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1 **Access to Parks and Green Spaces in Quebec City, Canada: Developing Children-Specific**
2 **Accessibility Measures**
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23 **ABSTRACT**

24 Accessibility indicators are gaining traction in research and planning as they provide a joint
25 understanding of how transport networks and land use patterns enable individuals to reach a variety
26 of destinations. Local accessibility is especially beneficial for children as they do not have the same
27 capacities to travel as adults and their independent mobility is generally constrained to active modes
28 such as walking and cycling. Further, active and independent travel are linked to their health and
29 wellbeing. Yet, there does not appear to be much work done in terms of developing accessibility
30 indicators specific to children. This study presents a methodology to specifically assess
31 accessibility to parks (a key destination for children) on foot and by bicycle for children in Quebec
32 City, Canada using open-access data. Accessibility indicators are generated for each residential lot
33 based on the suitability of the pedestrian and cycling infrastructure for children. The number of
34 parks accessible is presented and the equity of accessibility to parks is considered through
35 population and socio-economic measures. The results reveal an important decrease in walking
36 accessibility when only dedicated pedestrian infrastructure is considered, and important differences
37 between walking and cycling accessibility. This enables the identification of accessibility gaps
38 where the existing infrastructure do not provide safe access to parks and green spaces for children
39 This research is of interest to researchers and planners aiming at refining accessibility indicators to
40 support children's independent mobility, while taking equity into consideration.
41
42 **Keywords:** Children, Active transport, Local accessibility, Parks and green spaces, Equity
43

44

1   **FUNDING**
2   This study was conducted as part of a research internship funded by the Natural Sciences and
3   Engineering Research Council of Canada.
4
5   **DATA AVAILABILITY**
6   All datasets were derived from the following public domain resources: Statistics Canada
7   (https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/index-eng.cfm) and Données
8   ouvertes - Ville de Québec (https://www.ville.quebec.qc.ca/services/donnees-services-
9   ouverts/index.aspx).
10
11

1   **INTRODUCTION**
2   Accessibility indicators are gaining traction in research and planning as they provide a joint
3   understanding of how transport networks and land use patterns enable individuals to reach a variety
4   of destinations. Efforts have been made to measure local accessibility to amenities via active modes
5   to support walking and cycling and the associated positive outcomes such as reduction in
6   greenhouse gas emissions, improved safety, and population health as well as social inclusion [1,
7   2]. Local accessibility to a variety of destinations such as small shops, parks and recreational
8   locations is especially beneficial for children who increasingly rely on their parents for their
9   everyday trips, possibly to the detriment of their health and well-being [3]. Considerable effort has
10 been made to examine children's trips to school [4, 5], highlighting children-specific determinants
11 of travel behavior and with other research highlighting the benefits of active travel [6]. However,
12 these studies have primarily focused on a single opportunity (e.g., the school that children attend).
13 In contrast, little research has examined local accessibility to different types of destination such as
14 parks and green spaces and to multiple opportunities (e.g., multiple parks) at the same time. Yet, a
15 review of active travel and environmental correlates found that the presence of parks and other play
16 areas in neighborhoods was often positively associated with children's active travel [7, 8]. Further,
17 having a range of parks accessible can increase the diversity of possible gathering points as well as
18 possible activities (as each park may have different equipment) and increase the likelihood that a
19 park is within range of two friends living in different locations [9]. Considering local accessibility
20 on foot and by bicycle to a diversity of destinations beyond simply schools is therefore of relevance
21 to support land use and transport planning that considers children's overall needs and well-being.
22
23 Several gaps remain in how active accessibility is conceptualized and measured, especially with
24 respect to distinct population groups [1]. Route characteristics and the distance to destinations are
25 both known to significantly impact the propensity to walk or cycle. Yet very few studies explicitly
26 and jointly account for these two factors to calculate local accessibility. For example, walkability
27 measures typically consider the characteristics of the neighborhood (e.g., density, street design) as
28 well as the distances to amenities, but without consideration for the characteristics (e.g., presence
29 of sidewalks) of the specific routes connecting origins and destinations. The presence of sidewalks
30 may be of greater importance to children's travel than adults' as parents may not give permission
31 to their children to travel due to traffic danger and children report feeling safer when using them
32 [10]. Other studies solely focus on distances to destinations [11, 12], yet the characteristics of the
33 route and the presence of infrastructure play a significant role in children's accessibility, as safety
34 is a major concern both for children and parents [13, 14]. Conversely, infrastructure-based
35 measures concentrate on the characteristics of the transport network (e.g., network connectivity,
36 density of sidewalks), without accounting for the origins and destinations. Another point that is
37 often overlooked is the distinction between walking and cycling accessibility. Although there are
38 important differences between the two, they are often grouped together as one concept, under the
39 term "active accessibility [15]. Namely, land use characteristics are key determinants of walking
40 accessibility, while the presence and quality of cycling infrastructure is much more influential for
41 cycling.
42
43 This study proposes a methodology to: (i) develop and apply **child-specific distinct walking and**
44 **cycling indicators** of accessibility to parks using open data, and (ii) consider the equity of
45 accessibility to parks within that population through population and income measures.
46 Accessibility indicators are generated for three different networks using a 1,000 m distance: the

1 pedestrian-street network (dedicated pedestrian infrastructures and residential streets with and
2 without dedicated pedestrian infrastructure), the pedestrian network (only dedicated pedestrian
3 infrastructure) and the cycling network. For each network, the number of parks accessible from
4 each residential lot is presented and spatial gaps are highlighted. Further, equity is considered
5 through a number of lenses: the density of children across the residential areas, the median
6 household income, the level of recent immigrants, and the percentage of elderly population. The
7 results enable the identification of accessibility gaps where the existing infrastructure do not
8 provide safe access to parks and green spaces by active transportation, without having to make a
9 significant detour. The results are of interest to researchers and planners who seek to refine
10 accessibility indicators to support the use of active modes to local destinations, while taking equity
11 into consideration.

12 **LITERATURE REVIEW**
13
14 **Walking and cycling accessibility**
15 Accessibility can be defined as "*the extent to which land-use and transport systems enable (groups*
16 *of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)*"
17 [16]. In line with this definition, we can think of children as a group of individuals who have
18 different capacities from a typical adult, and that their available modes of transport are also
19 different from those of a typical adult, which points to the relevance of developing measures
20 specific to them. For the purpose of this study, we focus on active modes that are typically available
21 to children, specifically walking and cycling, and on place-based accessibility. This measure, which
22 is commonly used in land use and transport planning, refers to the level of accessibility measured
23 at a specific location and reflects the potential to reach locations from this specific origin.
24
25 Several studies have shown that to encourage both walking and cycling, cities must assure
26 proximity to key locations and provide safe and attractive pedestrian and cycling infrastructure [1,
27 12, 17]. Active travel is also associated with greater network connectivity, urban density and land-
28 use mix [1, 4, 17]. With respect to walking specifically, a large body of literature has focused on
29 measuring walkability or walking accessibility, to identify which land use and transport factors
30 support higher walking rates. There is a consensus that the presence of sidewalks, street
31 connectivity as well as land use density and diversity are the key elements that support walking for
32 adults [18]. Other elements that are also considered, although to a lower extent, include street
33 canopy and landscape as well as human scale development [19, 20]. Low levels of traffic (no heavy
34 or high-speed traffic) as well as separation from traffic are also considered as they have an influence
35 on the perceived security of pedestrians [18]. A few studies have also demonstrated the importance
36 of off-street pedestrian links as a way to increase connectivity and walking accessibility to
37 destinations, especially in suburban areas [17, 21, 22]. To account for the presence of dedicated
38 pedestrian infrastructure such as sidewalks and off-street pedestrian links, recent studies conducted
39 in North America have generated accessibility measures using a pedestrian-enhanced network [23-
40 25].
41
42 Cycling accessibility differs from walking accessibility, though the two are too often categorized
43 as the same concept [15, 26]. As such, cycling accessibility has received less attention in research,
44 often being included in non-motorized or active accessibility, which typically reflects pedestrian
45 accessibility. Whereas walking is more influenced by land-use policies such as density, mixed land-
46 use and network connectivity, bicycle use is more influenced by the quality of the infrastructure in

1   terms of connectivity and safety as well as the denivelation of paths [15, 17, 27]. The level of
2   interaction with motorists and the presence of separated infrastructure is among the key
3   determinants, especially for less experienced cyclists [28, 29]. For children, average distances for
4   travel to school by non-motorized modes increase when travelling by bicycle [30]. As well, some
5   studies have aimed to examine preferences for children and parents toward bicycle infrastructure
6   with children (and parents) preferring separated (and raised) infrastructure [31]. Whereas cycling
7   rates for children are quite high (22 to 48 %) in several Northern European countries [30, 32, 33],
8   cycling rates of children in Canada are often found to be under 2% [34]
9
10   As such, measuring cycling accessibility is more complex than walkability, as cyclists are often
11   expected to ride on streets for their trips. Accordingly, and since interaction with traffic is a major
12   determinant, several studies have developed Level of Traffic Stress (LTS) indicators for cyclists.
13   For example, Furth, et al. [35] established four LTS indicators to measure different levels of
14   tolerance to stress. It goes from LTS1 that corresponds to the links that are suitable for almost all
15   cyclists, including children, to LTS4 that includes all links that a cyclist can legally ride on. LTS1
16   includes links that are physically separated from traffic and residential routes that propose a low-
17   speed differential (i.e., a small difference between the cyclists' and motorists' speeds) with low
18   traffic density.
19
20   It is important to note that the definition of the speed criteria for each LTS depends on the context
21   [36]. Ideally, the observed prevailing car speed would be used, but such data is rarely available for
22   all street segments. Instead, speed criteria can be decided based on speed limit, street design, type
23   of bicycle lanes as well as available data. For example, in their study conducted in San José, USA,
24   Furth, et al. [35] used specific speed limit thresholds for each LTS and type of bicycle lanes, given
25   that the different speed limits reflect different road types in their study area.
26

Children's accessibility and independent mobility
28   Children's travel differs from adults in a number of ways. A clear difference is that they are not
29   legally allowed to operate motorized vehicles on roads. This directly affects their mobility
30   resources, and thus their accessibility. Further, the types of destinations that they frequent are
31   different from adults. However, children are not typically directly considered in transport planning
32   and can be considered a marginalized group [3, 37]. This lack of consideration is likely part of the
33   explanation to the lower levels of children's independent mobility (CIM) that has been noted in
34   many studies [38].
35

36   Children's independent mobility is defined in various ways, but a commonly used definition is
37   travel without an adult. The strongest explanatory factor of actual CIM (i.e., actually conducting
38   an independent trip as opposed to simply having the right) and active travel for children is
39   repeatedly found to be distance [4]. In a review of North American active travel to school, features
40   of the built environment such as sidewalks were found to be weakly associated, but the authors
41   point out that sidewalks are not consistently considered in analyses [4]. In contrast, the world's
42   highest levels of active and independent travel by elementary-aged children can be found in Japan
43   where sidewalks are not common, but the norm for residential streets is essentially shared streets
44   [39]. The concept of a shared street aims to eliminate the physical separation between the modes
45   and typically limits vehicle speeds to 20 km/h or less. However, in the context of North America,
46   the presence of sidewalks is associated with the perception of safe travel for children by parents

1   [14, 40]. For other built environment influences, opposing findings are found. In some studies,
2   density and mixed land-use were found to be overall positive to active travel [7], while in a study
3   of CIM measures, those measures were found to be negative [41]. One possible explanation is that
4   the first examined actual travel, whereas the second included measures of CIM license (i.e., being
5   allowed to travel independently) which does not necessarily mean that the children make
6   independent trips. In general, built environment variables were found to be significant for
7   children's independent trips [42-44].
8
9   To conclude, the literature has identified several common and distinct factors that affect the
10 propensity to walk and cycle as well as what children and parents consider a safe and comfortable
11 network. Yet, there does not appear to be much work done in terms of developing children-specific
12 accessibility indicators. Further, few studies have distinctly assessed accessibility by cycling and
13 by walking, accounting for both distance to destinations and path characteristics. This study aims
14 to fill these gaps by proposing a methodology to develop child-specific walking and cycling
15 accessibility measures, by excluding walking and cycling segments that are considered unsuitable
16 for children. The method is based on open data and conducted at the finest spatial resolution
17 available, making it transferable to planners.

18 **METHODOLOGY**
19
20 **Case study area**
21 The accessibility measures are applied to Quebec City, a medium-size city with just above 500,000
22 residents located in the Province of Quebec, Canada. Quebec City is an interesting case study, since
23 it presents an important variability in terms of urban patterns and active transport infrastructure, as
24 illustrated in **Figure 1**. The central areas of the city are characterized by a high density and mixed
25 land use with a well-connected street network developed well before the automobile era (the city
26 is over 400 years old). Most streets are narrow and offer sidewalks in the core. Conversely,
27 peripheral areas are mostly low-density residential suburbs with disconnected street networks. The
28 way suburbs are configured encourages the presence of dead-end streets and winding streets that
29 can complicate access to parks and green spaces, especially for pedestrians and cyclists. The street
30 design (wide streets) permits high speeds and the density of safe crossing points is lower. Further,
31 most streets in these areas do not have sidewalks, as is clearly visible in **Figure 1**. The absence of
32 sidewalks in such conditions likely limits whether children would be allowed to go outside of their
33 cul-de-sac to destinations such as parks. It is also important to mention that the speed limit in these
34 residential areas is 50 km/h, with obstacle-free wide streets that do not naturally restrict traffic
35 speed. The territory is also characterized by important barriers to active mobility, including an
36 expansive highway network and the presence of a cliff separating the Upper (dense street network
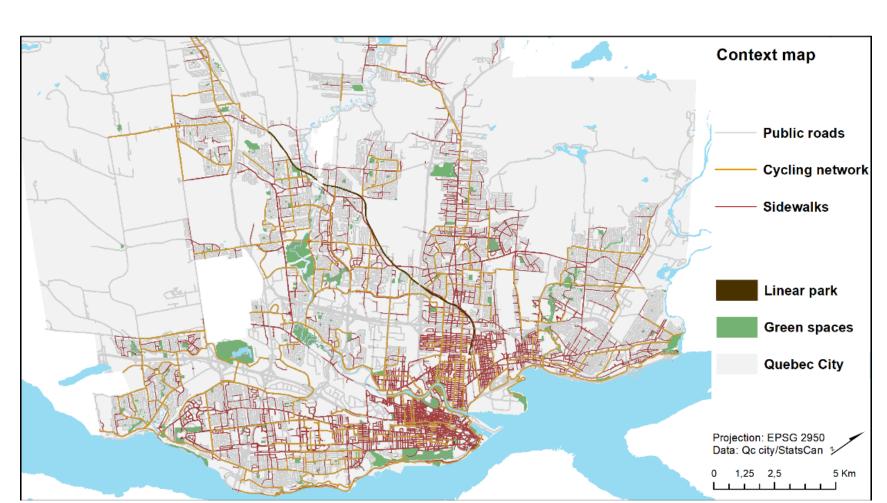37 at the bottom of the map) and Lower Towns.

1

2
3 **Figure 1 Green spaces, roads, and active transport infrastructure in Quebec City. Public roads include off-street pedestrian and cycling links.**

4

1 **Data and Methods**
2 *Data sources and networks construction*
3 The data used for this study are all open data. The land use and transport infrastructure data was
4 obtained from the Quebec City open data [45]. First, a land use shapefile provides the geometry of
5 parks and green spaces, identified with polygon features [46]. Parks and green spaces are
6 considered as one category and the two terms are used interchangeably in this paper. Only public
7 parks identified and maintained by the city are selected. Residential lots are also included as
8 polygon features and are used in this study to distribute the population across the territory. As for
9 the transport infrastructure, two shapefiles were necessary: (i) the public road network (which
10 includes public roads as well as dedicated pedestrian and cycling links other than sidewalks) [47],
11 and (ii) the pedestrian infrastructure, where sidewalks are provided as line features [48].
12
13 Using these two transport infrastructure shapefiles, three networks were generated, as summarized
14 in **Table 1**. For comparison purposes, two networks were generated to reflect accessibility to parks
15 by foot. The first one, the pedestrian-street network considers dedicated pedestrian infrastructure
16 and local streets (regardless of whether they might be appropriate or not to walk along), while the
17 second one, the pedestrian network, only considers dedicated pedestrian infrastructure.
18
19 The **pedestrian-street network** reflects the current network design in Quebec City. Indeed,
20 numerous residential streets in Quebec City lack sidewalks, which requires individuals to walk on
21 the side of the road to access destinations. Yet, the speed limit of these streets in Quebec City is 50
22 km/h, which demonstrates the car-oriented culture and the potential unsuitability of these streets
23 for pedestrians including children [49]. The generated network includes all public roads with a
24 speed limit of 50 km/h or less to account for local streets that do not have sidewalks, in addition to
25 the off-street pedestrian links. As such, this network represents the current planning approach,
26 which provides mostly residential streets without sidewalks and considers them suitable for
27 walking regardless of their design.
28
29 The **pedestrian network** was generated to reflect a safer way to travel by foot in Quebec City for
30 all individuals, but in particular children. This network only includes links with dedicated
31 pedestrian infrastructure: all off-street pedestrian links provided in the public road network as well
32 as all streets with sidewalks. Roads along which a sidewalk feature ran, at least partially, were
33 included in this network. Although there might be cases of incomplete sidewalks along a street
34 segment. This network includes the safest segments for walking trips.
35
36 The **cycling network** considers cycling infrastructure as well as public roads with a speed limit
37 under or equal to 50 km/h. The LTS1 elaborated by Mekuria, et al. [36] guided the selection of the
38 different links for the cycling network. However, with respect to the speed, a limit of 25 mph
39 (approximately 40 km/h) was identified by Mekuria, et al. [36] as LTS1 when in mixed traffic (no
40 dedicated bicycle infrastructure). This was done mainly to reflect calm residential streets. Given
41 that most residential streets in Quebec City have a speed limit of 50 km/h or above, we decided to
42 use a 50 km/h threshold. We acknowledge that our approach overestimates accessibility for
43 children, given that this speed limit, combined with a street design that legally allows such speeds
44 (and likely suffers higher practiced speeds) is not suitable for young children. The sidewalks and
45 the pedestrian links were not included, as cyclists are not legally allowed to ride on them. This is a
46 point to investigate as in practice, children do use the pedestrian infrastructure to cycle to limit the

1 danger cars impose on them. However, the purpose here is to examine how the official
2 infrastructure, as opposed to the informal solutions children must find, allows (or does not allow)
3 access to parks.
4
5 **Table 1 Description of the three networks generated for the accessibility analysis**

Mode	Network	Database	Links considered
Walking	Pedestrian-street network	Public roads and pedestrian network	All roads with sidewalks Off-street pedestrian links Public roads without sidewalks under or equal to 50 km/h limit *Excluded*: highways, highway junctions, boulevards, ramps, bridges, tunnels, service roads, driveways
Walking	Pedestrian network	Public roads and pedestrian network	All roads with sidewalks Off-street pedestrian links
Cycling	Cycling network	Public roads	Cycle paths Cycle lanes Designated roadways Public roads under or equal to 50 km/h *Excluded*: highways, highway junctions, boulevards, ramps, bridges, tunnels, service roads, driveways, stairs

6
7 Finally, in addition to the land use and transport data, population data were obtained from the
8 2016 Canadian census data to distribute the population within the residential lots and to provide
9 equity insights. The data was obtained at the finest spatial grain for which the detailed census data
10 is published, the dissemination area (DA). A DA contains between 400 and 700 individuals.
11
12 *Service area*
13 A service area is an area in which all segments providing access to the different parks are included.
14 Using each of the three networks described above, three service areas were generated for every
15 green space provided in the land use shapefile. A park was determined to be accessible as soon
16 as you stepped inside, no matter which side you were coming from. Accordingly, entry points were
17 identified all along the perimeter of the parks (see **Figure 2** – left). More specifically, they were
18 determined by placing points within 20 m of each other along the perimeter of each parks'
19 polygon, as done by Apparicio, et al. [50]. Then, a 30 m search tolerance radius was set to identify
20 entry points that are accessible from the pedestrian, pedestrian-street and cycling networks
21 ("located" park entrances in **Figure 2**– left). By doing so, the perimeter of parks behind residential
22 lots (see **Figure 2** – left for an example) and forests were not identified as entry points as it would
23 require access over private land. This is especially relevant in the case of Quebec City, where
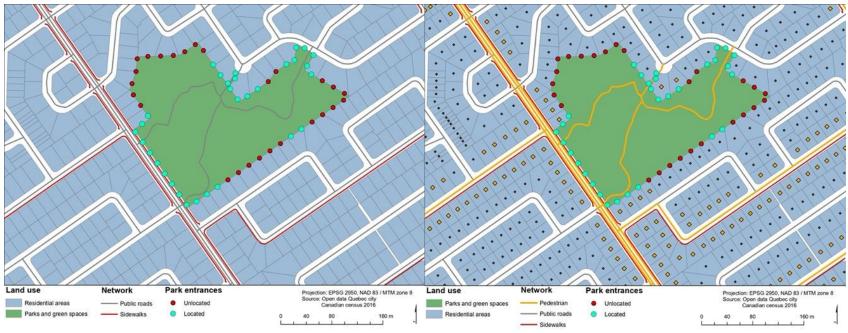24 several parks are located behind houses.

1
2 **Figure 2 Determination of entry points of parks (left figure) as well as connected residential areas (right figure). Located points represent points that are connected to**
3 **the network. Yellow dots (right figure) represent the residential lots that are within 1,000 m of the park via the pedestrian network.**

4

9

1 Service areas were generated for each of the entry points identified above, again for each of the
2 three networks. A threshold of 1,000 m was selected as it represents a reasonable distance for
3 children to walk and cycle, corresponding to a 10-15 min walk [50, 51] (this distance is based on
4 distances walk by children in Quebec [52] and could be adjusted to a reasonable walking distances
5 in different cultures). The service areas were then aggregated at the park level (dissolving the
6 service areas of all the entry points belonging to the same park into one service area) to calculate
7 the level of accessibility of each park.
8
9 *Accessibility to parks, gaps analysis and equity analysis*
10 After having generated the service areas for each network, the next step consisted of combining
11 this data with the distribution of the population across the territory, knowing that what matters is
12 not how well the territory is connected to parks, but rather the access provided to the population.
13 The residential lots and the population data were combined. The DA population was spatially
14 distributed into the residential lots as a function of their area, inspired by the work of Ural, et al.
15 [53]. Note that it was impossible to consider the number of floors with the information available.
16
17 The next step was to determine whether a residential lot was in the service areas generated above
18 for each of the three networks. Determining which residential lots are in the service areas allowed
19 for the calculation of the number of parks within 1,000 m of each residential lot. The centroids of
20 the residential lots were snapped to the closest feature from the network. For each of the three
21 networks, the residential lots that were along the respective service area were identified (see
22 **Figure 2** – right).
23
24 Afterwards, it was possible to visually identify accessibility gaps. The accessibility gaps were
25 analyzed together with data on the population of children aged 0-14 and median household income.
26 In this way, it was possible to draw conclusions about the equity of access to parks and to propose
27 recommendations to improve accessibility to parks in these specific residential areas, based on the
28 characteristics of their population.

29 **RESULTS AND ANALYSIS**
30 **Service areas**
31 **Figure 3** presents the service areas that are reachable within 1,000 m of parks and green
32 spaces in Quebec City, using each of the three networks (pedestrian-street, pedestrian and cycling
33 networks). As is visible in **Figure 3**, the service area covered by the pedestrian-street network
34 (which excludes highways and cycling-only infrastructure) is the most extensive one. It represents
35 70.2% of the entire network (the public road dataset which considers all roads as well as dedicated
36 pedestrian and cycling links), with gaps dispersed across the territory. These gaps are mainly the
37 results of barriers caused by the highways as well as the absence of public green spaces in some
38 less dense areas of the periphery.

39 Conversely, the proportion of the public road network that is accessible with the pedestrian network
40 is only 34.0% and is mainly concentrated downtown. This is largely the result of the lack of
41 sidewalks and off-street pedestrian links outside central areas (see **Figure 1**). Although there are
42 several green spaces located in the peripheral areas, the absence of sidewalks and off-street
43 pedestrian links considerably restricts access to them via pedestrian infrastructure. This is reflected
44 in the large difference in the proportion of accessible public network within 1,000 m of residential

1 lots, via the pedestrian-street network (70.2%) versus the pedestrian (34.0%). It also indicates the
2 needs for individuals to adapt their travel behavior to walk to destinations in Quebec City, namely
3 by using the pedestrian-street network that lack dedicated pedestrian infrastructure or by travelling
4 with other modes (such as by car) to increase their perception of safety.

5 The service area of the cycling network represents 58.6% of the public road network. This
6 proportion is around 12% lower than for the pedestrian-street network. The difference is mainly
7 explained by two reasons. First, pedestrian links, on which cyclists are typically not allowed to
8 cycle, are not included in the cycling network. These links are largely present around parks. The
9 second reason is that boulevards are excluded from the cycling network, given their speed and
10 traffic level, but they are present in the pedestrian-street network due the presence of sidewalks.
11 These findings have two implications. First, it sheds light on the barriers imposed on children when
12 forbidding them to cycle on sidewalks and off-street pedestrian links, regardless of their age.
13 Second, it also reflects the challenge of developing accessibility measures that closely reflect travel
14 behavior, as children who cycle to parks potentially use the dedicated pedestrian infrastructure
15 (even though it is illegal) in order to avoid the danger of the infrastructure they are legally obliged
16 to use. Future efforts are warranted to assess how pedestrian infrastructure can be considered when
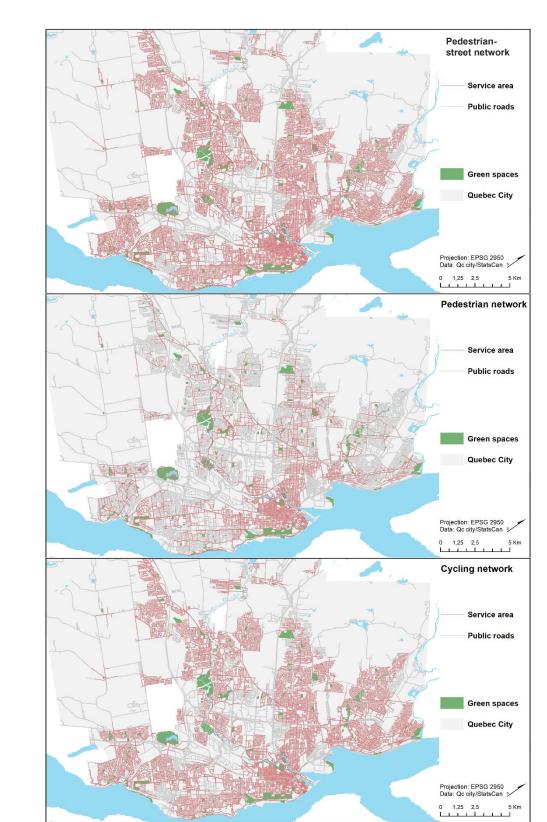17 measuring cycling accessibility for children.

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Figure 3 Service areas within 1,000 m of green spaces in Quebec City

6

Accessibility to parks from residential lots

The service areas presented above indicate the road segments that are within 1,000 m of green spaces via each of the networks. To capture the accessibility provided to the population, these results are combined with the residential lots and population data of Quebec City, which indicate where the population resides. **Figure 4** presents the number of parks that are accessible from each residential lot. Since the population density varies across the territory, the proportion of individuals (and children specifically) that have access to 0, 1, 2 and 3 or more park was also calculated (**Table 2**). It is interesting to note that the proportions are generally lower when specifically considering children. These findings highlight the importance of developing children-specific analyses.

For the pedestrian-street network, most residential lots and almost 60% of the children have access to three or more parks. Nonetheless, 12.5% of children still do not have access to any park within 1,000 m on foot. These gaps are identified with circles in **Figure 4**. They are mostly located outside the central areas. This may highlight a contradictory belief between central and suburban neighborhoods where the latter may be associated with greater access to green space related to simply being less intensely developed. However, the lack of appropriate infrastructure means that children in such locations may be limited in their access to public green spaces. The perception of green space access though may be related to (typically) larger private spaces such as backyards. This can relate to studies that find that children in more urban areas play in public spaces, whereas children in low-density areas play at their home [44].

When looking at the pedestrian network, the figure is very different. Most residential lots outside the central areas do not have access to a park, mainly due to the scarcity of sidewalks. Overall, 67% of children do not have access to at least one park via the pedestrian infrastructure, whereas around 20% of all children have access to three or more parks. This clearly illustrates the two distinct types of urban environments in Quebec City: residential areas with few sidewalks or central areas with well-connected street networks offering sidewalks. The fact that 67% of children and almost 59% of general population have no access to a park within 1,000 m of their residence can illustrate the concentration of families with children in suburban residential areas without sidewalks, further from the centers.

As for the cycling network, the accessibility patterns are similar to those of the pedestrian-street network, although with slightly lower proportions. Around 50% of all children have access to three or more parks, and around 20% have no access a park. Most gaps observed with the pedestrian-street network are also visible, with a few additional ones. These additional gaps are largely the results of boulevards without lanes reserved for cyclist connecting these areas to green spaces. While these boulevards are included in the street (and pedestrian) networks as they include sidewalks, they are not considered accessible to cyclists (who cannot legally use sidewalks). If the law was to change to allow children under 16 for example to use sidewalks, the analysis could be adjusted, and the access would improve in both this academic analysis and likely in reality.

Note that the areas that are mostly rural were not considered in the gap analysis. Further, the gap analysis for walking focuses on the pedestrian-street network rather than the pedestrian network. With the latter, the areas without access to a park in Quebec City are too widespread to provide a meaningful gap analysis. Basically, the analysis would point out all the areas deprived of sidewalks, while analyzing the pedestrian-street network illustrates how the gap analysis can help identify specific areas. Nonetheless, the comparison of the two maps emphasizes the extent of the reduction

1   in accessibility when limiting it to what is recognized as safe infrastructure for children in the
2   literature (i.e., the presence of pedestrian infrastructure). Finally, while the focus is on areas with
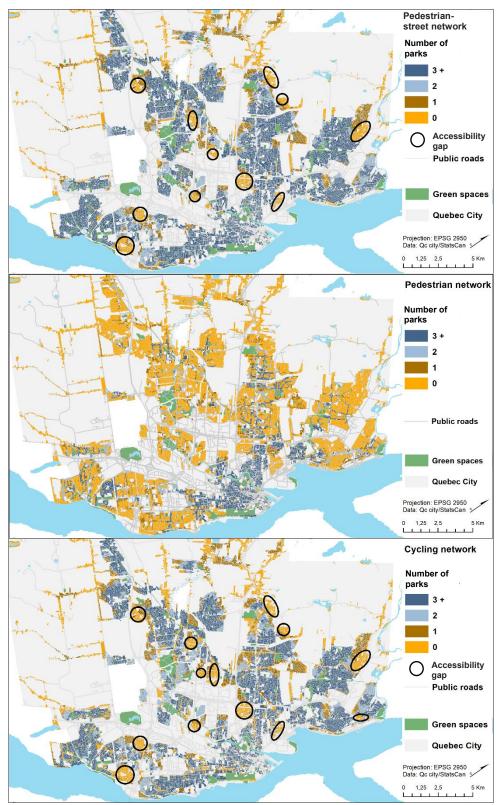3   no access to a park, different thresholds could be set to consider the gaps in terms of park diversity.
4

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5
Figure 4 Number of parks and green spaces available from residential lots

6

1   **Table 2. Distribution of the population based on the number of parks accessible for each network**

Network	with access to 0 park (%)		with access to 1 park (%)		with access to 2 parks (%)		with access to 3 parks or more (%)	
	Population	Children	Population	Children	Population	Children	Population	Children
Pedestrian-Street	11.4	12.5	11.8	13.7	13.3	14.3	63.5	59.5
Pedestrian	58.9	67.0	8.7	8.2	5.8	5.1	26.6	19.7
Cycling	19.0	19.9	13.2	14.8	14.4	15.4	53.4	49.9

2

3   *Equity analysis*
4   From an equity standpoint, it is relevant to identify areas with lower levels of accessibility to parks
5   and that are characterized by a greater concentration of children. In addition, knowing that lower-
6   income households are more likely to rely on active modes and to be negatively affected by
7   transport-related disadvantages [54], the median household income is considered in **Figure 5**
8   (right). Building on the analysis presented above (which focuses on areas with no access to at least
9   one park), the density of children aged between 0 and 14 years old is considered together with the
10   accessibility gaps (see **Figure 5** – left). This age range includes children that can currently travel
11   independently in their neighborhood and the ones that we know will develop this independence in
12   a near future. Knowing that children mostly access parks on foot or by bicycle, both walking
13   accessibility and cycling accessibility are part of the equity analysis. As for walking accessibility,
14   the gaps identified with the pedestrian-street network are considered, since, as shown in **Figure 4**,
15   the accessibility gaps to parks and green spaces with the pedestrian network are too widespread
16   across the territory. It is, thereby, more relevant to prioritize interventions based on the pedestrian-
17   street network, which reflects the current street design.

18   For both the street and cycling networks, the accessibility gaps with a high density of children are
19   located just outside the central neighborhoods. Prioritizing these areas in terms of park accessibility
20   would increase the proportion of children that have access to at least one park. Those areas are also
21   of lower income. This relates to the fact that lower-income households are more concentrated in
22   central areas in Quebec City, but it also reflects that lower-income households also tend to
23   concentrate in areas that might be less desirable in terms of active mobility, urban fabric and
24   amenities. This has important implications in terms of social equity.

25   From the maps, it appears that these accessibility gaps are characterized by the absence of parks
26   directly within the neighborhoods. Further, these areas are located at the periphery of their
27   neighborhood, where a fracture in the urban fabric (i.e., layout of the streets and buildings) can be
28   observed. More specifically, the proximity of the highway network creates dead ends within the
29   pedestrian and cycling network, thereby isolating these areas from the zones located on the other
30   side of the highway. Thus, they represent a contrast between high adult mobility by car with low
31   accessibility for children. These areas are central enough to exhibit a high population density, but
32   their location presents more street disconnection and barriers to active mobility. Given the existing
33   urban fabric, the implementation of green spaces directly in these areas should be explored.

1   To pursue the equity analysis, the second set of maps (see **Figure 6** – left) presents the density of
2   elderly people (individuals aged above 65). Although the method was developed with children in
3   mind, the literature has shown that accessibility to green spaces also has significant benefits for
4   elderly people, and that this group of individuals is also more likely to experience mobility
5   constraints.

6   In the second sets of maps (see **Figure 6** – right), the density of recent immigrants is also
7   considered. Recent immigrants are more likely to cumulate transport-related disadvantages and
8   socio-economic disadvantages. For the recent immigrants, the results are similar to the ones
9   presented above, with gaps concentrating this population groups at the periphery of or just outside
10 the central areas.

11 It is interesting to note that the accessibility gaps with a high density of elderly and high density of
12 immigrant are mostly the same as for children. This is likely because these gaps have a high density
13 of population in general, whereas suburban areas have a low density. While this study focuses on
14 children, the maps discussed here illustrate how the method can be applied to other vulnerable road
15 users and also reflects that addressing the needs of children can achieve broader societal objectives.
16 Future research could also build on the methodology and findings of this study to further explore
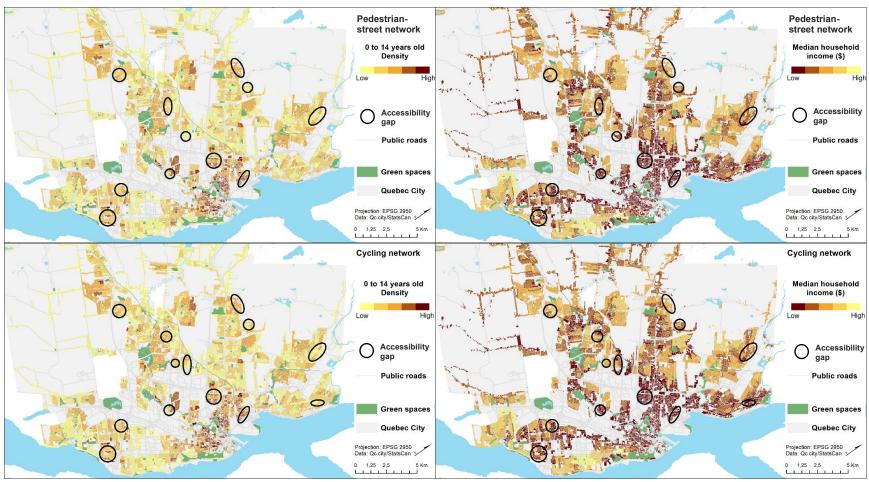17 the correlations between socio-demographic characteristics and levels of accessibility.

18

Figure 5 Density of children (left) and median household income (right), together with the accessibility gaps
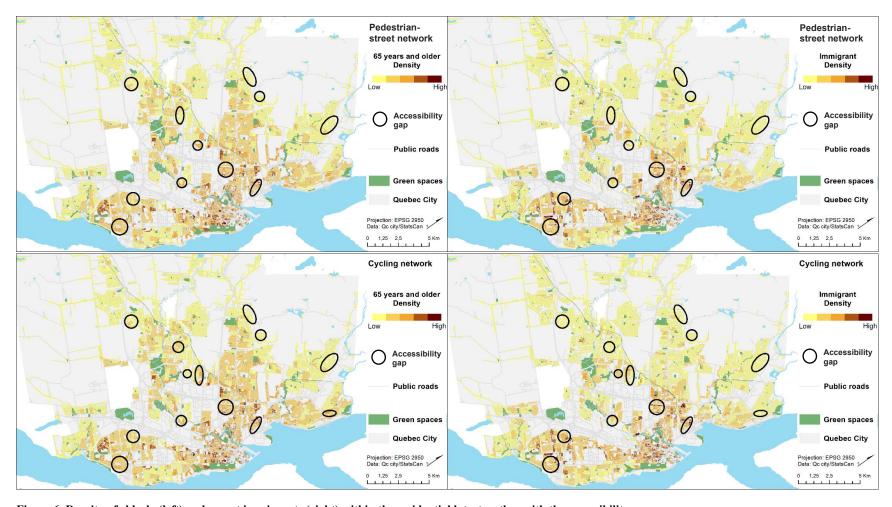
Figure 6. Density of elderly (left) and recent immigrants (right) within the residential lots, together with the accessibility gaps

1 **CONCLUSION**
2 This study presented a methodology to specifically assess accessibility to parks by walking and by
3 cycling for children using open data. The method is applied to Quebec City, Canada and considers
4 the distribution of the population across the territory using the finest spatial unit available, the
5 residential lot. Three accessibility measures are generated based on the specific needs and
6 constraints of children and the distinct needs of pedestrians and cyclists using three distinct
7 networks: (i) a pedestrian-street network, (ii) a pedestrian network, and (iii) a cycling network.
8
9 The results highlight the limited accessibility provided by the actual pedestrian network given the
10 lack of sidewalks in Quebec City with the central areas having good access, while the suburban
11 areas lack access. It also reveals the impacts of the lack of bicycle lanes on the main boulevards of
12 the city. Further, the spatial representation of accessibility to parks allows gaps in accessibility to
13 parks to be identified across the territory. Equity and access to parks were considered through:
14 population density (in general and only children under 14), household income, recent immigrant
15 population, and elderly population, to illustrate how the analysis can help identifying hotspots and
16 prioritizing intervention areas. Important similarities could be seen between higher density areas
17 (general and child-only) with the recent immigrant and elderly populations. Low-income areas
18 located at the border of neighborhoods just outside the central areas were identified. Their
19 proximity to the highway network, which creates a fracture in the urban fabric, together with the
20 absence of parks within the neighborhoods result in having access to no park. Overall, the proposed
21 method allows for a comprehensive analysis of accessibility to parks for children, by walking and
22 cycling, and is transferable to other study area.

23 There are nonetheless several limitations and further potential developments that are worth
24 mentioning. Importantly, the open data used in this study presents significant opportunities and
25 limits. First, the provision of street, pedestrian and cycling infrastructure into one single and
26 consistent dataset enabled the calculation of network distances with ease. To facilitate the
27 generation of the three different networks, detailed information on the presence of sidewalks on
28 street segments, data on traffic levels, street width and number of lanes could be incorporated in
29 the public road dataset to provide a more realistic approximation of the level of traffic stress.
30 Indeed, the only information about traffic in the public road files are the speed limit and type of
31 street (e.g., highway, boulevard, avenue). For the case of Quebec City, this led to an overestimation
32 of the cycling accessibility for children, knowing that the majority of streets with a 50km/h speed
33 limit that do not correspond to a low LTS [36]. In line with this, the equity analysis both for walking
34 and cycling overestimates the accessibility as it expects individuals to use segments that are not
35 suitable for children (wide residential streets without sidewalks and with speed limits of 50 km/h).
36 The findings highlight that the current design requires individuals to adapt their travel behavior to
37 access parks and green spaces of Quebec City. Second, the detailed representations of parks via
38 polygons made it possible to account for entry points into the parks. However, this approach is
39 certainly limited in identifying all the entry points correctly. Including the entry points directly in
40 the land use file could be a significant improvement. Also, only public parks and green spaces were
41 included, which leaves out a few private areas. Along these lines, it is important to note that only
42 the number of parks was considered. Surface area, and the type of parks and amenities could also
43 be considered as done by El-Murr, et al. [55], for the city of Montreal. Moreover, a 1,000 m

1   threshold was selected for both walking and cycling. This single threshold was selected to illustrate
2   the feasibility of the method.

3   Further studies could investigate other thresholds with this methodology, namely distinct
4   thresholds for walking and cycling depending on the urban and cultural context. The threshold
5   could also vary based on the age of the children, by considering a bigger threshold for independent
6   trips of adolescent for example. Further efforts are also required to consider other types of
7   destinations that are relevant for children, which could also vary by age group. It would also be
8   relevant to build on the methodology developed here to integrate information about the traffic
9   condition of the network and intersections that act as barriers to CIM, to generate accessibility
10 measures that better reflect the network safety from the perspective of children and their parents.
11 Finally, having developed accessibility measures based on the literature, future research is
12 warranted to investigate how actual travel by children relates to these measures. This would be
13 similar to research conducted to evaluate popular measures such as Walk Score for the general
14 population [19, 56]. Future research could also investigate how land use influence accessibility to
15 parks for children.
16
17 Notwithstanding the limitations discussed above, the methodology developed in this study enables
18 a children- and mode-specific assessment of accessibility to parks. Accessibility gaps as well as
19 land use and transport barriers across an urban area can be identified using this method. Further
20 context-specific assessment can then be conducted to develop specific recommendations. Also, the
21 development of these indicators is of interest to researchers and planners wishing to explore the
22 relationship between accessibility (using the method proposed here), travel behavior and well-
23 being of children, and therefore improve land use and transport planning. Finally, the study sheds
24 lights on the potential provided by high-quality open data.
25

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: A. Robillard, G. Boisjoly, E.O.D. Waygood; analysis and interpretation of results: A. Robillard; draft manuscript preparation: A. Robillard, G. Boisjoly, E.O.D. Waygood. All authors reviewed the results and approved the final version of the manuscript.

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