day-parked, primarily close to the place of work of the commuter.

According to the study, a maximum of 97 percent of autonomous vehicles will occupy this designated zone, whereas the remainder may revert back to residential zones space after dropping the passengers (Zakharenko 2016). Similarly, shared autonomous vehicles can also drive around while waiting for passengers, increasing the average VKTs and decreasing the need to park. Millard-Ball (2019) studiedthe effects of autonomous vehicles not having to park to determine parking behaviour andpricing cost reduction.

The increase in shared mobility offers potential valuable benefits, including improved parking availability, reduced need to construct new public or private parking (Millard-Ballet al., 2005, pg. 98). Kondor et al. (2018) evaluated the impacts of car-sharing, shared parking, and autonomous vehicles on the number of parking stalls required. Autonomous vehicles can potentially provide a 50 percent reduction in the number of parking spots while increasing the overall miles travelled by 2 percent. The relationship is offsetting as the implication of reduced parking allows for significant advantageous benefits for all stakeholders. Better utilization of shared automobiles can serve the same mobility demandwhile minimizing the parking problem (Fagnant and Kockelman, 2015).

Since curb space is valued as a high-priced commodity, curb space re-use is a topic of planning concern. With autonomous vehicles dropping and picking up passengers at the curb, curb space may need significant redevelopment plans. According to Clark (2019), ridership growth in transportation network companies (e.g., Uber and Lyft) has increasedon average by eight percent per month from 2013 to 2017 in Seattle, increasing the use of curb space for their operations. Cities might want to consider optimizing parking facilitiesin other neighbourhoods to repurpose them for new uses of the public space (Clark, 2019).This optimization strategy may potentially increase traffic flow and ease the demand for parking soon.

2.8 Alternatives to Car Use – Active Transportation & Public Transit

The future demand for parking could also be impacted by a possible switch to non-motorized modes of transport, such as walking and biking, or by a more significant uptick in transit mode share. The impact of transit and bike networks on land value and parking demand is intertwined with broader urban planning goals. Well-designed and integrated transportation systems can contribute to more sustainable, livable, and economically vibrant cities. Studies have shown that with affordable mobility alternatives, households can reduce their transportation costs by benefiting from economically advantageous travel options (Alonso, 1964). A shift from private automobiles to public or active transportation can reduce traffic congestion, air and noise pollution, and engage residents towards an active lifestyle (e.g., Litman, 2015; Cortright, 2009).

The most-cited metric for an improvement in the transport system is how it impacts property values for neighbouring structures (Cervero & Kang, 2011; Dubé et al., 2013; Diao et al., 2017). The proximity to transit capitalizes positively into property values because of more diverse mobility alternatives. The impacts vary based on transit attributes and neighbourhood composition. For instance, Dubé et al. (2011) analyzed the impact of the new BRT system in Quebec City. The study found that property value appreciations by 2.9 to 6.9 percent for properties near the service corridor. In a similar study, Cervero and Kang (2011) demonstrated that transit improvements create land value premiums and prompt nearby residents to convert the existing land uses to higher-density developments.

Additionally, recent research has shown that bike facilities are associated with higher home values (El-Geneidy et al., 2016; Liu & Shi, 2017; Conrow et al., 2021). El-Geneidy et al. (2016) demonstrate that home sales prices in Montreal increase in locations with better bicycle share station availability by an average of 2.7 percent. Connolly et al. (2019) also find an overall positive price appreciation associated with proximity to bike facilities; however, through an interconnectivity approach, the study posits that when on-road bike facilities are interconnected with bus stops, their capitalized value decreases. The opposite is evident when bike facilities connect to public space features (Connolly et al., 2019).

Rowe et al. (2011) examined the relationship between parking demand and transit service in First Hill-Capitol Hill (urban) and Redmond (suburban) in the state of Washington. The study chose these two sites based on the different levels of transit services. First Hill-Capitol Hillis is an urban area close to downtown Seattle, and Redmond is a suburban area outside of Seattle with lower population density and less transit service. The case study analysis found that parking demand was about 50 percent less in the urban area than in the suburbs. Efficient public transit, active modes of travel, and higher land-use intensity contribute to dense and diverse living environments.

In the empirical analysis reported later in the report, we uncover a compelling correlation between the valuation of parking spaces and the proximity of dwellings to higher order transit systems, such as subways. Evidently, residences situated near well-established public transit networks exhibit a markedly lower parking valuation compared to those situated at greater distances. This trend underscores the influence of public transit accessibility on commuting patterns. It implies that individuals residing near robust transit options are less dependent on personal automobiles, benefiting from a diversified range of commuting modes. Conversely, dwellers in areas with limited access to public transit are more reliant on personal vehicles for commuting, thereby placing a higher premium on the availability of designated parking spots. This phenomenon reflects a distinct variation in transportation preferences and necessities, shaped significantly by the accessibility and viability of public transit alternatives.

2.9 CONCLUDING REMARKS ABOUT DEMAND FOR PARKING

This review of the literature has provided empirical and theoretical perspectives on the future of parking demand by exploring the trends in automobile ownership. The emergenceof mobility alternatives led to an incredible increase in shared mobility dependence (e.g., Cervero et al. 2007; Martin et al. 2010). This dependence on shared mobility leads to lower ownership levels for private vehicles that contributes to several social and economic benefits.

The use of shared mobility varies by regions. The literature has found that those in high-density areas tend to use ride-hailing services more than others. Since the emergence of teleworking, significant geospatial differences have been observed for individuals who telecommute than those who do not. Some households that lived and worked in the urbanregions relocated to inner and outer suburbs. According to an Upwork report released in 2020[67], working remotely motivated households to move farther away from their place of work—the resulting population growth in surrounding suburbs, which may lead to increased traffic.

As shared mobility, ride-hailing and telecommuting increase, the need for vehicle ownership may see a change; however, it may be subjected to household situations. A recentstudy found that low-income households who move from the suburbs to urban neighbourhoods are more likely to forego their vehicles than high-income households.

Recent literature has suggested that density patterns, socioeconomic and demographic patterns, and individual housing characteristics influence vehicle ownership. With the expected adoption of autonomous vehicles in the coming years, the future of mobility andurban development will see a drastic change.

Using an exhaustive database, Liu et al. (2020) studied automobile ownership for young Americans (25-34 years old) through spatial analytics. The study found that young Americans did not have any particular interest in owning a car, a finding corroborated byother studies (e.g., Oakil et al. 2016). The authors noted that the results varied across the country indicating that young Americans in Northeast states were more likely to be car-less. Additional factors such as income, cost of living, traffic congestion, proximity to school, number of workers, and number of drivers contributed to the probability of vehicle ownershiplevels (e.g., Song and Wang, 2017). At the same time, these stated preferences might be an artifact of individual's demographics where tastes and preferences would change with age and circumstances. The younger cohorts not indicating a preference for owing cars might change when their demographics change with growing families.

From a Canadian perspective, Potoglou and Kanaroglou (2008) estimated a multinomial logit model to assess the influence of various characteristics on the number of vehicles owned by a household in Hamilton, Ontario. They found that automobile ownership correlated with distance to work, income, household size and the number of part-time/full- time workers. The results

[67] https://www.upwork.com/press/releases/economist-report-remote-workers-on-the-move

suggested a negative relationship between mixed density index –defined as households and jobs per acre within a traffic analysis zone – and vehicle ownership. In other words, as the jobs and household mix increase, the probability of owning two or more automobiles decreases. Similarly, Gonzalez et al. (2021) found that thelikelihood of owning a vehicle in high residential areas reduces by 11 percent. As parking availability reflects automobile ownership demand in urban areas (Christiansen et al., 2017) emphasis on unique private parking structures must vary conditionally.

Reducing vehicle ownership in urban areas can mitigate the imbalance between supply anddemand of parking. In addition to the aforementioned factors, private parking availability is a key determinant of automobile ownership. In Madrid, Gonzalez et al. (2021) observed that the number of vehicles per household with private parking is higher relative to households without the availability of private parking. While promoting transport policies to improve urban sustainability and reducing private cars, the authors found a negative impact on vehicle ownership. Areas in Madrid that enforced "Regulated Parking Service Zone (SER)" and "Low Emission Zone (MC)" policies were 39 percent and 33 percent less likely to own a vehicle compared to areas outside the policies, respectively.

As populous urban cities adopt autonomous vehicles, parking and traffic congestion, pollution, and other concerns will decrease as a direct result. The impact of autonomous vehicles on parking space requirements and design will need to be changed to accommodatethe added benefits. Unique parking structures can maximize and optimize space to accountfor the change in parking demand. Optimal car-park layouts can decrease the need for parking space by an average of 62 percent and a maximum of 87 percent (Nourinejad et al.,2018). Simulation models have found that 4.5 percent of public parking space can be emancipated with a conservative adoption of autonomous vehicles (Zhang and Guhathakurta, 2017).

Not only can autonomous vehicles help solve parking constraints in urban settings, they could also influence parking patterns by utilizing a strategy that reduces costs. By driving away from the initial drop-off location, autonomous vehicles can better utilize shared automobiles platform and offer the same mobility demand while minimizing the parking problem. Changes in transportation technology and shared mobility services suggest that automobile ownership may experience noticeable decline in the future. Autonomous vehicles can replace the traditional parking structures in core metropolitan areas by relocating to areas where land is much cheaper. The biggest impact though will be in the space consumed for parking and the location of parking facilities.

3 IMPUTED AND EXPLICIT VALUE OF PARKING

3.1 INTRODUCTION

Recent research has demonstrated that the future arrival of autonomous vehicles and recent changes in mobility technology and culture, i.e., shared mobility or telework, will influence the demand for parking. The redesigned parking lot layouts for autonomous vehicles, for instance, will lower the number of parking spaces required in the future (e.g., Zhang and Guhathakurta, 2017; Nourinejad et al., 2018). In multi-family residential buildings, the cost of parking provisionis bundled into the price of the dwelling unit. Research has shown that zoning bylaws in most municipalities specify minimum parking requirements per unit for multi-family residential dwellings. Because of these by-laws, many contractors and developers incorporate the value of parking in the selling price. This concept of bundling refers to the idea that parking spaces could be economically tied to theselling price of dwellings (McDonnell, Madar, & Been, 2011).

In the past, when mobility was increasingly dependent on the private automobile, an abundant supplyof parking infrastructure was a positive amenity that could elicit a premium from homebuyers. However, when mobility may not be as dependent on private automobiles in the future, providing parking spaces at the same rate could mean that homebuyers be required to pay for an amenity that may not be of much use to them. Moreover, bundling the cost of parking with the price of dwelling units (i.e., condominiums), means that all buyers are required to pay for the same amenity, irrespective of their desirability or intended use. This will inadvertently increase the price of the dwelling unit while offering no direct benefit to some buyers. Hence, estimating the impact of the imputed cost of parking on the overall transaction price of condominiums is a relevant concern, especially when fast-accelerating housing prices have brought housing affordability concerns to the forefront.

This report has three parts. The first part is based on the econometric analysis of the sale price of condominiums to isolate the imputed value of parking provision. This requires imputing the hedonic value of parking space that is embedded in the overall transaction price of a dwelling. We achieve this by analyzing transaction prices of about 40,000 condominium sales in Toronto using econometric tools. The second part reviews the offerings on the Multiple Listing Service for parking spots in multi-residential buildings in Toronto to estimate an explicit value of parking spots. Lastly, we analyze how rents in newly constructed buildings differ by the provision of parking spaces. We first document the estimation of the imputed value of parking with a discussion on hedonicprice modelling.

3.2 Hedonic Price Estimator

We deploy econometric tools to estimate the value of parking bundled with a dwelling. The priceof a heterogenous good, such as a condominium, depends on its structural attributes, such as size, location, and other amenities. Purchasing a property within any real estate market is similar to purchasing a bundle of attributes (Lancaster, 1966). A buyer purchases a property for a variety of reasons; these could be as a direct result of the geographical area, the amenities offered, the number of rooms, proximity to the nearest shopping center, age of the home, and location to the nearest transit hub, among other attributes. Each of these attributes contributes tothe overall value of the dwelling, and together these characteristics comprise a basket of tangibleand intangible assets contributing to the price of a condominium.

Following Rosen's (1974) theory of hedonic pricing, we estimate the hedonic price function to determine the price of a condominium based on its structural attributes and locational characteristics. Specifically, using a hedonic pricing model, we estimate the imputed cost of parking and its possible impact on housing affordability based on condominium sales data from the City of Toronto. The hedonic price model helps estimate the magnitude each factor has on the dependent variable (property value), which provides critical insight into the attributes believed to maximize the utility for the home buyer. The emphasis is primarily on the parking attribute to determine empirically whether parking availability substantially affects a property's value. We do so by controlling other attributes of the dwelling constant.

The hedonic price model is estimated from a combination of dwelling characteristics, such as location, proximity to amenities, e.g., central business district, structural attributes, amenities, and market conditions. Hence, a hedonic price model will allow us to compare the price difference between two condominiums that may be identical in other observable attributes but differ only in parking provision. The difference in the relative price is assumed to be a direct result of the difference in access to parking infrastructure between the two dwelling units.

The sales data is provided by a real estate analytics firm for residential properties sold in the City of Toronto between Q1.2016 and Q1.2018. Using the universal definition of the hedonic pricing model by Malpezzi (2003), we estimate a similar hedonic regression model to estimate the dwelling's value. Any change in the property value because of a marginal change in any of the dwelling characteristics in the model is therefore referred to as *hedonic price change.* The following function describes the model, including the dependent variable representing condominium transaction price and the explanatory variables representing a vector of characteristics observed for each property.

$PropertyValue = f(L, C, A, P)$

Where L represents the location within the market (i.e., distance to CBD),

C represents the dwelling characteristics (i.e., bedrooms, Central Air Conditioning)

A represents the structural amenities included in the property building (i.e., Pool orRecreation Area).

P represent if the property is located in a building with parking infrastructure.

The hedonic regression method uses the sold price of the condominium and its logarithmic transformation as the dependent variable to determine the change in price relative to access to parking space.

3.3 Parking and Dwelling Prices

Many studies conducted in dense metropolitan areas have determined the impact of parking requirements on house prices. Researchers have noted that imposing parking requirements changes the landscape of supply and increases the overall cost of a home. In a newspaper commentary in the early 90s, DeParle (1994) explains and discusses how implementing parking requirements in the denser areas of San Diego led to construction stoppage for single-room occupancy hotels, which were designed to house transient labourers and railroad workers. Manville, Beata, and Shoup (2013) evaluate whether residential minimum parking requirements impact housing and population densities in New York and Los Angeles urbanized areas. The authors find that minimum parking requirements increase parking supply while encouraging developers to bundle the additional parking into the dwelling price. Comparing both cities, Manville, Beata, and Shoup (2013) find that in New York, a 10 percent increase in parking requirements yields a decrease in population and house density by 6 percent. The same 10 percent increase results in vehicle density growth by 4 percent.

An earlier study by Jia and Wachs (1999) uses a hedonic regression model to evaluate the price impact of parking on single-family condominiums. Jia and Wach's model found significant price differences with homes with off-street parking in the San Francisco neighbourhood. From their sample period, single-family homes with off-street residential parking sold for $46,391 USD ($63,259 CAD) [68], more than homes without off-street parking. Similarly, the average condominium selling price with garage parking sold for 13 percent ($38,804 USD ($52,913 CAD)) more than a condominium without parking. Alternatively, using the 2011 American Housing Survey, Gabbe and Pierce (2017) use multiple hedonic specifications to understand the critical

[68] Values are reported in 1996 dollars, with an average USD/CAD exchange rate of 1.3636.

relationships between minimum parking requirements and dwelling prices. The results indicate that parking space costs about $142 USD per month or roughly $1,700 USD ($1,682 CAD)[69] yearly. The model also indicates that the parking spot increases the average rent by 17 percent, suggesting that parking spaces comprise nearly a fifth of rental pricesin the United States. The authors also estimate the total deadweight cost of residents who do notown a vehicle but are provided with a parking spot. The survey data revealed that approximately US$440 million is paid for unused garage parking spots by residents annually. This notion of unused spaces results in an abundance of underutilized space as the demand for parking is less than the natural supply provided to society.

Manville (2013) compares the parking provisions and zoning changes of properties converted into residential buildings from old and vacant commercial and industrial properties in the Los Angeles area. The city passed the Adaptive Reuse Ordinance law, which reduced parkingrequirements for many construction projects in the downtown core. Manville (2013) applied a Logit regression model to regress the price of bundled parking on other household characteristics and found that bundled parking increases the unit's asking price by $22 per squarefoot. He also found that an apartment with bundled parking increases the average rent by $200. The author reported that the average selling price increased by $43,000 USD ($63,889 CAD)[70] with bundled parking for a condominium.

3.4 Data

As mentioned above, the dependent variable in all model specifications is the observed sold price and the natural logarithmic transformation of the price. The structural attributes of the property included the number of bedrooms, washrooms, family room, availability of parking in the building, Central air conditioning, and a balcony. Condominium buildings are often bundled with other amenities, such as ensuite laundry and storage locker, which are accounted for in the model specification. Also included are indicators of whether condominium fees include charges for water, heat, and hydro. Furthermore,distance to the downtown core, i.e., the central business district, is also included as a log-transformed explanatory variable in the model. The market conditions are proxied by the days the property waslisted on the Multiple Listing Service. When the demand outpaces supply, properties take less time to transact and report fewer days on the market, and vice versa. Lastly, we included average after-tax income recorded in the 2016 Census and the share of immigrants in the Census Tract where a condominium was located as proxies for socio-economic neighbourhood conditions.

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[69] Values are reported in 2011 dollars, with the average USD/CAD exchange rate of 0.9892.
[70] Values are reported in 1999 dollars, with an average USD/CAD exchange rate of 1.4858.

The location of a building relative to its proximity to a transit station and downtown core can influence how residents may value accessibility to parking infrastructure. For instance, households who intend to travel primarily by public transit often locate near transit stations, which is also associated with their lower levels of automobile ownership. Similarly, households who choose to live near or in downtowns are also the ones who have a greater likelihood of commuting by walking or bike modes, and hence their location is also correlated with lower levels of automobile ownership. This suggests that those who prefer proximity to subway stations or downtown may have a lower valuation of parking infrastructure than those farther away from either transit or downtown because their suburban location necessitates a higher reliance on mobility by private automobile. Stated otherwise, one would expect a higher imputed value for parking infrastructure in automobile-dominated suburbs than in neighbourhoods near the central business district or transit stations.

The modelling strategy adopted in this study allows for variations in the valuation for parking infrastructure differentiated by the location of the building. Therefore, in addition to the base hedonic price model that includes condominiums sold during the study period, we estimate models for subsets of data based on the property's location. The following table describes the location-driven submarkets analyzed individually in the analysis.

Table 3-1: Definition of market segments based on property location

Name	Description
All sales	Includes all sales recorded in the City of Toronto during the study period (Q2.2016 to Q1.2018. Anomalous records are excluded from the analysis, such as a dwelling with ten washrooms.
Near transit	Properties are located within 1.6 km of a subway station.
Far from transit	Properties located more than 1.6 km away from a subway station.
Near downtown	Properties located within 3.5 km of downtown Toronto.
Far from downtown	Properties located more than 3.5 km away from downtown Toronto.
Suburbs	Properties located more than 3.5 km from downtown Toronto and 1.6 km from a subway station.

We used straight-line distances (as the crow flies) to define the buffers. The underlying hypothesis is that the imputed value of parking estimated by the hedonic price model will be lower for buildings located near transit or downtown Toronto relative to those located far from transit and downtown. We also estimate results for properties that are located more than 3.5 km from the downtown and 1.6 km from the subway stations to determine whether suburban properties located farther away from transit infrastructure value parking infrastructure more than the rest.

The choice of distance cut-offs is based on the assumptions stated and prior studies. The 3.5 km buffer to delineate downtown is based on the conventional definition of the central business district used in previous studies and the transportation literature. Furthermore, research in transportation planning has explored benchmarks for pedestrian access to transit infrastructure. The literature suggests that pedestrians are more likely to walk to a bus transit if their trip origin is within 400 meters of the bus stop. Similarly, the cut-off for rail-based transit is 800 meters. However, recent research from Montréal suggests that these pedestrians are willing to walk greater distances, i.e., approximately 524 meters for bus stops and 1259 meters for transit stations (El-Geneidy et al., 2014). The 1.6 km cut-off used in the study is informed by the benchmarks defined for pedestrian access to transit stations. In addition to walking, some residents may choose a short bus ride to access the transit station. Hence, a 1.6 km buffer approximates a five-minute bus ride to a nearby transit station.

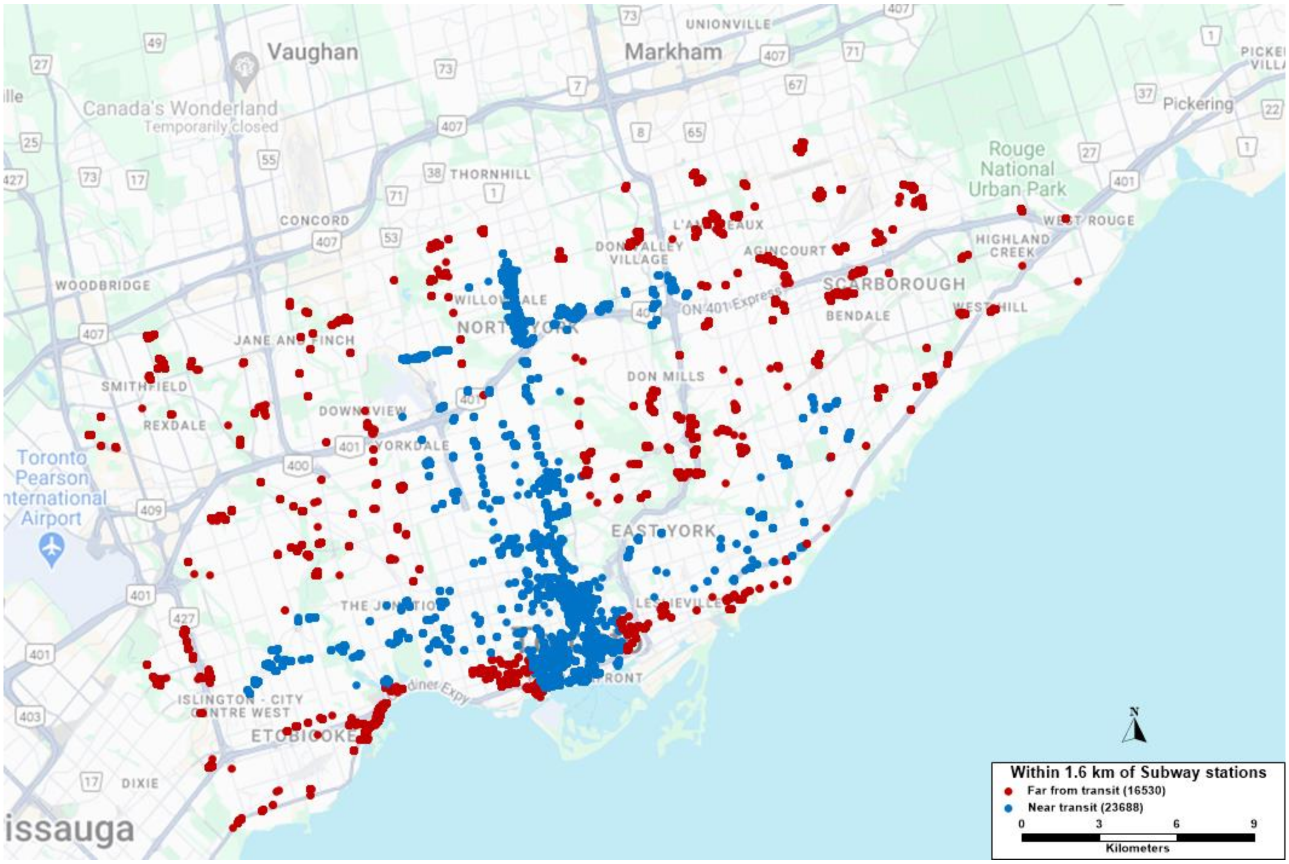

Figure 3-1: Location of condominium buildings differentiated by proximity (within 1.6 km) to TTC subway stations.

We illustrate the spatial distribution of properties in three maps. Figure 3-1 presents the location of condominium buildings that are colour-coded for their proximity to Toronto Transit Commission-operated subway stations. Properties within 1.6 km of the subway stations are coded blue, while the rest are coloured pink. Figure 3-2 highlights properties located in downtown Toronto in blue colour. These properties are located within 3.5 km of the King and Bay streets intersection. Finally, Figure 3-3 marks the location of properties that are neither in downtown Toronto nor located near a subway station. These properties (in blue) essentially represent neighbourhoods where dependence on private automobiles for mobility is likely higher because of the lack of ready access to public transit and lower population densities.

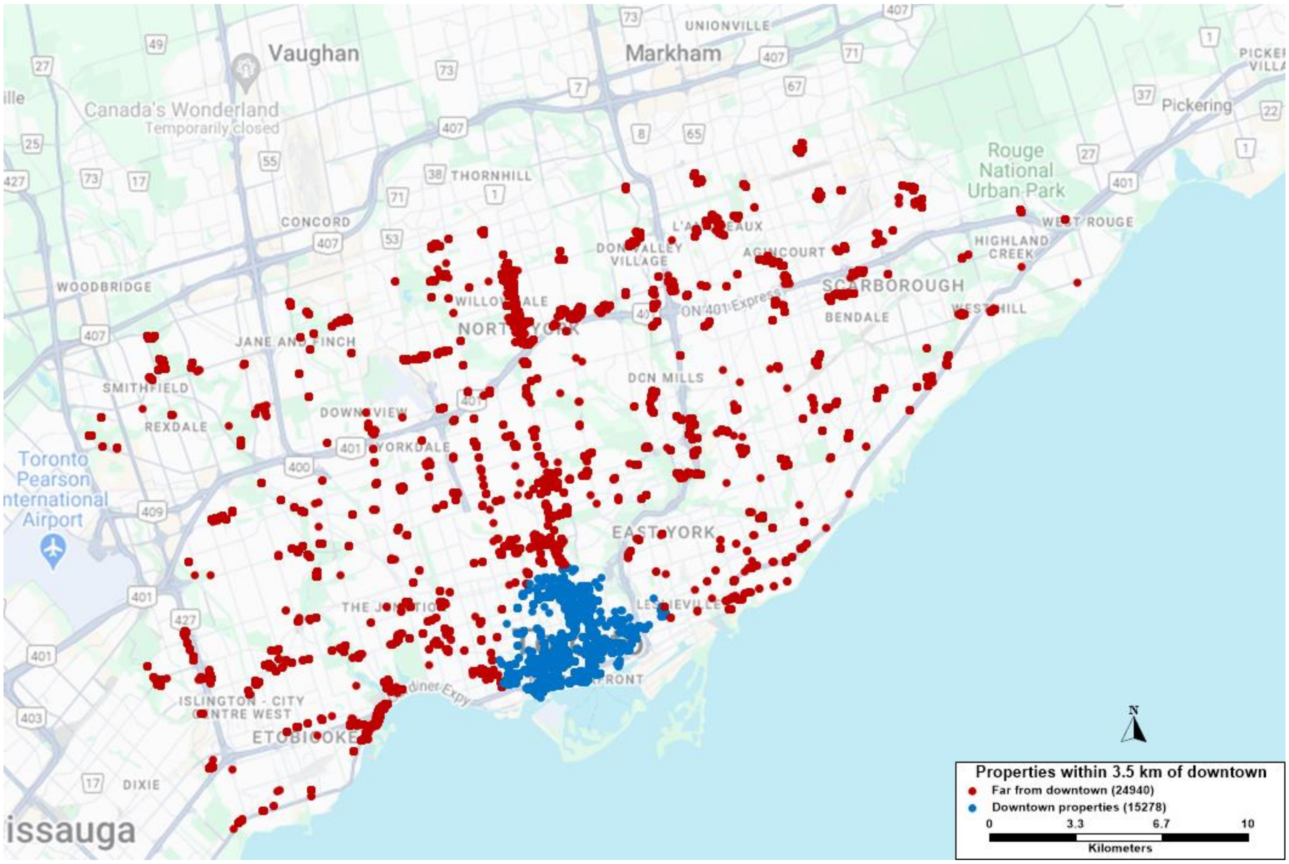

Figure 3-2: Location of condominium buildings differentiated by proximity (within 3.5 km) to downtown Toronto.

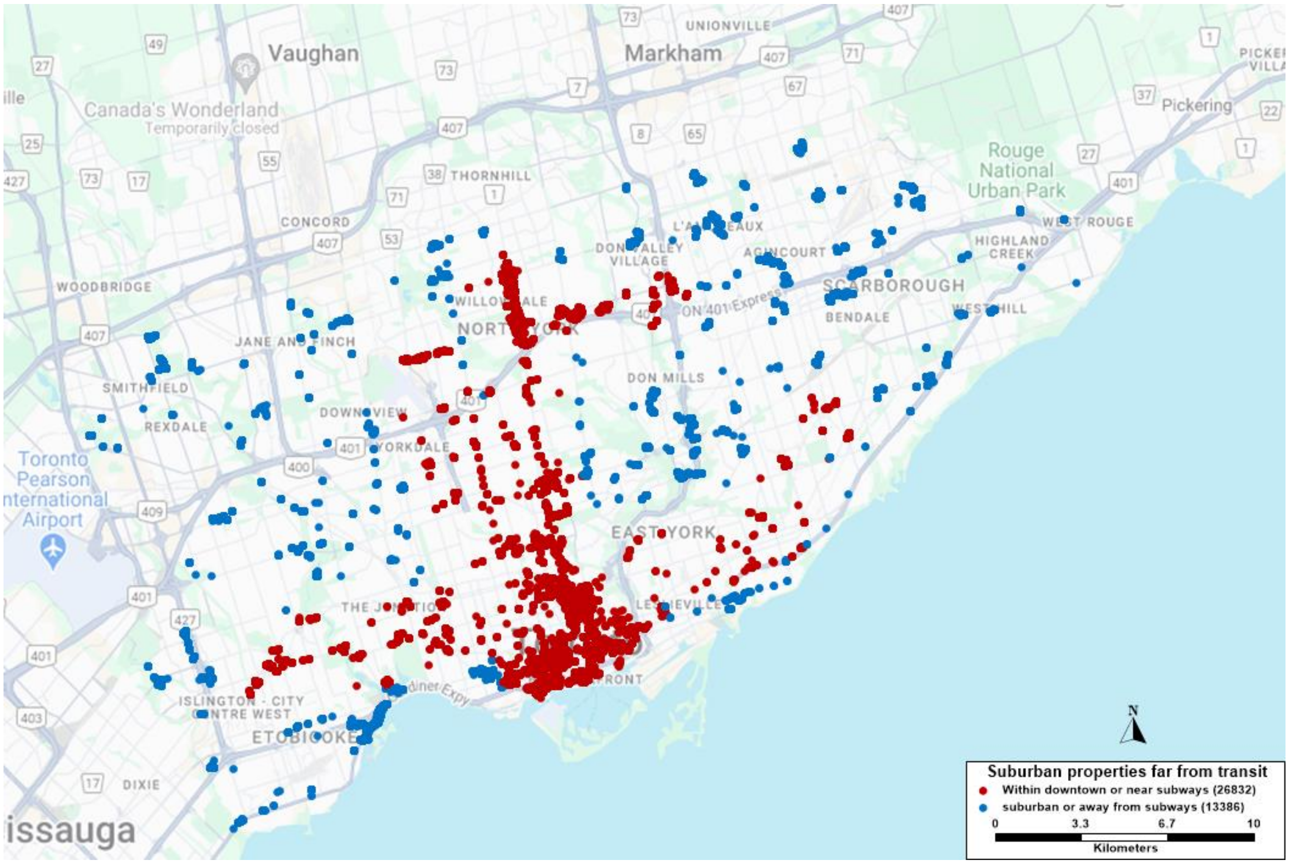

Figure 3-3: Location of suburban buildings more than 3.5 km away from downtown and 1.6 km from a transit station.

We present the empirical findings in the following section.

3.5 Empirical Results

Table 1 presents the results for two model specifications. The column labelled $mod.level$ presents the estimation including all sales with sold price being the dependent variable while the column labelled $mod.log$ reports results for the estimation with the log-transformed dependent variable. We present a detailed discussion of the variables listed in Table 3-1. The purpose is to set the stage for a more nuanced discussion about the imputed value of parking that is reported in subsequent tables. The complete list of covariates in our models are removed from the tables for brevity.

Once the anomalous and incomplete records were removed, 39,000-plus observations were used in estimating the base models. In the first model, where the dependent variable is sold price in levels, the estimated coefficients meet our expectations such that bigger and more spacious homes, proxied by the number of bedrooms and washrooms, carried a premium, whereas dwellings located farther away from downtown Toronto carried a discount. The model shows that properties located in neighbourhoods with higher incomes are associated with higher values such that a dollar increase in neighbourhood-level after-tax income is associated with a two-dollar increase in property values. Furthermore, a higher concentration of immigrants in the neighbourhood is also associated positively with the sold price of condominiums in Toronto.

Some variables may be affected by multicollinearity, where the sign of the estimated coefficients is different from what was expected. Multicollinearity is when one or more variables are correlated with other explanatory variables. The first model ($mod.level$) suggests that including hydro, water and other utilities in the condominium fees is somehow associated with lower property values. Since these attributes are not the primary focus of the research question, and their negative coefficients do not necessarily influence the primary variable of interest, i.e., parking, we have retained them in the model specification.

The variable labelled $new.balcony$, refers to a new variable created to dichotomize the balcony variable that initially comprised more than two types, i.e., Full, half, Juliette, and terrace. The provision of a balcony is also positively associated with condominium values.

The primary variable of interest is $new.parking$. The coefficient is statistically significant and suggests that access to parking is associated with an additional $34,000. These results are comparable to previously published research that showed parking availability capitalizes positively in property values. In addition, our estimate of $34,000 is within the range of estimates documented previously in other jurisdictions.

Econometric research often transforms the continuous dependent variable by taking a natural logarithm. The advantage of such an approach is that the estimated coefficient for a dichotomous explanatory variable can be explained in percentage terms or elasticity. In the second model, the dependent variable is the log-transformed sold price; the coefficient for parking suggests that dwellings with access to parking are likely to sell for 6.5% more than those without parking.

Results presented in Table 3-2 are estimated for the entire sample. Hence, properties located near or within downtown and those situated closer to public transit stations or otherwise are all part of the data used to estimate the models. Urban economics literature and theory suggest that the demand for parking, and hence its valuation, will partially depend upon the location of residential buildings. For instance, transportation literature suggests that public transit mode share is significantly higher in neighbourhoods around subway stations relative to those located farther away. The reason for such differences in transit ridership levels is self-selection exercised by those who intend to commute by public transit and hence locate in transit-proximity neighbourhoods.

Given that many households living in transit-accessible neighbourhoods are more likely to use public transit for daily commuting rather than the private automobile, they are likely to attach a lower valuation to parking availability than those with residences in neighbourhoods far from transit stations. At the same time, the reverse might apply to those residing in neighbourhoods farther away from transit stations as their valuation of parking will be higher given their greater reliance on the private automobile for daily commuting. We test this hypothesis by estimating separate models for condominiums located within 1.6 km of transit stations and those located farther away. The results are presented in Table 3-3.

Table 3-2: Base models with all observations in level and log transformed specifications.

	mod.level	mod.log
Dependent Var.:	sold.price	log(sold.price)
(Intercept)	53,484.5*** (7,487.8)	12.10*** (0.0149)
new.park	33,876.6*** (2,509.8)	0.0648*** (0.0050)
washrooms.2	121,946.0*** (1,681.9)	0.2441*** (0.0033)
new.beds	39,103.5*** (1,560.0)	0.0695*** (0.0031)
central.ac	82,052.1*** (4,271.4)	0.2297*** (0.0085)
new.balcony	25,214.8*** (1,793.1)	0.0603*** (0.0036)
S.E. type	IID	IID
Observations	37,310	37,310
R2	0.48065	0.50100
Adj. R2	0.48040	0.50076

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3-3 presents results from two estimations, one for the 22,017 properties within 1.6 km of a transit station in Toronto labelled as $near.tran$ and the other labelled as $far.tran$, which is estimated for 15,338 properties located at least 1.6 km away from a subway station. The models suggest that parking in buildings near a transit station is valued at 5.7% cent of the sale price. In comparison, parking contributes 7.2% to the price of properties located farther from transit stations. These results provide preliminary evidence supporting the argument that implicit valuation of parking infrastructure differed by location, with a higher valuation for parking in neighbourhoods where transit dependence is low, and reliance on automobiles is high.

Table 3-3: Parking valuation differentiated by proximity to transit stations.

Dependent Var.:	near.tran log(sold.price)	far.tran log(sold.price)
(Intercept)	12.17*** (0.0193)	12.09*** (0.0238)
new.park	0.0572*** (0.0054)	0.0724*** (0.0090)
washrooms.2	0.2195*** (0.0041)	0.2288*** (0.0048)
new.beds	0.1393*** (0.0040)	0.0570*** (0.0043)
central.ac	0.2244*** (0.0145)	0.1727*** (0.0096)
new.balcony	0.0495*** (0.0045)	0.0055 (0.0051)
S.E. type	IID	IID
Observations	22,017	15,338
R2	0.51076	0.51455
Adj. R2	0.51036	0.51398

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Self-selection also applies to those who may choose to live within or near downtown Toronto, the largest employment hub in Canada with over 480,000 jobs. Those who live downtown, which this study defines as neighbourhoods within 3.5 kilometers of the intersection of King and Bay Streets, are more likely to work downtown. For this reason, Statistics Canada's data reveals that commutes by non-motorized modes of travel and public transit are much higher for such residents. Hence, one can assume that proximity to downtown will also impact the valuation of parking infrastructure such that downtown residents are less likely to value access to parking than those living farther away. Results reported in Table 3-4 evaluate this hypothesis.

Table 3-4: Parking valuation differentiated by proximity to downtown Toronto.

Dependent Var.:	near.dtown log(sold.price)	far.dtown log(sold.price)
(Intercept)	12.14*** (0.0363)	12.21*** (0.0199)
new.park	0.0582*** (0.0055)	0.0539*** (0.0084)
washrooms.2	0.1995*** (0.0050)	0.2554*** (0.0041)
new.beds	0.1772*** (0.0050)	0.0426*** (0.0037)
central.ac	-0.0142 (0.0313)	0.2155*** (0.0088)
new.balcony	0.0309*** (0.0050)	0.0645*** (0.0046)
S.E. type	IID	IID
Observations	13,937	23,373
R2	0.48764	0.49190
Adj. R2	0.48698	0.49151

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 3-4 is estimated for approximately 14,000 properties located in downtown Toronto. The results are labelled as $near.dtown$. Similarly, results labeled as $far.dtown$ are estimated for 23,173 properties located at least 3.5 kilometres from the king and Bay Street intersection in downtown Toronto. The estimated parking valuations do not meet our initial hypothesis. We see that parking valuation is higher at 5.8% of the property value for downtown-located properties compared to 5.4% for those located farther away. For practical purposes, these differences in valuation are minor. However, we expected the parking infrastructure to have contributed more to the property valuation for non-downtown properties, which is not the case in Table 3-4.

There could be several explanations for this outcome. For one, the construction of underground parking in downtown Toronto is more expensive as it accounts for a higher proportion of the total property value. At the same time, compared to their suburban counterparts, downtown-located condominiums are significantly more expensive on a per-square-foot basis and are much smaller. Hence, relative to the total price of the condominium, one can see why the provision of parking may account for a greater or at least the same share as the suburban properties.

Since subway stations are not confined only to downtown Toronto, many suburban properties are also located within 1.6 km of a subway station. Hence, a relevant question to ponder is whether parking infrastructure valuation differs for suburban properties more than 1.6 km away from a subway station than those suburban properties near subway stations. Figure 3-3 identifies suburban properties located farther away from subways in blue.

Results in Table 3-5 are estimated for the 12,400 properties located in the suburbs and away from transit stations. The model suggests that access to parking is valued at 6.3% of the sold price of a condominium, which is higher than the 5.4% reported for all suburban condominiums in Table 3-4. These results provide some support for the argument that parking accessibility may be valued higher for units located in neighbourhoods away from public transit stations.

Table 3-5: Parking valuation differentiated by simultaneous proximity to transit stations & downtown.

	suburbs
Dependent Var.:	log(sold.price)
(Intercept)	12.16*** (0.0273)
new.park	0.0625*** (0.0114)
washrooms.2	0.2404*** (0.0053)
new.beds	0.0357*** (0.0046)
central.ac	0.1707*** (0.0098)
new.balcony	0.0189*** (0.0055)

```
___________________________ _____________________
S.E. type                                      IID
Observations                                12,402
R2                                         0.48012
Adj. R2                                    0.47937
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Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
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3.6 TORONTO PARKING SPACE LISTING ANALYSIS:

To complement the findings from the hedonic pricing model, we analyzed parking spaces in Toronto that were listed on Realtor.ca during January 2022. There were 35 parking spaces for sale whose listings included sale price, monthly maintenance fees, and annualproperty taxes. Table 3-6 provides a summary of the parking spaces for sale on Realtor.ca.

Table 3-6: City of Toronto Parking Space Listing Summary

	Listing Price	**Monthly Maintenance Fees**	**Annual Property Taxes**
Mean	$50,057	$58	$116
Median	$46,000	$53	$55
Standard Deviation	$22,478	$46	$134
Minimum	$15,000	$0	$0
Maximum	$125,000	$211	$420
Range	$110,000	$211	$420

The average listing price for parking spaces in Toronto on Realtor.ca in January 2022 was $50,057, while the median listing price was $46,000. Parking space listings ranged from $15,000 to $125,000. Monthly maintenance fees averaged $58 with a median of $53 and ranged from $0 to $211. Annual property taxes averaged $116 with a median of $55 and ranged from $0 to $420.

About 33 of the 35 parking spaces (94%) listed were in parking structures belonging to multi-family residential buildings. The remaining two parking spaces (6%) were locatedon street level, one in a mid-rise condominium development and the other in a townhouse development. Also, 28 parking space listings (80%) specified thatthe purchaser must own or rent a unit in the building or nearby buildings. Onlytwo listings (6%) stated that the parking space was available to non-residents of the building or development.

While this analysis considers all parking spaces in the City of Toronto listed on Realtor.ca during January 2022, the dataset can be further divided into two groups – parking spaces located within downtown Toronto and parking spaces outside of the downtown core. Forthis analysis, the downtown core is considered the area within 3,500 metres fromthe CBD.

Eighteen of the 35 parking spaces (51%) listed on Realtor.ca were in downtown Toronto while the remaining 17 spaces (49%) were located outside the downtown core. Parking spaces outside the downtown core were in the former municipalities of North York, Scarborough, Etobicoke, and in areas of the old City of Toronto outside of downtown. Dividing the listings intotwo groups allows for analysis of the differences in price, monthly maintenance fees, and annualproperty taxes for parking spaces downtown compared to parking spaces in the rest of Toronto.

Table 3-7 summarizes the parking spaces for sale in downtown Toronto onRealtor.ca in January 2022.

Table 3-7: Downtown Toronto Parking Space Listing Summary

	Listing Price	**Monthly MaintenanceFees**	**Annual ProperyTaxes**
Mean	$58,167	$73	$145
Median	$52,400	$56	$65
Standard Deviation	$24,355	$57	$160
Minimum	$25,000	$12	$0
Maximum	$125,000	$211	$420
Range	$100,000	$199	$420

The average listing price for parking spaces in downtown Toronto was $58,167, while the median was $52,400. Parking space listings ranged from $25,000 to $125,000. Monthly maintenance fees averaged $73 with a median of $56 and ranged from $12 to $211. Annual property taxes averaged $145 with a median of $65 and ranged from $0 to $420.

Table 3-8 summarizes the parking spaces for sale in the City of Toronto outside of the downtown core on Realtor.ca in January 2022.

Table 3-8: Outside Downtown Toronto Parking Space Listing Summary

	Listing Price	**Monthly MaintenanceFees**	**Annual ProperyTaxes**
Mean	$41,470	$41	$85
Median	$41,000	$50	$55
Standard Deviation	$17,063	$20	$95

Minimum	$15,000	$0	$0
Maximum	$75,000	$60	$300
Range	$60,000	$60	$300

The average listing price for parking spaces outside of downtown Toronto was $41,470, while the median listing price was $41,000. Parking space listings ranged from $15,000 to $75,000. Monthly maintenance fees averaged $41 with a median of $50 and ranged from $0 to $60. Annualproperty taxes averaged $85 with a median of $55 and ranged from $0 to $300.

Table 3-9 summarizes average listing prices, monthly maintenance fees, andannual property taxes for parking spaces both outside and within the downtown core.

Table 3-9: Comparison of Toronto Parking Space Listings Outside and Within the Downtown Core

	Outside of Downtown	**Within Downtown**	**Percent Difference**
Listing Price Mean	$41,470	$58,167	34%
Monthly MaintenanceFees Mean	$41	$73	56%
Annual Property TaxesMean	$85	$145	52%

3.7 RENTAL RATES DIFFERENTIATED BY PARKING AVAILABILITY

The evidence presented in this report refers to the imputed value of parking spaces estimated from hedonic price models or the price for parking spaces listed for sale on the Multiple Listing Service in Toronto. A related question pertains to the rental market: does the availability of parking also affect rent?

To answer this question, we contacted Bullpen Consulting in Toronto, a real estate analytics firm specializing in commercial and rental real estate data. The analysis is based on rental condominiums in downtown Toronto that were available to rent between November 2020 and November 2022. The data are differentiated by the number of bedrooms and availability of parking space. Average rental values are computed from 2,108 condominiums without parking and 706 condominiums with parking. Figure 3-4 shows that rents increase with the number of bedrooms.

Furthermore, average rents are also higher for units with parking spots than those without parking. Rents for properties without parking averaged around $2,235 compared to $3,061 with parking. Whereas condominiums with parking command a much higher rent than those without parking, one can also see that the living space for dwellings with parking at 793 ft.^{2} is much higher than the average living space of 549 ft.^{2} for dwellings without parking.

One can deduce from the results presented here that the average rent for dwellings with parking is higher than those without parking. However, some rent differences result from larger living spaces for dwellings bundled with parking. Furthermore, the difference in rents for one-bedroom condominiums with and without parking is negligible. The rent difference is more pronounced for condominiums with 1.5, 2, and 2.5 bedrooms.

	Bedroom Type						
Parking Spaces	0	1	1.5	2	2.5	3	Grand Total
0	$1,795 387 sf $4.64 psf 301 units	$2,060 513 sf $4.02 psf 769 units	$2,230 570 sf $3.91 psf 683 units	$2,871 694 sf $4.14 psf 255 units	$3,084 767 sf $4.02 psf 80 units	$4,287 934 sf $4.59 psf 20 units	$2,235 549 sf $4.07 psf 2,108 units
1		$2,094 598 sf $3.50 psf 59 units	$2,445 663 sf $3.69 psf 145 units	$3,062 780 sf $3.93 psf 208 units	$3,287 873 sf $3.76 psf 194 units	$4,085 968 sf $4.22 psf 100 units	$3,061 793 sf $3.86 psf 706 units
Grand Total	$1,795 387 sf $4.64 psf 301 units	$2,062 519 sf $3.97 psf 828 units	$2,267 586 sf $3.87 psf 828 units	$2,957 732 sf $4.04 psf 463 units	$3,228 842 sf $3.83 psf 274 units	$4,118 962 sf $4.28 psf 120 units	$2,442 610 sf $4.00 psf 2,814 units

Figure 3-4: Rental prices differentiated by living space and availability of parking

3.8 Concluding Remarks About Value of Parking

We have used condominium sales data for properties sold between Q1.2016 and Q1.2018 to determine the value of a condominium in the Greater Toronto Area. The hedonic models used the actual selling price and the logarithmic transformation of the selling price as the dependent variables to assess the price change. Based on rigorous data analysis, our models suggest that a condominium bundled with a parking unit increases the total transaction price by approximately 6.5% for the entire sample. This finding resonates with Manville's (2013) Los Angeles study, in which the average selling price for a condominium with parking increased by roughly US$43,000.

To further explore the imputed cost of parking, we differentiated sales by location, comparing how parking valuation differed for properties located near (within 1.6 km of a subway station) versus far from transit (more than 1.6 km away from a subway station) and for properties in downtown versus those located away from downtown. Condominiums in the downtown core are defined as those within 3.5 km of the King and Bay Steet intersection in downtown, while those located farther away were classified as suburban.

The results indicate that parking accounts for 5.7% of the sold price for units sold near transit. However, for condominiums located more than 1.6 km from a subway station, parking accounted for a larger share of about 7.2% of the sold price. This suggests that parking is valued more for dwellings farther away from subway stations, where residents are more likely to commute by private automobile than public transit. Conversely, the proximity to subway stations reduces the need to own a personal automobile and hence less demand for parking spaces.

For downtown versus suburban comparison, we posit that the abundance of public transitinfrastructure in the downtown core will result in lower demand for private automobiles and parking spaces. In addition, the difference in vehicle ownership in denser geographic locations would explain why parking could have a limited influence on the price in the downtown core (e.g., Schouten, 2021).

The urban-suburban comparison of parking space valuation suggested that the data do not support our hypothesis for higher parking space valuation in the suburbs. Parking contributed 5.8% to the sold price downtown versus 5.4% in the suburbs. We were expecting a higher valuation for parking in the suburbs, given the higher reliance on private automobiles for mobility. These results suggest that parking valuation is a more complex phenomenon influenced by, among others, relative differences in prices between urban and suburban condominiums. We acknowledge that the average price of a condominium is much higher in the downtown core than in the suburbs. Hence, the imputed parking space valuation might be influenced by the relative difference in urban-suburban prices.

Furthermore, on average, the supply of parking in high-rise buildings on a per-unit basis is much lower in the downtown core than in the suburbs, which suggests that the scarcity of parking spots in the downtown core would make them more valuable than in the suburbs where parking is far more ubiquitous and abundant on a per unit places in multi-family residential buildings.

Finally, we estimated the imputed value of parking for properties that were neither located downtown nor near a suburban subway station. We found that, on average, parking accounted for 6.3% of the sold price. Hence, we conclude that parking availability contributes more to suburban properties, not near the subway stations.

We reviewed the list price of parking spots made available for sale on the Multiple Listing Service in Toronto. We found that, on average, the list price for parking spots was 34% higher downtown than in the suburbs. This provided further evidence in support of the argument that the scarcity of parking in multiple-family residential buildings in downtown makes them more valuable than the more abundant supply of parking in suburban condominium buildings. While the sample size for this analysis is small at only 35 parking spaces, listing prices coincide with much of the literature and our hedonic pricing model, which states that parking spacesaccount for anywhere between $40,000 and $60,000 of the total selling price of a condominium.

Lastly, we reviewed the rents for a sample of condominiums available between November 2020 and November 2022. We found evidence for higher rents for condominiums bundled with a parking spot than those without parking. However, the rent difference is more nuanced and noticeable for specific-sized condominiums than others. We also acknowledge that condominiums bundled with a parking spot, on average, have more living space than those without parking. This implies that some of the rent differences are due to the relative difference in the size of the living space.

4 Developing Construction Cost Scenarios for Parking Infrastructure

This section serves two purposes. First, it provides a literature review of the impact of parking requirements and construction costs on housing affordability. Second, it provides construction cost estimates for multi-family residential buildings in three Canadian cities - Toronto, Montreal, and Edmonton. Construction cost estimates are calculated based on parking requirements listed in the scan of municipal parking regulations from earlier in the report and compared with scenarios where parking requirements are reduced to understand the impact of parking on overall cost of construction in multi-family residential buildings.

Four estimates will be developed for each city. The first estimate will calculate construction costs for multi-family buildings based on current parking requirements or 'business as usual'. The second estimate will reduce parking requirements by 10 percent. The third estimate will reduce parking requirements by 25 percent. Finally, the fourth estimate will reduce parking requirements by 40 percent. These scenario estimates capture the cost of parking under 'conservative' and 'aggressive' parking requirement changes. In total, 16 estimates will be developed to help determine the impact of reduced parking requirements on overall construction costs for multi-family residential buildings in Toronto, Montreal, and Edmonton.

4.1 Impact of Parking Construction Costs on Housing Affordability

As cities embrace change through technological innovation and sustainable initiatives, the demand to live in these urban neighbourhoods will gradually increase. Residents will also want to live in convenient areas close to transit hubs, amenities, and other social opportunities. With trends suggesting that automobile ownership in the urban core is likely to be lower in the coming years, adjusting the number of parking stalls required may help address housing affordability concerns, thus impacting the overall appeal to live in these dense cores. We realized the imputed and explicit value of parking for condominium properties in Toronto from the preceding report. In multi-family residential buildings, the cost of parking is bundled with the property's transaction price, which, from our estimates, can inflate the selling price by 4 – 10.5 percent. This section will review the impact of construction costs of parking requirements on housing affordability.

According to the North American cost construction report by Rider Levett Bucknall (RLB), Toronto and Calgary experienced the most significant increase in construction costs during the fourth quarter of 2021 (Figure 1). Using a cost index as a comparison metric, the annual construction cost for Toronto and Calgary increased by 13.25 and 10.28 percent[71], respectively. The index provides an

[71] Construction cost boomed in Canada since last quarter because of the $5.5 Billion Scarborough Subway Extension project and the start of the$500 million expansion of the BMO Centre. The quantity and size of these projects have led to rapid increases in costs from last year.

accurate estimate of construction costs by including costs of labour and materials, overhead expenses and fees and any applicable sales taxes.

Statistics Canada (2022a) provides a Building Construction Price Index (BCPI) that measures the change in price contractors charge to construct a range of buildings (i.e., commercial, industrial, or residential). The data is collected through an online survey questionnaire (Construction Contractors Survey) to capture quarterly change in construction costs (Statistics Canada, 2022b). The study by Statistics Canada found that construction costs for residential building increased by 5.6 percent in the first quarter of 2022. Residential construction costs for 11-census metropolitan areas saw a year-over-year growth by 22.6 percent, in which the third largest increase was in Toronto (26.5 percent). Figure 4-1 summarizes the quarterly change in construction cost from Q3.2017 to Q2.2022. The rapid increase in costs post-2021 is due to an increased demand for residential construction, supply chain disruptions that started during the COVID-19 pandemic, and labour shortages during the COVID-19 pandemic, resulting in limited availability and higher prices for materials and labour.

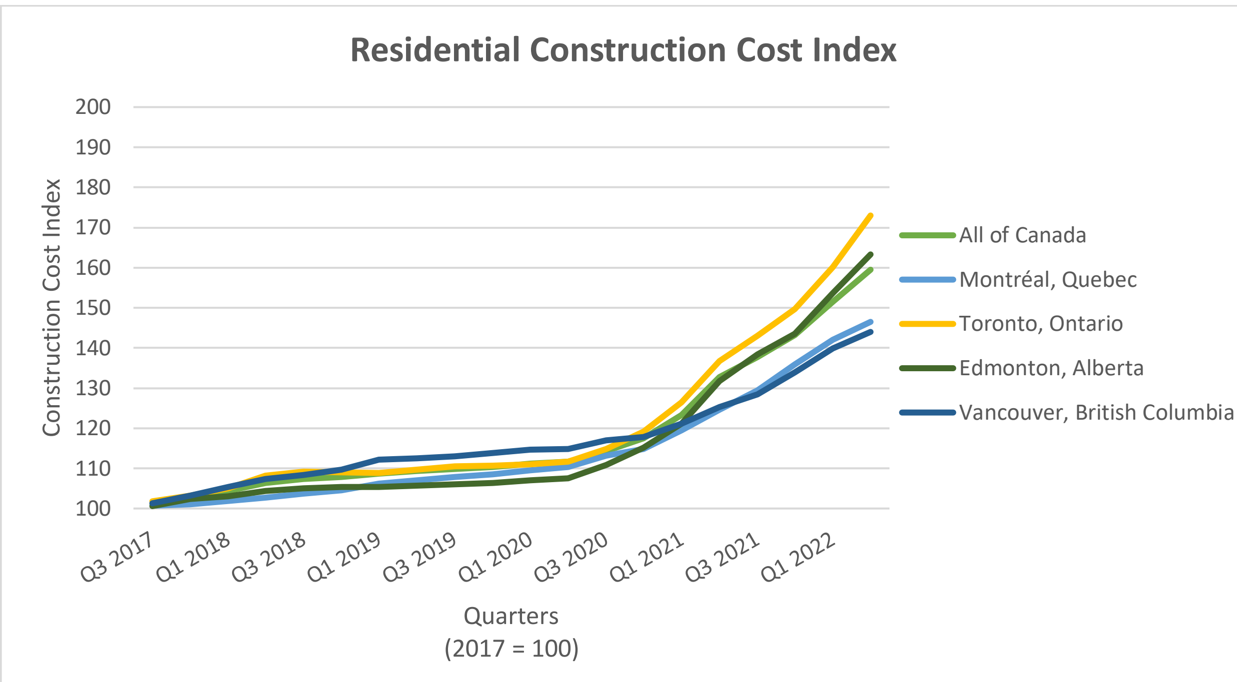

Figure 4-1: Construction Cost Index
Source: Statistics Canada (2022c)

4.2 Parking Construction Costs

Residential Construction Council of Ontario (RESCON) showed that an average of 67 percent of parking was sold in new condominium projects, leaving a third of parking unsold. The market survey led them to one builder who reported that about 90 percent of parking was still available for sale as the building neared complete construction (Lyall, 2022). However, the cost to develop underground parking stalls is not cheap. A detailed report published in 2019 by the Urban Analytics Institute revealed through industry information that the cost per underground space was in the range of $80,000 to $100,000, dependent on a variety of factors. In section 3 of the report, we analyze the sale price of condominiums to isolate the imputed value of parking provision. We find that parking accounts for 5.7% and 5.8% of the sold price for units sold near transit and in the downtown core, respectively. Additionally, our imputed value estimates of parking for properties not located downtown or near a suburban subway station suggest that, on average, parking accounts for 6.3% of the sold price. The results between the two studies indicate that constructing parking adds more to the cost of the building than the value returned.

Understanding soil and groundwater composition, levels of parking required and proximity to buildings all exacerbate the cost of parking. In essence, the deeper the parking, the higher the cost. Deep multi-level parking structures in new residential buildings can now cost upwards of $165,000 per stall (Lyall, 2022). Litman (2021) further analyzes the impact of parking on development costs and finds that the increase in parking stalls per unit decreases the profit and increases the average price per unit (see Table 4-1).

Table 4-1: Parking Impact on Development Costs.

Parking Impacts on Development Costs

Parking Spaces Per Unit:	0	1	2	3
Units / Acre	20	16	12	8
Land Cost / Unit	$25,000	$31,250	$41,667	$62,500
Paving costs.	$0	$1,600	$3,200	$4,800
Housing construction costs / Unit.	$100,000	$100,000	$100,000	$100,000
Land, parking & construction costs.	$125,000	$132,850	$144,867	$167,300
Construction financing (12%).	$15,000	$15,942	$17,384	$20,076
Total construction costs.	$140,000	$148,792	$162,251	$187,376
Developer's profit (10%).	$14,000	$14,879	$16,225	$18,738
Retail price per unit.	$154,000	$163,671	$178,476	$206,114
Parking as percentage of retail price.	0%	6.3%	15.9%	33.8%
Developers' profit per acre.	$280,000	$238,067	$194,701	$149,901

(Assuming Two-Story, 1,200 Square Foot, Multi-Family Housing)

Source: Litman (2021)

As noted above, construction costs have steadily increased over the years, with the most significant boom occurring during the height of the pandemic. Multiple industry reports have indicated that parking and construction costs are linked to various economic factors. Cudney (2017) explains that the construction markets were slowly growing in the past, and the growth of materials was relatively low because of low fuel costs, low foreign competition, and a stable labour market. However, the construction industry has experienced an exorbitant increase in construction costs due to issues with supply chain disruptions and climate change adaption (i.e., climate change mitigation activities such as LED lights, photo-voltaic solar, or recycling building material (Hurlimann et al., 2019)). Gary Cudney provides detailed construction costs information for below-grade parking in various U.S cities. In a 2014 cost outlook report, Cudney (2014) found that the median construction cost for new parking structures increased by 2.9 percent to over $18,000 per space. Parking structures' national median construction costs increased by 9 percent over three years. Comparing the construction cost report from 2014 (Cudney, 2014) to 2020 (McConnell and Smith, 2020), the average per square foot cost of parking in dense U.S cities increased significantly. For instance, the per square foot cost in New York, Los Angeles, and San Francisco increased by 23.6, 28.1, and 29.3 percent, respectively. McConnell and Smith (2021) outline that there is still ambiguity and not enough evidence to understand the actual effects of the pandemic on construction markets.

Rowe (2013) reports that King County, Seattle experienced an oversupply of parking in multi-family buildings by 0.4 stalls per dwelling. The extra supply added approximately $400,000 to the total development costs, which the study found to be unused parking. Unless the developer absorbed this cost, the cost of unused parking would transfer to a tenants rent or be capitalized in the sale price.

Cutter, Franco, and Lewis (2016) suggest the use of the "multiplier method" to estimate the cost for underground parking. The multiplier method is used to calculate the cost of all floors underground in relation to the cost of the first floor above grade. In this paper, the authors suggest that underground parking construction costs increase linearly with the depth of construction. Relative to the above grade, the first-floor underground will cost 1.5x, the second-floor below grade will cost 3x, the third-floor below grade will cost 4.5x, and so forth.

Graham (2022) uses information from cost guides to present a general guide for underground parking costs. Every level below ground increases the total cost by 20 percent.
To illustrate this parking cost calculation, we propose a simple example outline the cost structure derived from Graham (2022). A residential developer plans to construct an underground parking facility with two floors below ground in the City of Toronto for a typical 20-story condominium, assuming equal parking stalls on each floor. Using the 2022 Altus Construction cost guide (Altus Group, 2022), we conservatively estimate the cost of the first above-grade parking floor to be approximately $150 per square foot. Then, using the method by Graham (2022), the cost for each floor is estimated as follows: the first underground floor is $180 per square foot and the second underground floor is $216 per square foot. Finally, assuming each floor can hold 25 parking stalls, the weighted average cost of just parking alone is estimated to be $182 per square foot. Therefore, multiplying the per square foot cost derived above by the average parking space (350 square feet per parking stall)[72], the construction cost per parking stall is estimated to be $63,700.

Parking requirements directly impact how many parking stalls are required, and an oversupply can lead to affordability concerns. For instance, Gabbe, Pierce and Clowers (2020) studied the impact of the 2012 policy reform in Seattle, where most transit-dominated neighbourhoods experienced a significant change in parking requirement by-laws. The authors built a counterfactual scenario of the parking reforms[73] to determine the societal impact of parking costs and savings in populated

[72] This estimate assumes that a parking stall is 300 square feet. The additional 50 square feet to get 350 total, captures the entirety of the underground space included for construction (i.e., drive and walk lanes, storm drainage, maintenance, and other costs associated with construction).
[73] As part of the 2012 parking reforms, Seattle introduced policies that reduced or eliminated off-street

urban areas. The number of actual parking spaces built were 39,213. Under the counterfactual scenario, the total parking spaces built were 57,099. Therefore, had there not been any parking regulation amendments, developers would have built over 17,886 (57,099 – 39,213) parking stalls, thus costing them over $537 million in a five-year span. Regardless of if there was no demand for parking at the time, evidence suggests that these premiums associated with higher parking costs would be filtered down to potential renters and homeowners (Lehe, 2018). Residents without cars indirectly subsidize those with cars because often parking-related costs are embedded in price or rent. When the parking infrastructure is oversupplied, all occupants are subject to higher costs/rents, further impacting affordability concerns because, as has been stated earlier, parking infrastructure increases the cost of the overall construction and has a distinct impact on affordability. By implementing reduced residential parking requirements, cities can enable more space for new housing and allow that housing to be built more economically with greater opportunities for affordable housing (Gabbe et al., 2020).

4.3 Factors Influencing Parking Construction Costs

Many factors go into considering the cost of parking construction in residential developments. Understanding the structural and parking efficiencies and requiring optimal parking stall to dwelling unit ratios can help lower construction costs. For example, with minimum parking requirements changing to a maximum in the City of Toronto, developers can reduce the overall parking construction cost by building only accessibility and visitor parking stalls, or in some cases, no parking. For a comprehensive list, Table 4-2 summarizes the features that impact the cost of a parking structure retrieved and reproduced from McConnell and Smith (2021).

Table 4-2: Cost Drivers: Example of Select Features That Can Impact the Cost of a Parking Structure

Features *Increase* Cost	Bicycle Housing	Sophisticated Parking Management System
	EV Charging Stations	LED lighting System Premiums
	Stormwater Management	Cast-in-Place Concrete Construction
Features *Decrease* Cost	Pre-topped Precast Concrete	Single Supported Level
	Reduced Durability Features (varies Regionally)	
	Eliminate Exterior Glass Stair Enclosures	
	Eliminate Grade-Level Barrier Wall	

Source: McConnell and Smith (2021)

parking requirements in multifamily zones in most central and transit-oriented neighbourhoods. The complete relaxation of parking requirements for most developments in urban centers and villages was accompanied by a 50% reduction in parking minimums for corridors outside growth centers but near frequent transit service stops.

4.4 Construction Cost Model Assumptions

The construction cost model in this section was developed in consultation with Altus Group and makes several assumptions. The scope of the model only accounts for construction or 'hard costs.' Land costs and 'soft costs' such as architectural fees, legal fees, taxes, etc. are not included. The model also assumes 'typical' construction on a greenfield site with no unusual ground water or soil conditions where footing design is similar at all depths.

The multi-family residential building in the construction cost model consists of 25 floors and a total of 550 units or an average of 22 units per floor. The above grade gross floor area (GCA) of the building is 500,000 square feet. Six floors are dedicated to below grade parking with 350 square feet needed for each parking spot as, beyond the space needed for the parking spots themselves, additional space is needed within the parking structure for driveways and ramps.

Table 4-3 lists the assumed costs per square foot for above grade (GCA) construction, below grade construction excluding footings, below grade footing construction, and extra over construction for footings under the tower according to the model. Above grade refers to any part of the building that is above the surface of the ground while below grade refers to any part of the building that is below the surface of the ground. Footings are part of the foundation that transfers the load to a larger soil area (Anderson, 2022). The term 'extra over" refers to additional costs that are not included in the original contract or estimate. For instance, any work that is not part of the original scope, such as adding an extra bathroom, installing additional electrical outlets, or creating custom-built features, would be considered 'extra over' (Designing Buildings, 2020). In the context of tower foundations, this could refer to additional costs associated with specific elements of the footings under the tower that are not covered by the basic measurement and pricing. These could be special materials, labor-intensive processes, or other factors that add to the foundation's cost beyond the basic structure. Construction costs for each category differ in Toronto, Montreal, and Edmonton and were developed in consultation with Altus Group.

Table 4-3: Construction model cost assumptions

	Toronto	Montreal	Edmonton
Above Grade (GCA)	$325/sf	$250/sf	$265/sf
Below Grade – Excluding Footings	$214/sf	$118/sf	$144/sf
Below Grade - Footings	$65/sf	$50/sf	$45/sf
Extra Over for Footings Under Tower	$65/sf	$50/sf	$45/sf

4.5 'Business as Usual' and Reduced Parking Requirements

'Business as usual' parking requirements for multi-family residential buildings in Toronto, Montreal, and Edmonton are based on current parking requirements listed in the scan of municipal parking regulations from earlier in the report.

Under the previous parking requirements in Toronto, a minimum of one resident parking space and 0.2 visitor parking spaces had to be provided for each dwelling unit in a multiple dwelling unit building. Therefore, the minimum number of parking spaces required in a multi-family residential building is 1.2 spaces per unit. After the changes in zoning by-law in 2022, a maximum of one resident parking space must be provides for each dwelling unit in a multiple dwelling unit building with additional visitor parking spaces[74].

In the Montreal borough of Ville-Marie, which includes the downtown area and Old Montreal, in multi-family residential buildings a maximum of one space is needed for each dwelling with a floor area of up to 50 m^2 (538 sf) and a maximum of 1.5 spaces is needed for each dwelling with a floor area of more than 50 m^2. In the proposed model, 25 percent of the units in the building would have less than 50 m^2 of floor space while the remaining 75 percent of units would have more than more than 50 m^2 of floor space. Under these conditions, the maximum number of parking spaces required would be 1.375 units per dwelling.

In Edmonton, the maximum number of parking spaces provided in multi-family residential buildings differs by the number of bedrooms in the dwelling. For studio and 1-bedroom dwellings, a maximum of one parking space is provided. For 2-bedroom dwellings, a maximum of 1.5 parking spaces are provided. For dwellings with 3 or more bedrooms, 1.75 parking spaces are provided. In the proposed model, there are an average of 22 units per floor with four 3-bedroom and eight 2-bedroom units per floor. Under these conditions, the maximum number of parking spaces required would be 1.3 units per dwelling.

Table 4-4 lists parking requirements used in the model under 'business as usual' conditions and under reduced parking requirements where the 'business as usual' requirements are reduced by 10 percent, 25 percent, and 40 percent.

Table 4-4: 'Business as Usual' and Reduced Parking Requirements for Multi-Family Residential Buildings

	Toronto (*minimum requirements*)	**Toronto** (*maximum requirements*)	**Montreal**	**Edmonton**
'Business as Usual'	1.2 spaces/unit	1.11 spaces/unit	1.375 spaces/unit	1.3 spaces/unit
10 Percent Reduction		0.99 spaces/unit	1.2375 spaces/unit	1.17 spaces/unit
25 Percent Reduction		0.83 spaces/unit	1.03125 spaces/unit	0.975 spaces/unit

74 Under the Zoning By-Law changes of 2022; a maximum rate of 1.0 per dwelling unit for the first five (5) dwelling units; and at a maximum rate of 0.1 per dwelling unit for the sixth and subsequent dwelling units must be provided for visitor parking in multiple dwelling unit buildings.

40 Percent Reduction		0.67 spaces/unit	0.825 spaces/unit	0.78 spaces/unit

4.6 Toronto Construction Cost Models

4.6.1 'Business as Usual'

In the 'business as usual' scenario, 1.2 parking spaces are provided per unit in multi-family residential buildings in Toronto under minimum parking provisions. For the 550-unit building in our model, 660 parking spaces will therefore be provided. The total below-grade floor area will be the product of the total number of parking spaces (660) and the floor area dedicated to each parking space (350 sf or 213,000 sf). This total below grade square footage is divided by six, as there are six floors dedicated to below grade parking in our model, to determine the average floor plate of 38,500 sf. The area for below grade footings is the same as the average floorplate or 38,500 sf.

Table 4-5 illustrates the Toronto 'business as usual' model, as with every other model in the report, the above grade area is 500,000 sf. The above grade construction costs for each Toronto model will amount to $162,500,000. The extra over for footings under the tower will also remain constant across all Toronto models at $1,300,000.

The below grade area excluding footings is 231,000 sf and the construction cost is $49,327,500
The area for the below grade footings is 38,500 sf and the construction cost is $2,502,500. Given these parameters, the total construction cost for the multi-family residential building in this model is $215,630,000 which amounts to $392,055 per unit.

Table 4-5: Toronto 'Business as Usual' Model under Minimum Parking Requirements

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$325/sf	$162,500,000
Below Grade – Excluding Footings	231,000 sf	$214/sf	$49,327,500
Below Grade - Footings	38,500 sf	$65/sf	$2,502,500
Extra Over for Footings Under Tower	20,000 sf	$65/sf	$1,300,000
Total			$215,630,000
$/Residential Unit			$392,055

Under the maximum by-law provisions, the 'business as usual' scenario outlines that 1.11 parking spaces are provided per unit in multi-family residential buildings in Toronto. For the 550-unit building in our model, 610 parking spaces will therefore be provided. The above grade construction costs for each Toronto model will amount to $162,500,000. The extra over for footings under the tower will also remain constant across all Toronto models at $1,300,000.

Table 4-6 illustrates the Toronto 'business as usual' model with maximum parking provision. The below grade area excluding footings is 213,483 sf and the construction cost is $45,488,248 The area for the below grade footings is 38,580 sf and the construction cost is $2,312,727. Given these parameters, the total construction cost for the multi-family residential building in this model is $211,600,975 which amounts to $384,729 per unit.

Table 4-6: Toronto 'Business as Usual' Model under Maximum Parking Requirements

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$325/sf	$162,500,000
Below Grade – Excluding Footings	213,483 sf	$213/sf	$45,488,248
Below Grade - Footings	38,580 sf	$65/sf	$2,312,727
Extra Over for Footings Under Tower	20,000 sf	$65/sf	$1,300,000
Total			$211,600,975
$/Residential Unit			$384,729

Table 4-7 shows the Toronto 10 percent parking reduction scenario under the maximum parking requirement provision; 0.99 parking spaces are provided per unit for a total of 545 parking spaces. The below grade area excluding footings is 190,575 sf and the construction cost is $40,467,688. The area for the below grade footings is 31,763 sf and the construction cost is $2,064,563. The total construction cost for the multi-family residential building in this model is $206,332,250 or $375,150 per unit.

Table 4-7: Toronto 10 Percent Parking Reduction Model under Maximum Parking Requirements

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$325/sf	$162,500,000
Below Grade – Excluding Footings	190,575 sf	$212/sf	$40,467,688
Below Grade - Footings	31,763 sf	$65/sf	$2,064,563
Extra Over for Footings Under Tower	20,000 sf	$65/sf	$1,300,000
Total			$206,332,250
$/Residential Unit			$375,150

Table 4-8 shows the Toronto 25 percent parking reduction scenario; a maximum of 0.83 parking spaces are provided per unit for a total of 457 parking spaces, with five floors dedicated to below-grade parking. The below grade area excluding footings is 159,775 sf and the construction cost is $33,371,175. The area for the below grade footings is 31,955 sf and the construction cost is $2,077,075. The total construction cost for the multi-family residential building in this model is $199,248,250 or $362,270 per unit.

Table 4-8: Toronto 25 Percent Parking Reduction Model under Maximum Parking Requirements

	Area	**Rate**	**Amount**
Above Grade (GCA)	500,000 sf	$325/sf	$162,500,000
Below Grade – Excluding Footings	159,775 sf	$209/sf	$33,371,175
Below Grade - Footings	31,955 sf	$65/sf	$2,077,075
Extra Over for Footings Under Tower	20,000 sf	$65/sf	$1,300,000
Total			$199,248,250
$/Residential Unit			$362,270

Table 4-9 shows the Toronto 40 percent parking reduction scenario under maximum parking requirements; 0.67 parking spaces are provided per unit for a total of 366 parking spaces, with four floors dedicated to below-grade parking. The below grade area excluding footings is 128,975 sf and the construction cost is $26,268,406. The area for the below grade footings is 32,244 sf and the construction cost is $2,095,844. The total construction cost for the multi-family residential building in this model is $192,164,250 or $349,068 per unit.

Table 4-9: Toronto 40 Percent Parking Reduction Model under Maximum Parking Requirements

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$325/sf	$162,500,000
Below Grade – Excluding Footings	128,975 sf	$204/sf	$26,268,406
Below Grade - Footings	32,244 sf	$65/sf	$2,095,844
Extra Over for Footings Under Tower	20,000 sf	$65/sf	$1,300,000
Total			$192,164,250
$/Residential Unit			$349,068

4.7 MONTREAL CONSTRUCTION COST MODELS

4.7.1 'Business as Usual'

The above grade construction costs for each Montreal model will amount to $125,000,000. The extra over for footings under the tower will also remain constant across all Montreal models at $1,000,000.

Table 4-10 outlines the Montreal 'business as usual' scenario with 1.375 parking spaces per unit for a total of 756 parking spaces. The below grade area excluding footings is 264,688 sf and the construction cost is $31,203,646. The area for the below grade footings is 44,115 sf and the construction cost is $2,205,729. The total construction cost for the multi-family residential building in this model is $159,409,375 or $289,835 per unit.

Table 4-10: Montreal 'Business as Usual' Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$250/sf	$125,000,000
Below Grade – Excluding Footings	264,688 sf	$118/sf	$31,203,646
Below Grade - Footings	44,115 sf	$50/sf	$2,205,729
Extra Over for Footings Under Tower	20,000 sf	$50/sf	$1,000,000
Total			$159,409,375
$/Residential Unit			$289,835

4.7.2 10 Percent Reduction in Parking Requirements

Table 4-11 shows the Montreal 10 percent parking reduction scenario with 1.2375 parking spaces per unit for a total of 681 parking spaces. The below grade area excluding footings is 238,219 sf and the construction cost is $27,983,281. The area for the below grade footings is 39,703 sf and the construction cost is $1,985,156. The total construction cost for the multi-family residential building in this model is $155,968,438 or $283,579 per unit.

Table 4-11: Montreal 10 Percent Parking Reduction Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$250/sf	$125,000,000
Below Grade – Excluding Footings	238,219 sf	$117/sf	$27,983,281
Below Grade - Footings	39,703 sf	$50/sf	$1,985,156
Extra Over for Footings Under Tower	20,000 sf	$50/sf	$1,000,000
Total			$155,968,438
$/Residential Unit			$283,579

4.7.3 25 Percent Reduction in Parking Requirements

Table 4-12 illustrates the Montreal 25 percent parking reduction scenario with 1.03125 parking spaces per unit for a total of 567 parking spaces, with five floors dedicated to below-grade parking. The below grade area excluding footings is 198,516 sf and the construction cost is $22,821,875. The area for the below grade footings is 39,703 sf and the construction cost is $1,985,156. The total construction cost for the multi-family residential building in this model is $150,807,031 or $274,195 per unit.

Table 4-12: Montreal 25 Percent Parking Reduction Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$250/sf	$125,000,000
Below Grade – Excluding Footings	198,516 sf	$115/sf	$22,821,875
Below Grade - Footings	39,703 sf	$50/sf	$1,985,156
Extra Over for Footings Under Tower	20,000 sf	$50/sf	$1,000,000
Total			$150,807,031
$/Residential Unit			$274,195

4.7.4 40 Percent Reduction in Parking Requirements

Table 4-13 shows the Montreal 40 percent parking reduction scenario with 0.825 parking spaces per unit for a total of 454 parking spaces, with four floors dedicated to below-grade parking. The below grade area excluding footings is 158,813 sf and the construction cost is $17,660,469. The area for the below grade footings is 39,703 sf and the construction cost is $1,985,156. The total construction cost for the multi-family residential building in this model is $145,645,625 or $264,810 per unit.

Table 4-13: Montreal 40 Percent Parking Reduction Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$250/sf	$125,000,000
Below Grade – Excluding Footings	158,813 sf	$111/sf	$17,660,469
Below Grade - Footings	39,703 sf	$50/sf	$1,985,156
Extra Over for Footings Under Tower	20,000 sf	$50/sf	$1,000,000
Total			$145,645,625
$/Residential Unit			$264,810

4.8 Edmonton Construction Cost Models

4.8.1 'Business as Usual'

The above grade construction cost for each Edmonton model is $132,500,000. The extra over for footings under the tower will remain constant across all Edmonton models at $900,000.

Table 4-14 displays the 'business as usual' scenario for Edmonton with 1.3 parking spaces per unit for a total of 715 parking spaces. The below grade area excluding footings is 250,250 sf and the construction cost is $36,011,875. The area for the below grade footings is 41,708 sf and the construction cost is $1,876,875. The total construction cost for the multi-family residential building in this model is $171,288,750 or $311,434 per unit.

Table 4-14: Edmonton 'Business as Usual' Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$265/sf	$132,500,000
Below Grade – Excluding Footings	250,250 sf	$144/sf	$36,011,875
Below Grade - Footings	41,708 sf	$45/sf	$1,876,875
Extra Over for Footings Under Tower	20,000 sf	$45/sf	$900,000
Total			$171,288,750
$/Residential Unit			$311,434

4.8.2 10 Percent Reduction in Parking Requirements

Table 4-15 illustrates the 10 percent parking reduction scenario for Edmonton with 1.17 parking spaces per unit for a total of 644 parking spaces. The below grade area excluding footings is 225,225 sf and the construction cost is $32,320,688. The area for the below grade footings is 37,538 sf and the construction cost is $1,689,188. The total construction cost for the multi-family residential building in this model is $167,409,875 or $304,382 per unit.

Table 4-15: Edmonton 10 Percent Parking Reduction Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$265/sf	$132,500,000
Below Grade – Excluding Footings	225,225 sf	$144/sf	$32,320,688
Below Grade - Footings	37,538 sf	$45/sf	$1,689,188
Extra Over for Footings Under Tower	20,000 sf	$45/sf	$900,000
Total			$167,409,875
$/Residential Unit			$304,382

4.8.3 25 Percent Reduction in Parking Requirements

Table 4-16 shows the 25 percent parking reduction scenario for Edmonton with 0.975 parking spaces per unit for a total of 536 parking spaces, with five floors dedicated to below-grade parking. The below grade area excluding footings is 187,688 sf and the construction cost is $26,502,375. The area for the below grade footings is 37,538 sf and the construction cost is $1,689,188. The total construction cost for the multi-family residential building in this model is $161,591,563 or $293,803 per unit.

Table 4-16: Edmonton 25 Percent Parking Reduction Model

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$265/sf	$132,500,000
Below Grade – Excluding Footings	187,688 sf	$141/sf	$26,502,375
Below Grade - Footings	37,538 sf	$45/sf	$1,689,188
Extra Over for Footings Under Tower	20,000 sf	$45/sf	$900,000
Total			$161,591,563
$/Residential Unit			$293,803

4.8.4 40 Percent Reduction in Parking Requirements

Table 4-17 outlines the Edmonton 40 percent parking reduction scenario with 0.78 parking spaces per unit for a total of 429 parking spaces, with four floors dedicated to below-grade parking. The below grade area excluding footings is 150,150 sf and the construction cost is $20,684,063. The area for the below grade footings is 37,538 sf and the construction cost is $1,689,188. The total construction cost for the multi-family residential building in this model is $155,773,250 or $283,224 per unit.

Table 4-17: Edmonton 40 Percent Parking Reduction Mode

	Area	Rate	Amount
Above Grade (GCA)	500,000 sf	$265/sf	$132,500,000
Below Grade – Excluding Footings	150,150 sf	$138/sf	$20,684,063
Below Grade - Footings	37,538 sf	$45/sf	$1,689,188
Extra Over for Footings Under Tower	20,000 sf	$45/sf	$900,000
Total			$155,773,250
$/Residential Unit			$283,224

4.9 Analysis of Construction Cost Scenarios

According to each of the models estimated, a reduction in parking requirements resulted in lower overall construction costs for a typical multi-family residential building. This is because fewer parking spaces will require less square footage for below grade construction which in turn saves on construction costs. Table 4-18 details the cost savings realized when reducing parking requirements in a typical multi-family residential building in Toronto, Montreal, and Edmonton.

Table 4-18: Total Construction Costs for a Typical Multi-Family Residential Building in Toronto, Montreal, and Edmonton

Total Construction Costs				
	Toronto (*minimum requirements*)	**Toronto** (*maximum requirements*)	**Montreal**	**Edmonton**
Business as Usual cost	$215,630,000	$211,600,975	$159,409,375	$171,288,750
-10% parking cost		$206,332,250	$155,968,438	$167,409,875
-10% parking % change		-2.49%	-2.16%	-2.26%
-25% parking cost		$199,248,250	$150,807,031	$161,591,563
-25% parking % change		-5.84%	-5.40%	-5.66%
-40% parking cost		$192,164,250	$145,645,625	$155,773,250
-40% parking % change		-9.20%	-8.63%	-9.06%

According to the construction cost models, Toronto is the most expensive city to build a multi-family residential building followed by Edmonton and then Montreal. Toronto is also the city where reducing parking requirements will have the greatest impact on construction costs.

The City of Toronto's shifting from the pre-2022 minimum parking requirements to the new maximum requirements, reduces the modeled construction costs from $215M to $211M – a savings of at least 1.89%. In reality, builders may provide less than the maximum allowable parking to better align with their anticipated buyer demand. Reducing minimum parking provisions by 10 percent from the new maximum BAU results in a 2.49 percent reduction in construction costs in Toronto compared to a 2.26 percent reduction in Edmonton and a 2.16 percent reduction in Montreal. Reducing parking provisions by 25 percent would result in an 5.84 percent reduction in construction costs in Toronto, a 5.66 percent reduction in Edmonton, and a 5.40 percent reduction in Montreal. Reducing parking provisions by 40 percent would realize a construction costs savings of 9.20 percent in Toronto, 9.06 percent in Edmonton, and 8.63 percent in Montreal.

For each of the four models estimated for a particular city in the study, above grade construction costs and extra overs for footings under the tower remain constant. The only parameter that changes within each model is the number of parking spaces required per unit which alters the cost of below grade construction. In turn, a model which attributes a higher percentage of construction costs to below grade items will result in a greater cost savings when parking is reduced. The cost contribution of below grade construction towards the overall cost of construction for a typical multi-family residential building in Toronto, Montreal, and Edmonton is outlined in Table 4-19.

Table 4-19: Below Grade Construction Cost as a Percentage of Total Construction Costs

	Toronto *(minimum requirements)*	**Toronto** *(maximum requirements)*	**Montreal**	**Edmonton**
Business as usual below grade cost percentage	24.04%	22.61%	20.96%	22.12%
10% parking reduction below grade cost percentage		20.61%	19.21%	20.32%
25% parking reduction below grade cost percentage		17.79%	16.45%	17.45%
40% parking reduction below grade cost percentage		14.76%	13.49%	14.36%

Below-grade construction costs account for a higher percentage of overall construction costs in Toronto compared to Edmonton and Montreal, according to our models. Under a 'business as usual' scenario, below-grade construction costs account for 24.04 percent of total construction costs in Toronto under minimum parking provisions and 22.61 percent under the maximum requirement provision, compared to 22.12 percent in Edmonton and 20.96 percent in Montreal. As parking requirements are reduced, the cost contribution of below-grade construction decreases because less space is needed for parking, which reduces below-grade construction costs, while above-grade construction costs remain the same. Because a typical multi-family residential building in Toronto has the highest proportion of construction costs earmarked for below-grade construction, a reduction in underground parking spaces will realize greater cost savings compared to a similar building in Montreal or Edmonton.

4.10 Concluding Remarks About Construction Cost Scenarios

This section of the report provides a quantitative analysis of the potential reduction in construction costs for multifamily residential buildings, should the minimum parking requirements per dwelling unit be decreased. As anticipated, the construction cost proformas indicate that reducing the required parking spaces per dwelling unit in a multifamily residential building results in a decrease in total construction costs.

The value of this analysis lies not merely in establishing this correlation, but in quantifying the total cost of construction under various parking requirement scenarios. Therefore, the focus of the analysis presented here is on quantifying the differential in construction costs when comparing the current requirements against lower thresholds.

While no attempt was made to quantify the proportion of cost savings that would be transferred to or shared with the end-users of the space, it can be reasonably assumed that a portion of the cost savings resulting from lower parking requirements would be passed on to the owners or renters of the space. This assumption is supported by urban economics literature, which suggests that housing markets are more affordable in areas with lower construction costs. Therefore, it is reasonable to infer that efforts to reduce construction costs, such as lowering the minimum parking requirements, are likely to benefit future homeowners by making housing more affordable.

5 REHABILITATION AND MAINTENANCE COSTS OF UNDERGROUND PARKING INFRASTRUCTURE

5.1 INTRODUCTION

This section of the report reviews the maintenance and rehabilitation costs associated with parking infrastructure in residential buildings. Review of published research revealed that studies focusing on parking rehabilitation in residential buildings are difficult to come by. Though unpublished data or reports from private sector consultants can be obtained, such documents and data are not peer-reviewed and might be project-specific, limiting their utility as generalizable findings.[75] The research reported in this section leverages local building-specific data where available combined with peer-reviewed publications related to parking infrastructure in Canada and internationally as well as other related non-parking infrastructure in the public sector.

Parking facilities constitute a considerable part of private and public infrastructure. In Ontario, all levels of government and the private sector have large parking facilities that require maintenance and rehabilitation. According to *Ontario's Long-Term Infrastructure Plan*, the replacement cost of the transportation assets owned by the province is about C$10.2 billion. This class of assets includes rail coach, locomotive, bus and parking assets (Ontario Ministry of Infrastructure 2017).

Over the past few years, Ontario has made significant progress in infrastructure asset management (Piryonesi and El-Diraby, 2021). This is primarily due to the introduction of the *Asset Management Regulation* by the Government of Ontario (2017). Many studies have examined the maintenance and rehabilitation of urban infrastructure such as bridges (Han et al. 2021; Taghaddos & Mohamed 2019), roads (Piryonesi and El-Diraby, 2020) and buildings (Ahmed et al., 2021). Despite progress in other sectors, limited work has been devoted to parking facilities. This is partially due to a lack of data on parking facilities' condition and maintenance and rehabilitation costs. The following section delves into the maintenance and rehabilitation costs of parking facilities. The appendix introduces the progress made in facility deterioration modelling, based on both physical and financial performance indicators, that can be tailored to the management of maintenance and rehabilitation costs of parking facilities.

5.2 MAINTENANCE COST MODELING

Parking will contribute to affordability troubles within the community if not adequately addressed. As previously discussed, we have conceptually analyzed the costs of constructing deeper underground parking facilities. Nevertheless, parking construction can make up a sizeable portion of property costs without considering land costs, opportunity costs, or maintenance and operations.

[75] Conversations with Professor Shamim Sheikh in the structural engineering section of the Department of Civil and Mineral Engineering at the University of Toronto.

Without addressing parking needs, issues of oversupply of parking can significantly affect economic development, consumers, and the community (Rowe, 2013, pg. 33). Consequently, overestimating the future of automobile dependency in urban cores can also exacerbate the parking problem, a sentiment shared by Xu, Wang and Liu (2012).

The oversupply of parking creates additional costs, such as maintenance and renovation. Underground parking facilities deteriorate over time and can weaken the structural integrity if not correctly maintained. Litman and Doherty (2013) explain that parking facilities need "resurfacing and repaving every 5-10 years, and parking structures require major reconstruction or replacement after 20-40 years, with higher maintenance costs in areas with harsh climates, particularly with frequent salt exposure". These maintenance schedules and renovation plans are designed to control degradation while sustaining the structural components of a building. In an article published by Construction Management and Economics, Farahani, Wallbaum and Dalenbäck (2019) provide an efficient way to schedule maintenance and renovation plans in a given setting. By comparing the different plans, the authors devised cost-cutting measures by determining the optimal maintenance interval for specific building components (i.e., window maintenance).

The cost to maintain an underground parking structure in Toronto is estimated to be between $100 - $500 per parking stall per year (Toronto Condo News, 2016) which includes, a power wash of parking decks, flush and clean of drainpipes, and inspection of moisture protection system According to a study conducted by the Victoria Transport Policy Institute in 2022, the projected annual operation and maintenance costs for an underground urban parking facility amount to $575 per parking space (Litman, 2022). Simply, the estimate is primarily for maintenance to extend the life of the parking structure. However, by optimizing the maintenance schedules and constructing only necessary parking, one can expect a significant decrease in the annual cost to maintain these parking facilities because of preventing major breakdowns and by the extension of service life (Deloitte (2021); Penny (2018).

Operation and maintenance costs for parking structures can include resurfacing, repairs, cleaning, lighting, security, landscaping, snow removal, access control, fee collection, enforcement, insurance, labor and administration. These costs are often estimated in dollars per parking space per year (Litman, 2022). A 2022 study from the Victoria Transport Policy Institute estimates that operation and maintenance costs for an urban underground parking structure are $575 per space per year (Litman, 2022).

Because operation and maintenance costs are generally estimated on a per space basis, a percentage reduction in parking requirements would result in the same percentage reduction in operation and maintenance costs. For example, in our 25 percent reduction in parking requirements scenario, operation and maintenance costs would also decrease by 25 percent. The information in *Table 5-1*.**Error! Reference source not found.** lists operation and maintenance costs for the 16 parking requirement models given an estimate of $575 per space per year.

Table 5-1: Annual Operation and Maintenance Costs for the 16 Parking Requirement Scenarios

	Spaces	Annual Operation and Maintenance Costs	Annual Savings Compared to Business as Usual
Toronto (*minimums*)			
Business as Usual	660	$379,500	
10% Reduction in Spaces	594	$341,550	$37,950
25% Reduction in Spaces	495	$284,625	$94,875
40% Reduction in Spaces	396	$227,700	$151,800
Toronto (*maximums*)			
Business as Usual	610	$350,750	
10% Reduction in Spaces	545	$313,375	$37,375
25% Reduction in Spaces	457	$262,775	$87,975
40% Reduction in Spaces	366	$210,450	$140,300
Montreal			
Business as Usual	756	$434,700	
10% Reduction in Spaces	681	$391,575	$43,125
25% Reduction in Spaces	567	$326,025	$108,675
40% Reduction in Spaces	454	$261,050	$173,650
Edmonton			
Business as Usual	715	$411,125	
10% Reduction in Spaces	644	$370,300	$40,825
25% Reduction in Spaces	536	$308,200	$102,925
40% Reduction in Spaces	429	$246,675	$164,450

Annual operation and maintenance costs are largest in Montreal which has the highest parking requirements in our model and smallest in Edmonton which has the lowest parking requirements. According to the model, reducing the number of parking spaces in Toronto by 10 percent, 25 percent, and 40 percent would result in an annual operation and maintenance cost savings of $37,950, $94,875, and $151,800 respectively. However, with the changes to the zoning by-law, reducing the parking under the maximum parking provision would result in in an annual operation and maintenance cost savings of $37,375, $87,975, and $140,300 respectively.

Reducing the number of parking spaces in Montreal by 10 percent, 25 percent, and 40 percent would result in an annual operation and maintenance cost savings of $43,125, $108,675, and $173,650 respectively. And finally, reducing the number of parking spaces in Edmonton by 10 percent, 25 percent, and 40 percent would result in an annual operation and maintenance cost savings of $40,825, $102,925, and $164,450 respectively. As stated earlier in this section, a 10 percent, 25 percent, and 40 percent reduction in parking requirements results in a 10 percent, 25 percent, and 40 percent reduction in operation and maintenance costs respectively because costs are estimated on a per space basis.

5.3 Drivers of Maintenance and Rehabilitation Costs in Parking Facilities

This section reviews studies that specifically focused on the drivers of rehabilitating parking facilities. As mentioned earlier, a lack of Canada-based research on the subject matter required us to rely on literature based on research done elsewhere in the world. Mosienko (2016) studied the repair of underground parking in Saint Petersburg, Russia with emphasis on waterproofing, and using a case study, reported several factors that can contribute to higher maintenance and rehabilitation costs:

- Not paying enough attention to weakest links, such as expansion joints, joints of concrete slabs (whether connecting themselves or to walls) and roof drains
- Lack of proper drainage for the roof
- Having a humid climate can result in moisture penetration.

Chrest et al. (2016) categorized the cost of underground parking maintenance into aesthetic, operational and structural maintenance costs. They suggested that a facility manager should predict the maintenance cost of each category separately to reach an accurate budget. From a planning perspective, the cost of parking maintenance is composed of the following categories:

- Cost of periodic maintenance or minor rehabilitation required to maintain the serviceability of the facility. This includes routine maintenance such as cleaning and patching the floor surface.
- Cost of replacing structural or operational elements at the end of their estimated service life, such as cost of replacing parts of (or the entire) parking door or the cost of rebuilding the pavement.
- Cost of preventive maintenance necessary to extend service life, such as sealing cracks in floors or walls.

The cost of routine maintenance is known to facility managers and is often accounted for in condominium status certificates and annual budgets. However, the cost of corrective actions and major rehabilitation, which includes replacing structural elements (e.g., doors, walls, or floor), are often overlooked or deferred to a later time. These costs are substantial and are significantly larger than routine maintenance costs. For example, a replacement of a structurally compromised parking lot may cost more than C$300 per square meter (Sarvinis 2020).

Chrest et al. (2016) presented the estimations in Table 5-2 for the operating cost of a parking facility. This data is based on a survey conducted in 1999 by Walker Parking Consultants. The numbers reflect the median cost of 150 parking structures throughout the United States. Chrest et al. (2016) did not provide any details about the number of underground parking facilities in this survey. However, the presence of cost items such as snow removal indicates that at least some of the facilities were not built underground.

The following table shows that the cost per space for a parking facility was $564.03. This means that the annual operating cost for a parking structure with 100 spots would be $56,403 in 1999 dollars. The annual cost for routine maintenance and major maintenance would be $3,702 and $3,802, respectively. The cost of structural maintenance reported in Table 5-2 (excluding costs such as cashiering salary and management cost) is about 57% of the total cost of $564.03. Note that maintenance costs account for about 14 percent of the median annual cost per space. This suggests that most of the funds spent on operating parking structures are not related to maintenance. For a longer service life, one may argue that a greater proportion of parking related expenses be dedicated to maintenance to keep the facility in a state of good repair.

Table 5-2. Median annual cost per space for 150 parking facilities in the US in 1999[76]

Cost item	**Median annual cost per space ($)**
Cashiering salary and benefits	184.57
Management cost	57.69
Security cost	90.65
Utilities	50.00
Insurance	13.76
Supplies	6.61
Routine maintenance	37.02
Structural maintenance	38.02

[76] For another table containing parking lot maintenance and rehabilitation cost estimates from 1990 refer to Chrest et al. (2016).

Snow removal	4.07
Elevator/parking equipment maintenance	6.07
Other expenses	75.43
Total cost	564.03

Researchers have also provided cost estimates related to full-scale rehabilitation. Sarvinis (2020) presented a case study of rehabilitating an aged multi-level parking facility in downtown Toronto using an external post-tensioning system and reported that the cost of the suspended slab used for rehabilitation was approximately C$301 per square meter.

In addition, the monthly cost per space associated with maintaining parking stalls differs for each type of facility. For instance, Litman (2021) illustrates that the monthly costs for urban underground parking are roughly three times more than surface parking in urban areas.

5.4 Maintenance Cost of Parking Facilities in Canada

Limited published information is available about maintenance and rehabilitation costs of underground parking facilities. We have relied on two separate sources of information that present different estimates, primarily because of project and location specific differences that may not render the findings to be generalized. The first source of information relies on data acquired indirectly in Greater Toronto Area (GTA) where 21 sample condominium status certificates were studied. A condominium status certificate is a document defined by Section 76 of the *Ontario Condominium Act* (Government of Ontario 1998) and must include information such as the common expenses for the unit and the default, if any, in payment of the common expenses. A condominium status certificate usually includes information about the cost of maintenance and repair.

Out of the 21 studied sample condominiums, only 15 included a breakdown of the maintenance and rehabilitation costs. These samples are presented in

Table 5-3. This table shows the maintenance cost for the last two years for each condominium (mostly 2020 and 2021) represented as year A and year B 2.[77]

[77] The authors would like to acknowledge the cooperation of Mr. Dave Elfassy (real estate manager at Team Elfassy) for providing samples of condominium status certificates.

Table 5-3. Maintenance and rehabilitation costs for Parking Infrastructure

Condominium number	Age of building	Number of stories	Number of units	Cost in year A ($C)	Percent of total cost in year A	Cost in year B ($C)	Percent of total cost in year B
1	17	12	228	4,026	2.03	4,557	2.61
2	-	-	-	-	-	2,769	2.27
3	46	13	277	9,887	4.85	4,252	1.64
4	-	-	-	2,769	2.27	16,128	6.02
5	9	25	98	13,649	4.8	22,543	4.04
6	18	24	231	3,974	10.45	4,285	9.63
7	9	13	511	20,584	8.48	16,111	7.78
8	10	41	453	13,006	11.71	19,303	17.68
9	19	27	267	3,558	5.62	2,385	7.47
10	16	8	156	3,000	0.6	4,500	0.8
11	6	15	450	-	-	105,690	8.96
12	30	19	412	6,000	1.35	6,000	1.15
13	12	14	364	15,000	11.03	10,000	7.07
14	7	7	228	4,475	2.62	4,542	2.95
15	35	16	199	1,500	4.73	650	23,350

Note: Maintenance and rehabilitation costs (in Canadian dollars) of parking in condominiums in two different years and the ratio of this cost to the total maintenance and rehabilitation cost

Except for sample 11, which underwent a major rehabilitation, the maintenance cost for other parking facilities does not exceed C$23,000. In cases where the maintenance cost for years A and B are significantly different, a major rehabilitation (such as the repair of a parking door, waterproofing or pavement rehabilitation) took place. Examples of such cases are condominium number 11, 5 and 3 in Table 2. In most condominium status certificates, the cost of non-routine maintenance/rehabilitation was recorded separately.

The second source of information comes from members of the of the Canadian Federation of Apartment Associations (CFAA). The data have been anonymized to protect the identity of multi-family residential building landlords. The data are for buildings located in Ontario.

Table 5-4. Maintenance and rehabilitation costs for Parking Infrastructure

Building	Repair period	Total Cost	Damaged spots	Repair duration	Cost per Space
A	2021-22	$3,768,104	95	1.25Years	$39,664
B	2018	$698,411	30	0.2Years	$23,280
C	2018-2020	$1,670,020	108	1.9Years	$15,463
D	2017-2018	$874,085	15	1.4Years	$58,272
E	2016-2018	$2,737,188	260	1.59Years	$10,528
F	2013-2014	$1,472,014	125	1.25years	$11,776
G	2021	$188,988	44	0.35years	$4,295
H	2019	$322,525	65	0.25years	$4,962
I	2019	$312,640	36	0.25years	$8,684

Source: Canadian Federation of Apartment Associations

CFAA data is more explicit in cost structures than the data shared by condominium corporations. The CFAA data presents a wide range of cost estimates ranging from a low of $4,295 to a high of $58,272, which reflects the extent of repairs needed for the parking structure.

While the literature cited earlier described how contingency planning ensures public sector assets are kept in a state of good repair, the following describes similar strategies for residential buildings. Capital planning in residential properties typically involves several key steps, beginning with assessing the current condition of the building. This includes evaluating the condition of various components, understanding the scope of required renovations, and prioritizing repairs or replacements based on their importance and urgency. The process often employs multi-criteria decision-making models to assess the costs and scope of the renovation, ensuring the property's long-term viability and physical condition (Bucoń & Tomczak, 2016); (Bucoń & Tomczak, 2018).

An integral part of this planning is the reserve fund study, which projects the future costs of major repairs and replacements over an extended period. This study typically includes a detailed examination of the building's condition and anticipates necessary expenditures to maintain it over time. Reserve fund studies often use building condition assessments to inform their projections (Schnare, 1991).

Capital planning also involves identifying the equipment condition, expected remaining life, repair spending, and potential for energy efficiency improvements. This is particularly relevant in evolving energy standards and the push for more sustainable and efficient building operations. A 5-year capital replacement plan is often developed to manage these aspects efficiently (Rutherford, 2018).

In addition to these technical aspects, capital planning must consider the economic dimensions. This includes the immediate costs of repairs and renovations and the long-term financial implications for the property owners and residents. The main part of the funds for these repairs often comes from property owners' contributions, necessitating transparent and equitable financial planning (Elyukina, 2017).

Furthermore, the planning process should integrate long-term perspectives and performance-based methods considering technical and economic criteria. This approach ensures that the repairs and renovations carried out are technically sound and economically viable over the long term (Dement'eva, 2017).

Hence, capital planning for major repairs and replacements at residential properties is a complex process that requires a thorough understanding of the building's physical condition, future needs, and financial implications. It involves a blend of technical assessment, economic analysis, and strategic long-term planning to ensure the sustainability and functionality of residential buildings.

5.5 Conclusions

Maintenance costs of parking infrastructure in multi-family residential buildings were explored to determine their impact on the cost of ownership or rents. It is assumed that parking infrastructure in multi-family residential buildings will require maintenance over time. The extent and pace of wear and tear will depend upon the exposure of the infrastructure to extreme weather or usage. The maintenance cost over time will increase with the extent of parking provision, such that costs will be higher for a more significant number of spots and costs can be reduced if fewer spaces are required.

The academic and grey literature does not offer much help with examples of rehabilitation costs of parking infrastructure in residential buildings. Hence, the analysis relied on examples of costs determined for similar infrastructure in other comparable land uses. In addition, property managers and owners of multi-family residential buildings were consulted for empirical evidence.

The use of concrete is pervasive in underground garages. While concrete is a durable material, it deteriorates based on exposure to elements, resulting in spalled concrete, delamination, leaking cracks and more. The rehabilitation of concrete structures is expensive and adds to the long-term maintenance costs of buildings, resulting in higher costs of ownership or rents.

The review of published research confirmed that periodic maintenance increases the service life of parking infrastructure. In comparison, deferred maintenance increases rehabilitation costs because infrastructure deteriorates faster, requiring more extensive repairs. The repair costs of parking infrastructure for condominiums and purpose-built rental buildings depicted a wide range, again depending upon the extent of wear and tear that differed across buildings. The review of maintenance costs, though, confirmed the apparent finding that maintenance costs would be higher for a building with more parking spots than one with fewer spots.

The end users, who may be owners or renters, bear the maintenance costs. Therefore, when minimum parking requirements require builders to provide a certain number of parking spots, it affects not only the initial construction costs but also the maintenance costs over the years, impacting housing affordability. Hence, there is a need to consider revising minimum parking requirements for their impact on housing affordability.

6 CONSTRUCTION MANAGEMENT IMPLICATIONS OF UNDERGROUND PARKING CONSTRUCTION

6.1 INTRODUCTION

The increasing demand for parking in urban areas, such as Toronto, and the limited availability of above-ground space has forced densely populated areas to consider underground infrastructure. For example, the PATH system in Toronto hosts 3.7 million square feet of retail space connected to more than 75 commercial buildings, subway stations, over 20 underground parking garages, and several other facilities[78]. Underground parking has become more popular than ever. However, the construction of underground parking facilities poses certain challenges related to deep excavations, the need for a soil disposal or reuse plan, limited space on construction sites and specific requirements such as waterproofing (Goel et al. 2012). Such issues can have construction management implications, such as an increase in the overall cost and time of construction. This section will discuss the construction management implications of underground parking with a specific focus on cost as one of the most important project objectives. This section will also elaborate on how the deep excavation requirements for underground infrastructure can result in an increase in construction costs, time, and overall level of risk compared to above-ground parking facilities.

6.2 REQUIREMENTS OF UNDERGROUND PARKING VERSUS ABOVE-GROUND PARKING

The design and construction of underground parking requires several additional steps that should be reflected in cost and schedule planning. These additional requirements may result from structural, logistical or legal requirements. For example, from a structural perspective, underground parking construction requires deep excavation, shoring or stabilization around the excavated area and structural capacity to withstand external (vertical and lateral) loads, including vehicles, neighbouring buildings and as well as the superstructure above (Chrest et al. 2016). From a building code perspective, in Ontario, there is a need for an HVAC system to provide adequate ventilation, as required by Section 6.2.2.3 of the *Ontario Building Code* (Government of Ontario 2012), sufficient lighting and fire protection and safety systems, such as fire sprinklers, as required by 6.2.2.5 of the *Building Code* and the *Fire Protection Act* (Government of Ontario 1997). Generally, planning of underground spaces, alongside above-ground spaces, building code requirements and building permits are sought out during the design phase. Most permits and building code requirements apply for all levels within a parking structure (i.e., emergency exits, lights, clearway space). It is necessary to account for such compliance measures to ensure safety and built standards during all aspects of construction (Goel et al., 2012). This ensures acceptable health and safety protocols are met during the construction phase. While the compliance measures stated here apply to above-grade and below-grade structures, the fact remains that the construction cost of

[78] City of Toronto: Path Facts, www.city.toronto.on.ca/path/.

underground parking is significantly higher than above-ground parking. According to Altus Group (2022), it takes around $5 – 27 per sq. ft to construct surface-level parking, $75 – 160 per sq. ft to build an above-ground garage and $115 – 265 per sq. ft to construct below-ground parking. In addition, the construction of underground parking facilities has other requirements that may affect the cost, quality, and schedule of the project. Some of these additional issues are discussed in further detail below.

6.3 Soil Reuse or Disposal

The first consequence of excavation, no matter how deep, is the amount of soil displaced. Excess soil can be reused on-site or moved to another site, but it can be costly. The Ontario Society of Professional Engineers (OSPE) (2016) conducted a survey of 24 construction projects in Ontario, with costs ranging from 1 to 50 million Canadian Dollars, and reported that, on average, the cost of handling and disposing of excess soil accounts for 14 percent of the total project cost in the projects evaluated. This study was performed before Ontario's excess soil regulation in 2019.[79]

To improve the management of excess soil on construction sites, the Ministry of the Environment, Conservation and Parks (MECP) announced a new regulation under the *Environmental Protection Act* titled '*On-Site and Excess Soil Management*' or *O. Reg. 406/19* (Government of Ontario 2019). This regulation aimed to improve the planning of soil reuse in construction projects. It introduced new requirements by employing qualified personnel to ensure appropriate displacement of excess soil (Government of Ontario, 2004), for the completion of a land use history assessment, development of a soil characterization report and sampling plan, with the eventual goal of restricting landfilling soils by January 1, 2025.

Excess soil regulation identifies excess soil as a resource which can be reused rather than wasted. The requirements of *O. Reg. 406/19* will increase the cost of handling excess soil. Currently, no case study is available examining the magnitude of these additional costs as the regulation has not yet been fully implemented. However, anecdotal reports have asserted that the cost of disposing of excess soil in Ontario has increased over the past decade, an issue partly linked to a scarcity of proper receiving sites (Piryonesi et al. 2021). Soil reuse or disposal is particularly more complicated for urban brownfield sites. This is because the soil in urban areas is known to be contaminated with different chemicals, including tire-derived contaminants (Challis et al. 2021). If the soil does not meet the reuse and waste clarification rules, the excess soil will be deemed waste and managed per the Province's waste management regulations[80].

[79] The regulation provides rules to reuse and manage excess soil that has been excavated as part of a project. The new excess soil framework provides overview on a) Reuse and Waste Management, b) Excess Soil Standards and Rules for Appropriate Reuse, c) Responsibility of the Project Leader. The benefit from this scheme is meant to reduce transportation and landfilling costs of excess soil by re-using the soil for other activities.

[80] https://www.ontario.ca/laws/regulation/r19406#BK1

6.4 IMPLICATIONS OF HYDROSTATIC PRESSURE

Hydrostatic pressure is a phenomenon where gravity acting on a fluid at equilibrium causes pressure to act on the surface submerged or surrounded by water. In other words, as you go deeper into a fluid, the weight of the fluid above you increases, leading to a higher hydrostatic pressure. This pressure increases with the depth and volume of water and can force water into any cracks, gaps, or imperfections in underground concrete walls or foundations. The surrounding soil or rock is saturated with water as the structure is below the water table. The weight of the water above the structure exerts hydrostatic pressure on the walls and base of the structure. This additional load can affect the stability and structural integrity of the underground construction (i.e., cracked concrete or water infiltration). In general, they are extremely costly due to long-term damage caused to the structure (Chrest et al. 2016).

To help prevent these types of damage, three key techniques should be considered in designing and constructing underground parking structures (Chrest et al. 2016; Mosienko 2016): waterproofing, crack sealing and proper drainage. A waterproof design is necessary for underground parking, especially in areas with wet climates or any site with high water table, such as Canada. Such a system must withstand a harsh environment and cracks that may form or close depending on concrete freeze and thaw cycles.

Dampproofing is different and less expensive than waterproofing. In short, unlike waterproofing, dampproofing only stops the passage of moisture with no hydrostatic pressure (ASTM 2010; Henshell 2016). Waterproofing, on the other hand, is more expensive, and a waterproofed surface will stop the flow of water into the underground facility (Henshell 2016). Although it is not mandatory, many developers choose to waterproof their underground parking structures to avoid possible leaks in future.

Finally, a proper drainage system must be implemented to ensure any water that has made its way into the vicinity of the parking garage does not pool up and is removed so as not to damage the sealant or waterproofing system (Goel et al. 2012). Temporary or continuous drainage and dewatering may be necessary to prevent future infiltration and flooding.

6.5 FLOODING IMPLICATIONS

Although the surface occupied by underground parking is considerably smaller than above-ground parking lots, having many underground facilities in densely populated areas can exacerbate the risk of flooding by affecting surface runoff. [81] This increase in the rate and volume of surface runoff can be mitigated using low-impact development solutions (LIDs), such as infiltration chambers

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[81] Constructing an underground parking garage displaces the natural ground and reduces the capacity to absorb and retain water. The installation of permeable surfaces, retention ponds, or other measures to help control and manage surface runoff. Additionally, proper waterproofing and drainage systems within the underground structure itself are crucial to prevent water infiltration and ensure the stability of the construction.

(Young et al. 2013) or dry wells (Edwards et al. 2017). However, the design, construction, and maintenance of LIDs can have additional costs, depending on the type of technology adopted. The flood risk is severe for more established Toronto neighbourhoods because of their lower volume capacity combined sewer systems (City of Toronto 2022). Traditionally, combined sewer systems were designed to collect and convey stormwater runoff and sanitary sewage. However, during heavy rainfall events, combined sewer systems may not have sufficient capacity, resulting in an overflow of untreated water and an increased risk of health issues and property damage. Such unforeseen events and unanticipated expenses during construction may cause the project budget to fall short. Less research is available about the impact of underground parking on flooding in comparison to above-ground parking. However, it is well known that underground parking facilities and their construction sites are always vulnerable to inundation, given that their entrance level may not be significantly higher than the ground level (Kron 2005).

The backflow from an existing storm or sewer system can also lead to flooding in an underground parking facility. This is because the stormwater or sewer outlets from an underground facility are well below the invert of the existing storm/sewer system (running below the streets parallel to the facility). Therefore, their connection can lead to backflow when the existing storm/sewer systems run full during peak rainfall (Sandink 2013). Backflow prevention valves are used to overcome this situation, as they are required under the authority of the building codes.

As mentioned in previous sections, proper drainage is necessary to avoid flooding of a parking structure, and drainage may be necessary during construction and operation periods. As per the *Toronto Municipal Code*, Chapter 681 (also known as sewer by-laws), any groundwater, sewer water, rain, or any other water discharge from a building will be charged by the city, and the builder will have to pay the charges (City of Toronto 2021). The builder will have to pay the short-term discharge fee of less than $20,000, generally levied during the construction period. This fee includes the discharge of dewatering during construction. As per Toronto's new by-law, effective January 1, 2022, the short-term discharge fees, which include the permanent discharge of water from the building to the foundation drainage up to $20,000 per year, will be charged to the builder. Builders will also have to incorporate the cost of the hydrological assessment report, which will be required before the commencement of the excavation. In British Columbia, applying for a wastewater discharge permit during construction projects comes at a cost. The initial application fee for a maximum instantaneous flow of 6 litres per second (L/S) or less is $500, and $1,000 for a flow of more than 6 L/S.[82]

6.6 Consequences of Deep Excavation

Design and construction of parking facilities with deep excavation require complex theoretical knowledge, skilled labour and expensive equipment. If designed or operated poorly, deep excavation in urban areas can cause many environmental, safety, and logistical issues, such as

[82] https://vancouver.ca/home-property-development/wastewater-discharge-permit-for-construction-at-contaminated-sites.aspx

unwanted settlements, damage to neighbouring structures, excess noise and vibration, interruption of traffic, and damage to underground utilities (Ou 2014). Excavation in unfavourable soil conditions or hard rock is more expensive and time-consuming (Gillani and Butt 2009; Ou 2014). Some of the issues of deep excavation that require more attention during construction are summarized below.

6.6.1 Slope stabilization

Deep excavation usually exacerbates the risk of unwanted settlement and different types of slope instability. Settlements that are beyond acceptable thresholds can create cracks in neighbouring buildings. Slope instability or failure could be even more damaging. To stabilize the soil, a retaining wall is built to withstand lateral loads such as soil and hydrostatic pressure. There are different types of retaining walls, including gravity, cantilever, counterfort, crib, gabion, mechanically stabilized earth (MSE), nailing, sheet pile and anchored retaining walls (Ou 2014). The last three types of retaining walls are prevalent for slope stabilization when working in a deep excavation. Hybrid systems, a combination of two or more of the above-mentioned methods (e.g., nailing and MSE), are popular too (Lazarte et al. 2015). Not all of these systems apply to all situations, but what they have in common is that they all come at an additional cost. For example, according to the *FHWA Soil Nail Walls Reference Manual*, the construction cost of a soil nail retaining wall is approximately $700 to $1,000 per square meter in 2014, which is 10 to 30 percent cheaper than other methods (Lazarte et al. 2015).

Furthermore, excavation and construction of a retaining wall create noise and vibration that could exceed acceptable thresholds defined by municipal by-laws. In addition to excavation, operations such as driving sheet piles or nailing can generate high levels of vibration and noise (Das 2011). Mitigating these issues requires careful planning and engineering, pre-construction surveys, continuous noise and vibration monitoring during construction, monitoring of the movements of neighbouring structures and overall due diligence.

6.6.2 Leakage and water control

Leakage through retaining walls could occur when the retaining wall is damaged or not correctly waterproofed, or the project is located in sandy soil with a high groundwater table level. If leaking through the retaining wall is significant, the excavation may collapse, causing numerous environmental and safety issues. When leakage is modest, fine-grain material may be carried into the excavation by water (Ou 2014).

To keep an excavation site dry, water should be continuously pumped out of the site. Keeping the site dry is necessary to adhere to construction schedules. In sites located in fine-grade soil, such as clay, keeping the site dry is a must to increase the effective stress and prevent upheaval failure (Craig 2004). Pumping water should be carried out with great caution since pumped water may wash away fine-grain soil and lead to unwanted settlement. Pumping water into the sewer system will incur additional costs, as discussed in the sections above. Furthermore, rapid dewatering can lead to soil consolidation and large undesirable settlements in neighbouring structures (Craig 2004; Liyanapathirana and Nishanthan 2016). Therefore, soil characteristics and groundwater levels should be examined before the beginning of excavation and dewatering.

6.7 Conclusions

This section examined the engineering aspects of constructing underground parking structures in multi-family residential buildings. Given the additional regulations regarding underground construction, the cost of providing underground parking is significantly higher than above-ground parking. According to Altus Group (2022), it takes around $5 – 27 per sq. ft to construct surface-level parking, $75 – 160 per sq. ft to build an above-ground garage and $115 – 265 per sq. ft to construct below-ground parking. The study focussed on deep excavation for parking infrastructure construction and resulting concerns for structural elements, vertical and lateral loads, hydrostatic pressure, disruption to neighbouring buildings, water leakage from retaining walls and more.

Underground parking infrastructure is increasingly susceptible to flooding. The surface runoff is intended to be handled by storm sewers in urban areas. However, given the extensive construction in urban centres, runoff absorption capacity is compromised in places where open green spaces are limited or nonexistent. At the same time, given the lack of sufficient storm sewer capacity, flooding risks are elevated, which are likely to impact the underground parking infrastructure. At the same time, backflow from an existing storm or sewer system can also lead to flooding in an underground parking facility. The end users of space, owners and renters will have to bear the costs, especially if insurance contracts do not have sufficient provisions for flood damage.

Deep excavation usually exacerbates the risk of unwanted settlement and different types of slope instability. Settlements that are beyond acceptable thresholds can create cracks in neighbouring buildings. Slope instability or failure could be even more damaging. A retaining wall is built to withstand lateral loads such as soil and hydrostatic pressure to stabilize the soil. Nevertheless, the hydrostatic pressure increases with the excavated depth, leading to additional concerns about leaking water that require expensive remedial measures at the design and construction stage, contributing to increased construction costs. Hence, construction costs increase because of safety provisions to mitigate risks from deep excavation.

Minimum parking requirements in multi-family residential buildings can lead to deep excavation to accommodate larger-sized underground parking infrastructure. Such requirements, therefore, have unintended adverse effects on the environment and the structural stability of the building and the surroundings. A revision in minimum parking requirements resulting in the construction of fewer parking spots could result in a reduction in excavation depth, thus reducing the adverse impacts of deep excavation.

7 ENVIRONMENTAL IMPLICATIONS OF UNDERGROUND PARKING

7.1 INTRODUCTION

The construction of underground parking facilities may cause numerous environmental issues. The list of issues caused by underground parking and their impacts may be smaller than that of the above-ground parking lots. However, some environmental implications concerning underground parking (e.g., soil contamination and additional emissions) require careful consideration. They are particularly carbon-intensive as their construction requires more energy and material. Limited, if any, research is available about the lifecycle assessment (LCA) of underground parking compared to above-ground parking. This report gathers evidence from the literature about the additional emissions of underground parking and other potential environmental issues.

The issues associated with above-ground parking have been known and documented for many years. They include increased risk of flooding (Frazer 2005; Mullaney and Lucke 2014), surface water pollution (Horner et al. 1997), urban heat island effect (Onishi et al. 2010; Yang et al. 2019), land cost-opportunity, increased vehicle travel and associated costs, sprawling costs, reduction or loss of wildlife habitat and aesthetic degradation (White et al. 2007). Underground parking is sometimes recommended as one of the possible solutions to alleviate these issues (Litman 2011), especially for problems related to sprawling and paved surfaces. This is because the above-ground area paved for underground parking is almost zero. Despite this, underground parking can cause several environmental issues, some of which are less well understood and are discussed below.

7.2 ENVIRONMENTAL IMPLICATIONS OF UNDERGROUND PARKING CONSTRUCTION

This section summarizes environmental issues caused by the construction of underground parking in comparison to above-ground facilities. Like other construction projects, underground parking construction can cause environmental issues related to soil and water pollution, abiotic depletion, acidification and greenhouse gas (GHG) emissions. Most of these challenges are associated with excavation, transportation, and soil disposal, which are fundamental aspects of underground parking construction.

7.2.1 Environmental issues of soil disposal or reuse

The construction industry perceives soil as a waste rather than a resource (OSPE 2016). Providing an ecosystem for fauna and flora, sequestrating carbon, filtering and storing water and preventing floods by absorbing runoffs are only a few benefits of soil (Victoria et al., 2012). Land use change and construction can disturb the soil and even contaminate it.

Excess soil generated during the excavation for building an underground parking facility is moved to another site for reuse. Landfilling excess soil has direct and indirect environmental impacts.

Direct impacts include greenhouse gas emissions and additional road deterioration caused by construction machinery and the transportation of soil to and from sites (Piryonesi and El-Diraby, 2020). The Ontario Society of Professional Engineers (2016) studied 24 construction projects in Ontario and reported that more than 75% of the projects require at least 100 one-way trips (on average, a 65 km travel distance) to transport their excess soil to a receiving site. The indirect impact is overwhelming municipal landfills. This is problematic as the space required to dispose of waste quickly runs out (Harris Ali 1999; Ismail and Abd. Manaf 2013).

Starting in 2025, the Government of Ontario (2019) will prohibit landfilling any soil that is not designated as waste. This is done by implementing *O. Reg. 406/19*. This change means that soil should be beneficially reused on-site or be transferred for reuse in another site. Local or on-site beneficial reuse of soil can reduce the emissions caused by soil transportation. Soil transportation between sites adds to the project's emissions and can lead to the spreading of microbiological and chemical contaminants. Examples of chemical contaminants in soil are different hydrocarbons and metals usually present in urban soil. While *O. Reg. 406/19* and associated rules and standards (MECP 2020) can sufficiently address the issues related to chemical contamination, they do not touch on other issues related to soil disposal or transportation, such as microbiological contamination or invasive species (Piryonesi et al. 2021a).

Microbiological contamination

When contaminated soil is transported to another site, microbiological contaminants can easily spread through soil and groundwater. Among the most dangerous microbiological contaminants are E. coli and other forms of coliform bacteria. These contaminants can be present in soil in urban areas as they can live and migrate via the sewage system. The contaminated soil is not necessarily sourced from deep excavations because contamination depends more upon proximity to the source of pollution. Such bacteria in soil and water could result from fecal waste from humans, birds, pets or wild animals. These contaminants may pose a risk, especially if they reach potable groundwater in rural areas (Welhan 2001). Such scenarios are possible when placing excess soil below the groundwater table (for example, during pit or quarry rehabilitation) (Piryonesi et al. 2021b).

Invasive species

If transported large distances, excess soil can cause issues related to invasive species (Buttleman 1992). In some jurisdictions, regulations are different for exotic and invasive species. Species moved or introduced by anthropogenic forces to a new location where they do not naturally occur are known as exotic species. Not all exotic species are invasive unless they invade land, water or native species, causing ecological or economic problems (Minnesota DNR 2020). In Ontario, the *Invasive Species Act* defines invasive species as "a species that is not native to Ontario, or to a part of Ontario" (Government of Ontario 2015).

The Ontario Ministry of Environment Conservation and Park (MECP) has listed some of the invasive species that could be potentially introduced due to soil removal and transport. Examples are phragmites and garlic mustard. The complete list is available at *MECP's Best Management Practice for Excess Soil Management* (MECP 2016).

Nematodes are another species known as a common invasive species introduced to new places in Ontario due to earthworks. Nematodes are particularly risky as they are not often visible to the naked eye. These organisms can be invasive and parasitic to plants (Celetti and Potter 2016; Singh et al. 2013) and animals (Baker 1986). Soil should be sampled at the correct times and locations and according to appropriate protocols for nematodes (Celetti and Potter 2016). There are multiple species of invasive or parasitic nematodes in Ontario, some of which include (Piryonesi et al. 2021a):

- Dagger nematode (*Xyphinema sp*.)
- Soybean cyst nematode (*Heterodera glycines*)
- Oat cyst nematode (*Heterodera avenae*)
- The sugar beet cyst nematode (*Heterodera schachtii*)
- The root lesion nematode (*Pratylenchus penetrans*)
- Bulb and stem nematode (*Ditylenchus dipsaci*)
- Falcaustra species such as *F. inglisi, F. chelydrae, F. wardi, F. affinis and F. catesbeianae*
- The northern rootknot nematode (*Meloidogyne hapla*)

The risk of nematodes becoming invasive species can be reduced or potentially eliminated through various strategies and regulations. Canada, along with international strategies, works to prevent the influx of alien invasive species, monitor their presence, and control established populations. These strategies are essential in managing the risk posed by invasive nematodes (Humble & Allen, 2006). Using self-organizing maps (SOM) can identify previously overlooked nematode species that could pose new threats. This method enhances the ability to reduce the risk of nematodes becoming invasive species by early detection and response (Singh et al., 2014). The International Plant Protection Convention provides a framework for measures against invasive alien species, including nematodes. This includes establishing pest-free areas, surveillance, and eradication programs, which are crucial for managing invasive nematode species (Schrader & Unger, 2003).

7.3 Lifecycle Assessment and Emissions

Construction of underground parking facilities results in large amounts of GHG emissions. Emissions may result from excavation (Forsythe and Ding 2014; Peng 2016), construction of retaining walls, construction of the walls and floors of the parking facility (Inui et al. 2011), waterproofing (Kim et al. 2014) and operation of the facility. This section highlights the GHG emitted during excavation and construction of retaining walls, as these walls distinguish underground parking from above-ground parking.

When only considering the impact on microclimates, underground parking may have some benefits compared to above-ground parking. For example, underground parking can be more environmentally friendly for reducing the urban heat island effect (Yang et al. 2019, 2014). Based on comparing underground parking and curbside parking in Sweden, Höglund (2004) reported that parking a vehicle in an underground facility can reduce emissions by up to 40% when compared to curbside parking. However, their study did not use a lifecycle approach and limited emissions to vehicle exhaust emissions. This means that they did not consider emissions resulting from the construction of the parking facility.

Excavation is among the first tasks in the construction of underground parking that releases additional carbon into the atmosphere. The percentage of carbon dioxide in the soil (0.25 to 0.5 percent) is significantly higher than in the atmosphere (0.03 to 0.04 percent) (Russell and Appleyard 2009). The trapped carbon in the soil is partially sourced by the sequestration process performed by plants and trees during their lifetime. In the process of excavation, the natural soil is disturbed. This causes a carbon efflux from the soil as the pores trapping gases are exposed in the atmosphere, and the confined gases are released into the air (Alvarez and Alvarez 2000; Aryan and Gupta 2019).

More importantly, the construction of underground parking structures releases considerable carbon dioxide (CO_2). Construction usually starts with deep excavation, which can emit a considerable amount of CO_2 due to fuel burned to operate heavy excavation equipment. Limited research is devoted to the emissions of deep excavation for parking. The available research is for multi-story residential buildings based on different assumptions and functional units for LCA calculation. Peng (2016) used kg CO_2 per cubic meter of excavated soil. Their findings are presented in the following table.

Table 7-1: The emission factor of different tasks in excavation, adopted from Peng (2016)

Construction task	**Emission factors**
Excavation, earth removal	1.05 kg/m^3
In-situ earthwork	0.11 kg/m^3
Backfilling, rolling and smoothing	0.99 kg/m^3
Horizontal transportation	0.19 kg/t.km

The numbers in the table above are for excavation work only. The amount of emitted GHGs for deep excavation is much larger as it requires more energy and material not only for excavation but also for constructing the foundational wall. Forsythe and Ding (2014) reported the kg CO_2 emitted from excavating one square meter for parking in residential buildings with different slopes. The numbers are presented in the following table. Their results demonstrate that as the excavation slope becomes steeper, the emission per square meter increases considerably. This is particularly important with respect to the construction of underground parking because, in urban settings, there are many land acquisition constraints, and achieving a mild slope is difficult. Therefore, more proactive and complex solutions, such as nailing and anchoring, may be required for slope stabilization, adding to the carbon emissions (O'Riordan et al. 2011).

Table 7-2: Average GHG per m² of building floor area by soil and slopes ($kgCO_2$-e/m²)

Slope/Soil type	Sand	Clay	Soft soil	Rock
1:10	72	39.1	19.7	137.4
1:6	224.5	80.9	100.7	189.7
1:4	248.4	116.3	43.1	260.4
1:2	-	-	-	2394.7

The carbon dioxide produced during the manufacturing of structural concrete with 14% cement is estimated to be around 290 to 410 kg/m^{3}, depending on the amount of pozzolan (Gregory et al. 2021; Latawiec et al. 2018). For steel, another common material used in underground parking construction, the carbon footprint is about 1,080 to 2,142 kg CO_2 per ton of crude steel (Hasanbeigi et al. 2016). These estimates may vary from one jurisdiction to another based on different practices in the production and supply chain of materials. Furthermore, the emissions due to excavation and the construction of retaining walls are not limited to CO_2 and other gases such as CH_4 (methane), SO_x (sulphur oxides), NO_x (nitrogen oxides) and N_2O (nitrous oxide) are emitted because of these projects (Inui et al. 2011). Each of these gases may pose certain risks. For example, CH_4 is a far more potent greenhouse gas than CO_2 or SO_2, and it could lead to acidification[83].

In short, the primary factor in determining the amount of released GHG is the volume of steel and concrete used in a retaining wall (or the rest of the structure). These values change depending on the type of the wall (O'Riordan et al. 2011), such as an anchored wall, soil nailing and mechanically stabilized earth (MSE) wall, and its physical characteristics or design parameters such as height and thickness (Molina-Moreno et al. 2017; O'Riordan et al. 2011) The optimal parameters for minimizing carbon footprint may result in a steel-concrete ratio that may not be necessarily optimal from a cost management perspective (i.e., more steel for certain parts of the wall). Furthermore, such a carbon-

[83] Acidification of soil is a process where the soil's pH level decreases over time, becoming more acidic. This change in pH can occur due to various reasons. Soil can become acidic naturally over time due to the leaching of essential nutrients (like calcium, magnesium, and potassium) from the soil, often as a result of high rainfall or water movement through the soil. As these essential nutrients are leached out, hydrogen ions accumulate, leading to a decrease in pH.

optimal design may require changing the steel-concrete ratio and the concrete class and cement content (Molina-Moreno et al. 2017).

As mentioned, the type of foundation wall will affect the carbon footprint of an excavation and stabilization project. A comparison between a concrete gravity and MSE wall (each 4.7 m tall) is presented in Table 3, adopted from O'Riordan et al. (2011). From an environmental perspective, MSE outperforms a gravity wall with a GHG emission of less than one-fourth.

Table 7-3: Comparison of the environmental implications of two retaining walls, adopted from O'Riordan et al. (2011)

Structure/Measure	**GHG emission kg CO_2 (equivalent)**	**Acidification kg SO_2 (equivalent)**	**Abiotic depletion kg Sb (equivalent)**
MSE wall	99,000	540	700
Gravity wall	420,000	1310	910

Inui et al. (2011) compared carbon emissions of several retaining wall systems: driven steel tubular pile, pressured-in steel tubular pile, secant concrete pile, propped driven steel sheet pole, propped pressured-in steel sheet pile and propped mini pile. They reported that the propped pressed-in steel sheet pile had the lowest carbon emissions (4,400 kg CO_2 per meter length), while the emission levels of the secant concrete pile were the highest (with 15,200 kg CO_2 per meter length).

7.4 Embodied Energy

The embodied energy of underground parking materials, i.e., the energy consumed to build the facility, is considerable. This embodied energy belongs to the material used for soil stabilization and the construction of the parking lot walls and floors. Table 4 shows the embodied energy in some of the underground parking construction materials.

Table 7-4: Embodied energy intensity (EEI) in material and equipment required for construction of retaining walls

Material	**Unit**	**Mean EEI**	**Maximum EEI**	**Minimum EEI**
Steel	Kg	37	63	12
Concrete	Kg	1.8	2	1.5
Cement mortar	Kg	1.54	3.5	0.1
Diesel fuel	L	37.2	41.2	35.4
Rubble	Kg	0.15	1	0.05

Electricity	kWh	9.75	-	-
Construction equipment	Kg	52.6	-	-

Note: adopted from Inui et al. (2011). (EEI numbers are in MJ per unit)

The type of retaining wall affects the embodied energy of underground facilities. O'Riordan et al. (2011) compared the energy consumption for constructing two retaining walls: MSE and gravity wall. Both walls were 4.7 m tall. They reported that the energy consumed for the gravity wall construction was 2,200 GJ, significantly larger than the 860 GJ of the MSE system. Inui et al. (2011) calculated and compared carbon emissions of several retaining wall systems: driven steel tubular pile, pressured-in steel tubular pile, secant concrete pile, propped driven steel sheet pole, propped pressured-in steel sheet pile and propped mini pile. The mean embodied energy of each wall measured in gigajoule per meter length (GJ/m-length) is summarized in Table 5. The specifications used in the study indicate the length of the wall to be 100 metres.

Note that there are equivalent carbon emissions associated with different materials and resulting from expenditures of energy during construction. These emissions were not calculated as part of this report, however in general the use of reduced amounts of energy and volumes/quantities of materials will result in lower emissions overall.

Table 7-5: The embodied energy of different retaining wall systems

Type of wall	**Embodied energy (GJ/m-length)**
driven steel tubular pile	204.4
pressured-in steel tubular pile	189.4
secant concrete pile	270.6
propped driven steel sheet pole	88.5
propped pressured-in steel sheet pile	79.2
propped mini pile	87.2

Source: Adopted from adopted from Inui et al. (2011)

7.5 Conclusions

The report examined the environmental implications of minimum parking requirements. Deep excavation displaces soil and creates the need for soil disposal. Estimates by the Ontario Society of Professional Engineers revealed in 2016 that handling and disposing of excess soil may account for 14 percent of the total project cost. Trucks carrying excess soil from construction sites for disposal travel hundreds of kilometres and contribute to congestion and greenhouse gas emissions. In addition, soil transportation across towns and cities can also lead to the spread of microbiological and chemical contaminants.

Environmental regulations require the excavated soil to be reused rather than wasted. However, this might not be cost-effective in urban areas where the excavated soil might require extensive remediation, thus contributing to the overall construction costs. Furthermore, space constraints for soil disposal are a growing concern in Canada.

When soil with impurities is relocated, there's a risk of spreading microorganisms through the soil and water systems. Particularly concerning are E. coli and similar coliform bacteria. These can be found in urban soils, often moving through sewage networks. The level of contamination in soil isn't solely linked to the depth of excavation but is more related to how close it is to the pollution source. These bacteria could originate from the fecal matter of humans, birds, and domestic and wild animals. There's a safety concern, particularly if contaminants infiltrate drinking water sources in rural settings. This risk increases in cases where surplus soil is placed beneath the water table, like during the restoration of pits or quarries.

Transporting excess soil over long distances can lead to problems with invasive species. Different jurisdictions have varying regulations for exotic and invasive species. Human activities introduce alien species to areas where they don't naturally occur. Not all exotic species are intrusive; they become invasive if they harm native land, water, or species, causing ecological or economic issues. In Ontario, invasive species are defined as species not native to the province or a specific part of it.

The Ontario Ministry of Environment Conservation and Park has identified several invasive species that might be introduced through soil removal and transport, such as phragmites and garlic mustard. Additionally, nematodes, often invisible to the naked eye, are a significant concern in Ontario due to their invasive and parasitic nature to plants and animals. Proper soil sampling is crucial to detect nematodes, and Ontario has multiple species of invasive or parasitic nematodes.

The construction of underground parking facilities is a significant source of greenhouse gas (GHG) emissions. These emissions arise from various activities, including excavation, construction of retaining walls, building walls and floors, waterproofing, and facility operation. Notably, excavation and the construction of retaining walls are critical differentiators between underground and above-ground parking, contributing heavily to GHG emissions. While underground parking might offer microclimate benefits, such as reducing the urban heat island effect, its environmental friendliness is debated. For instance, it can lower vehicle emissions compared to curbside parking, but this doesn't account for the emissions from construction. Excavation is particularly impactful as it releases trapped carbon dioxide from the soil, where its concentration is higher than in the atmosphere. The construction process, especially the deep excavation involving heavy equipment, produces significant CO_2 emissions.

Lastly, embodied energy in underground parking materials refers to the total energy required to produce and construct the facility. This includes the energy used in the entire lifecycle of the materials, from extraction and processing to transportation and assembly. Specifically, it encompasses the energy consumed in stabilizing the soil and constructing the walls and floors of the parking lot.

The environmental impacts of constructing underground parking infrastructure are extensive and broad ranging. By revising minimum parking requirements for multi-family residential buildings, one can contribute to lowering the adverse environmental impact of the construction industry and introduce sustainable construction practices.

8 CONCLUSIONS

This study explored the multi-faceted impacts of minimum parking requirements for multi-family residential buildings on housing construction costs, affordability, congruence with future mobility trends, and environmental sustainability. This section summarizes the conclusions drawn from the findings and identifies opportunities for future research.

A jurisdictional scan of minimum parking requirements in Edmonton, Toronto, and Montreal revealed a diverse landscape for municipal regulations. The study found that of the three municipal jurisdictions reviewed, the focus on minimum parking requirements has moved from strict minimum thresholds to flexible thresholds, relaxing the minimum parking requirements based on the location and nature of residential development. Hence, new buildings proposed near higher-order public transit, such as subways, were granted relaxed parking provisions. In some instances, they were partially, if not entirely, exempted from such restrictions. Furthermore, two municipal jurisdictions were found to be moving away from minimum parking requirements to maximum parking requirements, recognizing the societal shifts in mobility and automobile ownership that are putting a premium on auto-based mobility.

The study concludes that large municipalities know the need to revise and improve parking regulations. Some municipalities have even embarked on ambitious revisions to their regulations. Revising parking regulations provides an opportunity to improve affordability and reduce the environmental footprint of the urban built-form.

A review of **current and future transportation technologies** and changing attitudes towards automobile-based mobility revealed a decline in the preference for private automobiles for everyday mobility. The mobility innovations are brought about by information and communication technologies intersecting with urban transportation. The emergence of ride-hailing apps, such as Uber and Lyft, is one example where one may still use an automobile for mobility, yet the demand shifts from privately owned automobiles to a shared resource, reducing the demand for personal vehicles and associated parking. Similarly, shared ownership models, which permit many households to collectively own a smaller number of vehicles and use them when needed, are also expected to impact long-term automobile ownership. Mobility as a Service (MaaS), autonomous vehicles, and numerous similar developments are expected to lower the demand for automobile ownership. Hence, as the population continues to increase, the increase in private automobiles is expected to be at a lower rate relative to the population increase. As a result, the study expects a relative decline in the demand for parking spaces.

The seismic shift in how people live and work brought about by COVID-19 also plays into the future demand for parking. A hallmark of COVID-19-induced lifestyle changes is the increase in **working from home**, where a large segment of the knowledge economy workers shifted to working from home rather than commuting to offices. Even when mobility and assembly restrictions were relaxed, the commute to work did not return to levels seen before the pandemic. As a result, hybrid work emerged as a compromise between working from home or the office exclusively. Many office-based workers now work from home and partially from the office, which has reduced the demand for commuting and subsequent parking demand. As autonomous vehicles become more pronounced, the location of parking facilities will also shift from high-priced places to low-priced places.

The innovation in transportation technologies and the evolving work culture of knowledge economy workers are causing shifts in how people travel and use motorized vehicles. The expected decline in automobile ownership levels will impact how much parking is needed. The location of parking garages will also shift from expensive land markets to cheaper alternatives. Reviewing parking requirements generally, not just for multi-family residential buildings, is critical for municipalities.

The **multi-family residential construction costs** were analyzed using proforma analysis. As expected, the study revealed that construction costs declined significantly under reduced minimum parking requirements scenarios. The resulting cost savings can likely be shared with the end-users, improving affordability for homeowners and renters. While the construction cost simulations offered sufficient proof that a reduction in the number of required parking spots would lower the construction costs, further study is needed to ascertain what proportion of cost savings would be passed on to the end users of the space.

The study deployed **hedonic price models** and found that access to dedicated parking spaces in multi-family residential buildings carries a premium. Apartments and condominiums bundled with dedicated parking slots were sold or rented at higher values than units without dedicated or assigned parking. The study found that parking provisions carried a higher premium in buildings farther away from higher-order public transit, such as subways. Furthermore, the study did not find any meaningful difference in the valuation of parking spaces between urban and suburban locations. The study supports the notion that proximity to efficient and reliable modes of public transit mitigates the need for mobility by private automobile, which results in a lower valuation of parking infrastructure.

The study reviewed the maintenance costs of parking infrastructures in commercial, publicly owned, and multi-family residential buildings. The study found that parking infrastructure requires significant costs over time to maintain it in a state of good repair. As expected, maintenance costs increased with the number of parking spots and/or floors. The study concludes that reducing minimum parking requirements will contribute to lower maintenance costs over time and improve housing affordability.

The study also reviewed the environmental and structural impacts of parking provisions on multi-family residential buildings. Since parking infrastructure is often built underground rather than aboveground, the environmental implications of underground construction are profound. The construction costs for underground parking infrastructure are higher than aboveground. However, depending on the cost of land, it might still be cheaper to build parking infrastructure underground, which introduces a host of other challenges and risks. During construction, deep excavation can result in flooding and structural damage to neighbouring properties. The study noted that deep excavations were associated with higher GHG emissions and higher use of energy. The study also found that excavated soil often is transported to landfills. If the soil is contaminated, its transportation exposes communities along the route to environmental hazards. Fossil fuels used by freight vehicles and subsequent generation of greenhouse gas emissions pose additional risks. Municipalities are advised to review procedures and regulations concerning excavation, onsite and excess soil management, and transportation.

8.1 Opportunities for Municipalities

The comprehensive analysis of minimum parking regulations presented in this study offers a pivotal opportunity for municipalities to reevaluate their current practices and policies. This reassessment is essential to align with the evolving patterns in travel behaviour, automobile ownership, and contemporary work environments. The imperative to revise planning regulations concerning parking and multi-family residential buildings is underscored by the necessity to mitigate the detrimental impacts on the natural and built environments, often exacerbated by new construction projects.

This report underscores the potential for municipalities to draw valuable insights from best practices in parking requirements and management within Canada and internationally. As documented in this study, the recent changes in parking regulations reflect the progressive strategies some municipalities have adopted, acknowledging the myriad benefits of relaxing minimum parking requirements.

It is crucial to note that the housing affordability challenges in Canada are not exclusive to densely populated areas. Although the escalation in housing prices has been more pronounced in certain jurisdictions than others, the surge in rental costs is a nationwide phenomenon, affecting regions irrespective of their size. Since the provision of parking spaces significantly contributes to elevated initial construction costs and ongoing maintenance expenses, revising these regulations presents a tangible opportunity to reduce these financial burdens. Ultimately, such amendments could lead to enhanced housing affordability over time.

8.2 Avenues for Future Research

The study identifies avenues for future research, particularly concerning the relationship between parking provisions and housing affordability. With some Canadian jurisdictions having recently modified their minimum parking requirements, there is a unique opportunity to analyze the effects of these changes on transaction values and rental prices in buildings with fewer mandated parking spots compared to those constructed under traditional scenarios.

Large and small municipalities may want to conduct a similar analysis of how existing parking regulations impact housing affordability and sustainability in their respective jurisdictions. The diversity in demographics, land values, structure of built form, provision of public transit, and other related factors would warrant similar studies done in jurisdictions with diverse circumstances. In addition, such studies would allow municipalities to discover other benefits or challenges resulting from maintaining the status quo in parking requirements or revising them accordingly.

The study also emphasizes the necessity to determine how much cost savings from reduced parking requirements are passed on to end-users, whether purchasers or renters of newly constructed units. As more buildings are developed under these revised parking norms, a comparative analysis of sales and rental agreements can shed light on the degree of savings accruing to end-users. Additionally, it is essential to investigate the proportion of savings that the owners of condominiums, particularly those purchased as investment properties, pass onto renters due to diminished parking requirements.

With new transactional data for condominium sales and rentals, applying the hedonic price models developed in this study to recent transactions under varied parking requirement regimes is feasible. This approach will enable a thorough assessment of the benefits accruing to both owners and renters, further enriching our understanding of the implications of these regulatory changes.

This research has illuminated significant gaps in our understanding of the maintenance costs associated with parking infrastructure in multi-family residential buildings. Predominantly, existing studies on maintenance and rehabilitation expenses have been concentrated on public infrastructure, such as bridges. However, there is a notable scarcity of research focusing specifically on parking infrastructure within residential settings. Consequently, the insights offered in this report are derived from anonymized data collated from rehabilitation projects in a limited number of buildings.

A substantial opportunity exists for a comprehensive, large-scale investigation into the maintenance and upkeep costs of parking infrastructure in residential buildings. Such a study would delineate the range of variability in these costs. Additionally, it would provide invaluable benchmark figures to assist landlords, tradespeople, construction managers, and other relevant stakeholders in making more accurate cost estimations.

This research will fill a critical knowledge gap and contribute significantly to optimizing resource allocation and financial planning in constructing and maintaining multi-family residential buildings. Continuing to advance this research could potentially lead to more cost-effective and efficient maintenance strategies, ultimately benefiting both building owners and residents.

The long-term impact of reduced parking requirements on parking valuation in existing buildings was not evaluated. Hence, the study cannot ascertain the future valuation of dedicated or assigned parking when newer buildings are more likely to be built with fewer parking infrastructure. The older buildings with a relatively higher supply of parking provisions, whose numbers in proportionate terms will decline over time, may become more desirable for those whose mobility needs are served better by private automobiles. This might result in a situation where units bundled with parking become more valuable in the future, given the expected decline in their relative numbers. The study recommends further research into simulating future scenarios where newer buildings are less likely to have as many parking spaces as older buildings, and the resulting impact on the valuation of units with assigned or dedicated parking.

The reduced supply of parking spaces in multi-residential buildings will likely divert some demand to spaces outside. This might result in increased demand for curbside parking or public parking lots. Parking studies and travel mode choice analysis of residents in buildings with reduced parking will help inform how much of the demand spills to other neighbouring locations and whether such diversion results in additional externalities.

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10 APPENDICES

10.1 APPENDIX 1: FINANCIAL AND PHYSICAL PERFORMANCE INDICATORS OF BUILDINGS

Numerous studies have been conducted on modeling the performance of buildings and predicting their maintenance and rehabilitation costs and their methodologies can be adopted in underground parking facility studies. Therefore, a summary of the literature regarding physical and financial performance indicators and algorithms for modeling their deterioration is presented here.

Buildings are among the most ubiquitous infrastructure assets. The replacement value of the buildings owned by the Government of Ontario is estimated to be around C$20 billion. Condition assessment and condition prediction of buildings along with the creation of budgets required for their maintenance and rehabilitation is instrumental to successful asset management. All asset management best practices and standards (e.g., ISO 55000 (ISO 2014)) recognize the importance of having proper performance indicators to measure the performance of assets. In Ontario, the Ministry of Infrastructure (MOI) and municipalities use different physical and financial performance indicators (Ontario Ministry of Infrastructure 2017), some of which could be used for measuring the performance of parking facilities:

- Age Condition Index, which is a numeric index between 0 and 1 that measures the expired ratio of an asset's useful life. Therefore, 1 represents an asset at the end of its life and 0 represents and recently built facility.
- Useful Life Index, which is a measure of the depreciation of an asset, or its components compared to industry standards.
- Facility Condition Index (FCI), which is a numeric value between 0 and 100 representing the ratio of deferred maintenance to current replacement value.

Furthermore, there are two performance indicators to measure the performance of parking pavements:

- Serviceability Condition Index (SCI), which is a numeric value between 0 and 100 explaining how an asset's condition affects its performance (rather than simply calculating repair cost).
- Pavement Condition Index (PCI), which is a number between 0 and 100 showing the physical condition of pavement based on the severity of distress.

10.1.1 Financial Performance Indicators

Among the performance indicators mentioned above, perhaps FCI is the most widely used for buildings and parking facilities. FCI allows for quantifying the condition of a building based on the need for maintenance. This performance indicator is especially common in the US because it is adopted by various federal departments and agencies, among which are the Department of the Interior (2008), NASA (2016) and Department of Defense (ASDS 2013). The FCI is widely used in Ontario as well (Ministry of Education 2021; Ontario Ministry of Infrastructure 2017).

FCI is defined as the ratio of the cost of deferred maintenance (DM) to the current replacement value (CRV) of a facility. It varies between 0 and 100, with 100 representing an almost failing building requiring reconstruction and 0 representing a newly constructed facility with no maintenance required. FCI has be applied at both the system and component levels (Dejaco et al. 2017; Re Cecconi et al. 2019).

Despite the popularity of FCI, several studies have suggested that FCI alone, as a financial performance indicator, cannot fully measure building condition and must be combined with physical and functional performance indicators (Lavy et al. 2010, 2014; Re Cecconi et al. 2019; Roberts 2009). Moreover, FCI cannot be used to compare the conditions of different assets. For example, the FCI of one parking facility may be higher than the FCI of another parking facility yet the latter facility may require more urgent maintenance because of compromised structural integrity of part of the structure.

Different FCIs used in different jurisdictions may have discrepancies that should not be overlooked. For example, the definition of DM in an FCI formula may differ based on jurisdiction. The definition proposed by Ontario MOI (2017) is the cost of required maintenance over the next three years while the definition proposed by the US Department of the Interior (2008) considers a ten-year horizon for defining DM, and its definition of DM varies as shown in Table 3.

Table 10-1. Definition of maintenance types according to the US Department of the Interior (2008)

Work Type Code	**Maintenance Type**	**Definition**
DMCM	Corrective Maintenance	Work required to restore a damaged, broken, or worn-out asset (e.g., building) or asset component.
DMRM	Recurring Maintenance	Planned preventive maintenance activity that recurs on a periodic and scheduled cycle of greater than 1 year, but less than 10 years that was not completed as scheduled.
DMCR	Component Renewal	Planned preventive maintenance activity that recurs on a periodic and scheduled cycle greater than 10 years that was not completed as scheduled.
DMDE	Demolition	Dismantling and removal, or the surplus of a deteriorated or otherwise unneeded asset or item of equipment,

		including necessary clean-up work.
DMRH	Rehabilitation	Renovation of an existing asset or any of its components in order to restore and/or extend the life of the asset. Because there is no expansion or change of function the work primarily addresses deferred maintenance.
DMRP	Replacement	Substitution or exchange of one existing asset, asset component, or item of fixed, in-place equipment for another having the capacity to perform the same function

Some of the limitations of FCI are as follows. The FCI adopted by the Province of Ontario is for the short-term needs of an asset given its three-year horizon (Ontario Ministry of Infrastructure 2017). Furthermore, it cannot represent asset levels of service or safety. For example, a component in a parking garage (e.g., window or air conditioning) may need to be replaced in three years. This results in an FCI increase while the building is still safe and offers a high level of service. Such issues have led to the development of other types of FCI that can represent the physical conditions of a building more realistically.

The conventional FCI definition proposed by Rush (1991) has been used by most researchers. However, recent efforts have been made to generalize this performance indicator (Kaiser 2009; NASA 2003). Unlike the conventional definition that limits DM to expenses caused by physical deterioration, other definitions have included additional expenses such as code compliance costs (Kaiser 2009; Re Cecconi et al. 2019).

The US Department of the Interior (2008) has developed an FCI that addresses both financial and physical aspects of maintenance and considers overall maintenance performance. It adds the following two terms to the numerator of the FCI formula: first, major rehabilitation and replacement, and second, maintenance recommendations registered during the periodic condition assessment (Moretti and Re Cecconi 2019).

While the above described how contingency planning is done to ensure public sector assets are kept in a state of good repair, the following describes similar strategies for residential buildings. Capital planning in residential properties typically involves several key steps, beginning with assessing the current condition of the building. This includes evaluating the condition of various components, understanding the scope of required renovations, and prioritizing repairs or replacements based on their importance and urgency. The process often employs multi-criteria decision-making models to assess the costs and scope of renovation, ensuring the long-term viability and physical condition of the property (Bucoń & Tomczak, 2016); (Bucoń & Tomczak, 2018).

An integral part of this planning is the reserve fund study, which projects the future costs of major repairs and replacements over an extended period. This study typically includes a detailed examination of the building's condition and anticipates necessary expenditures to maintain it over time. Reserve fund studies often rely on building condition assessments to inform their projections (Schnare, 1991).

Capital planning also involves identifying the equipment condition, expected remaining life, repair spending, and potential for energy efficiency improvements. This is particularly relevant in the context of evolving energy standards and the push for more sustainable and efficient building operations. A 5-year capital replacement plan is often developed to manage these aspects efficiently (Rutherford, 2018).

In addition to these technical aspects, capital planning must consider the economic dimensions. This includes not only the immediate costs of repairs and renovations but also the long-term financial implications for the property owners and residents. The main part of the funds for these repairs often comes from property owners' contributions, necessitating transparent and equitable financial planning (Elyukina, 2017).

Furthermore, the planning process should integrate long-term perspectives and performance-based methods that consider both technical and economic criteria. This approach ensures that the repairs and renovations carried out are not only technically sound but also economically viable over the long term (Dement'eva, 2017).

Hence, capital planning for major repairs and replacements at residential properties is a complex process that requires a thorough understanding of the building's physical condition, future needs, and financial implications. It involves a blend of technical assessment, economic analysis, and strategic long-term planning to ensure the sustainability and functionality of residential buildings.

10.2 Appendix 2: Facility Deterioration Modeling

Buildings constitute a substantial portion of the infrastructure in Canada. Over the past two decades, both the private and public sectors have shown interest in modeling the deterioration of buildings and predicting their remaining life. Proper modeling of deterioration can assist decision makers in allocating funds for maintenance and rehabilitation (Lavy and Shohet 2007). Much research is available on building deterioration modeling. Some of the well-established approaches for service life estimation have been recommended by standards (ISO 2011).

Modeling the deterioration of parking facilities is like modeling the deterioration of other types of infrastructure, such as roads and bridges. However, there are unique challenges given the large number of building components in parking facilities and the complexity associated with the fact that underground parking structures are embedded in larger complex structures. Furthermore, parking facilities have pavement that should be modeled separately.

Models used for deterioration modeling of facilities are broadly categorized into deterministic and probabilistic models. Deterministic models are simpler and cannot entertain probabilities. Probabilistic models are more sophisticated and account for the probabilistic nature of deterioration. However, their calibration requires more data.

While deterioration modelling is undertaken for large-scale infrastructure, for typical residential and commercial buildings, lifespan estimates for building components are used to determine the functional life of the structure that is updated with periodic assessments of the structure. The building reserve funds are thus revised every few years in light of the assessments.

10.2.1 Determining Facility Deterioration Models

Among the most common deterministic models are deterministic curves. These curves can be linear or nonlinear (Balaras et al. 2005; Shohet et al. 2002). From a conceptual perspective, they could be empirical (e.g., based on age) or mechanistic-empirical (i.e., incorporating mechanistic features too). Deterministic curves are popular in the asset management industry because of their simplicity and ease of interpretation (Edirisinghe et al. 2015). Another well-known deterministic method is the factor method presented by ISO 15686 (2011).

10.2.2 Probabilistic models for building deterioration modeling

Probabilistic models can account for aleatory and epistemic uncertainty. Probabilistic models used in facility deterioration modeling can be time based or state based. Time-based models are continuous. They predict the time that a facility or one of its components remains at a certain condition state. These methods use parametric, semiparametric and nonparametric methods to model probability distributions for a transition from a state to another (Ahmed et al. 2020). Thus, they can be used for predicting the probability of a certain deterioration state, or they could be used in order to develop survival curves (Duchesne et al. 2013; Meegoda et al. 2014). Well-known examples of time-based methods are Weibull Distribution and Gamma Processes (Edirisinghe et al. 2012; Grussing et al. 2006; Meegoda et al. 2014).

Unlike time-based models, state-based probabilistic models are discrete. They divide the deterioration lifecycle into multiple discrete condition states and predict the transition among these states. The most well-known state-based deterioration models are based on Markov models, which are applied to the deterioration of pavement, bridges, buildings and sewers (Ens 2012; Ford et al. 2012; Pulugurta et al. 2009).

Markov deterioration models are based on a stochastic memoryless process called Markov chain. Markov models simulate the deterioration process as a set of discrete events called 'states'. The interval between these states is referred to as time step, which is a function of data collection frequency (Yamany et al. 2021). These condition states can be linked to each other using a transition probability matrix. Accordingly, the output of a Markov model is a discrete variable representing infrastructure condition (such as good, fair or poor).