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Foot-based microscale audit of light rail network in Montreal Canada

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ABSTRACT

Introduction: Light Rail Transit offers the potential to encourage physical activity, but the extent to which it does may depend on station design.
Methods: A microscale audit was conducted around the stations of the Réseau Express Métropolitain light rail network currently under construction in the Greater Montreal Area (GMA), Canada, to measure how conducive its stations are to walking. The audit made use of the Mini version of the Microscale Audit of Pedestrian Landscape (MAPS-Mini audit tool) audit tool, which generates a score for each segment, with additional questions being added for auxiliary data collection. Extensive data cleaning was conducted using inter-rater reliability testing and validated online verification methods.
Results: The findings of the audit reveal a large disparity in the scores whereby urban stations tend to score higher than suburban ones. A case study is presented examining the well-designed micro-geographies of the suburban Du Quartier station as an exception to this trend. No relationship was visually observed between the socioeconomic variables around each station and their MAPS-Mini audit tool scores or the mapped amenities.
Conclusions: The results of this study demonstrate the strength of the MAPS-Mini audit tool in highlighting stations with room for improvement. As such, we recommend its usage for future microscale audits as an efficient alternative to longer-form audits. We also suggest that new suburban transit stations emulate the micro-geographies of the Du Quartier station to promote an environment conducive to active transport.

1. Introduction

Light Rail Transit (LRT) has become increasingly popular in cities across the globe in recent years. In North America, more than 16 light rail projects were planned in 2019, compared to 1 in 2012 (Sinclair, 2019). Four light rail networks are currently scheduled to open in 2021 alone in North American cities (Freemark, 2021). The Réseau Express Métropolitain (REM) will be joining this growing number of new light rail systems when its first phase opens in 2022. This fully electric and fully automated LRT network will span 67 km, providing reliable and frequent service.

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Public transit stations have the potential to increase utilitarian walking (Boarnet et al., 2011; Wasfi et al., 2013) and LRT has been found to be positively associated with increases in walking levels around stations (Huang et al., 2017; van Soest et al., 2020). Promoting active transport through these new networks is a great way to not only reduce greenhouse gas emissions but to improve populational health through increased physical activity. However, the potential for walking depends on the design of the area surrounding a station and how conducive it is to walking (Boarnet et al., 2011; Huang et al., 2017). Many tools exist to evaluate the quality of the built environment around a station, in effect its walkability (Cain et al., 2015; Day et al., 2006). Macroscale audits of stations evaluate the larger physical design of an area, for example, land-use and street connectivity. Microscale audits look at the micro-geographies of a neighbourhood like the presence of benches, bicycle paths, and tree cover (Oluyomi et al., 2019; Steinmetz-Wood, Velauthapillai, O'Brien and Ross, 2019). Bivina, Gupta, and Parida (2020) recently found that microscale factors influenced riders' decision to walk to metro stations in Delhi, India, more than macroscale factors or socioeconomic variables. Microscale factors also present an opportunity for relatively cost-effective, and potentially significant, improvements to the walkability of an area (Steinmetz-Wood et al., 2019).

The aim of this study was to determine the state of the microscale built environment around each station prior to the arrival of the new REM transit network, as well as to document measures taken by municipal governments to adapt the built environments around stations to promote active transport. To best capture the current state of the built environment surrounding each station a foot-based, street-segment level audit was conducted using the Mini version of the Microscale Audit of Pedestrian Landscape (MAPS) audit tool (Cain et al., 2015). This tool was chosen due to its compact and efficient size. Additional questions were added for auxiliary data collection with the 15 original questions from the MAPS-Mini audit tool used to compute scores for each segment and subsequent station averages. A secondary goal of this paper was to visually explore whether a relationship exists between station walkability and socio-economic variables. Given that past research has identified income-based inequalities in the built environment where higher income neighbourhoods tend to have access to more health-promoting resources (Ravensbergen et al., 2016; Su et al., 2017), we hypothesize that stations in higher income areas are better designed to promote physical activity than stations in lower-income neighbourhoods.

2. Literature review

Built environment audits have been designed to address regular shortcomings from walkability indices to properly reflect the influence of micro-scale elements of the built environment on walking behaviours (Day et al., 2006). Such tools have been shown to present a more accurate portrait of the built environment, displaying potential to be linked with utilitarian walking patterns (Boarnet et al., 2011; Sallis et al., 2015). The Irvine Minnesota Inventory (Boarnet et al., 2011; Day et al., 2006) is among the first wave of comprehensive built environment audits to be conducted for walkability purposes. However, its substantial size – 162 items – makes it less efficient to use (Boarnet et al., 2011). More recent tools such as the MAPS audit tool (Cain et al., 2015; Millstein et al., 2013; Sallis et al., 2015) build upon such work to produce tools that are more accessible and efficient to use. This audit tool was developed in 2015 by Cain et al. (2015) and has been adapted to three different sizes, all validated: the original MAPS containing 120 questions, MAPS-abbreviated with 60 questions and MAPS-Mini, with 15 questions. Further, the MAPS-Global audit tool has been developed to better capture walkability in international settings, for instance by accommodating higher densities and including built environment features more commonly found in settings outside of the North American context (Cain et al., 2018; Queralt et al., 2021; Vanwolleghem et al., 2016).

While most audit tools are designed to be conducted by foot, MAPS has been validated to be replicable through online methods such as Google Street View (Fox et al., 2021; Kurka et al., 2016; Steinmetz-Wood et al., 2019). This is also true of MAPS-Mini audit tool which was applied virtually to assess the streetscape of several large European cities (Bartzokas-Tsiompras et al.2020). Such online methods have been shown to make it easier to cross-reference results and ensure proper data is collected (Bartzokas-Tsiompras et al., 2020), a step that is not commonly taken in audits conducted by foot (Frank et al., 2019; Oluyomi et al., 2019).

While audit tools have mainly been used in the context of health-related research, they have also been used to evaluate the built-environment around new public transport stops. Previous research has specifically applied such methods to assess the built environment surrounding the stations of new light rail lines in Houston, Texas (Oluyomi et al., 2019) and Portland, Oregon (Frank et al., 2019). We add to such studies in this paper to further demonstrate the applicability of audits – especially condensed ones like the MAPS-Mini audit tool – to support transit development. We also expand on current research by making use of mixed-methods – both in the field and online – to conduct the audit and ensure adequate data collection.

3. Methodology

3.1. Audit design

The MAPS Mini audit Tool (Sallis et al., 2015) was used as the basis for the survey component of the audit. The tool was adapted to audit both sides of a street as one segment rather than each side individually. To maintain the integrity of the validated tool, questions were adapted to reflect the increased choice possibility while keeping the same scores that were attributed to each question. In addition to the 15 questions from the MAPS mini audit tool, two additional questions were added from the MAPS abbreviated audit tool (Cain et al., 2015), one from the SPACES Instrument (The University of Western Australia, 2000), as well as four original ones to complement the data acquired (Table 1). In addition to the survey, components of the built environment were also mapped. These consisted of benches, trash cans, stop signs, bicycle racks, speed bumps, drinking fountains and public toilets. Photos were also taken for each

Table 1
Content of the survey component of the REM built environment audit.

Questions	Responses	Score	Source
Segment Code	Written	-	-
Street Name	Written	-	-
Cross Streets	Written	-	-
Is the segment auditable?	Yes/No	-	-
Intersection			
1. Is a pedestrian walk signal present?	No	0	MAPS
	Yes at one intersection	1	Mini
	Yes at both intersection	2	
1.1 What is the crossing time given to pedestrians?	# of seconds	-	Authors
2. Is there a ramp at the curb(s)?	No	0	MAPS
	Yes, at least at one curb at one intersection	1	Mini
	Yes, at all curbs at one intersection	1	
	Yes, at both intersections but not at all curbs	1	
	Yes, at all curbs at both intersections	2	
3. Is there a visible marked crosswalk?	No	0	MAPS
	Yes, at one intersection	1	Mini
	Yes, at both intersection	2	
3.1 What is the composition of the marked crosswalk?	Different Material/Painted/Raised	-	Authors
Land Use			
4. Residential land-use [4 categories]	Count [Buildings with separate entrances]	-	MAPS Abb.
5. Other land-uses [22 categories]	Count [Buildings with separate entrances; lots]	-	MAPS Abb.
5.16 Parks	0	0	MAPS
	1	1	Mini
	2+	2	
6. Main type of land use	Greenspace/Vacant/Industrial/Residential	0	MAPS
	Commercial/Mixed	1	Mini
Street Amenities			
7. How many public transit stops are present?	0	0	MAPS
	1	1	Mini
	2+	2	
8. Are streetlights installed?	None	0	MAPS
	Some	1	Mini
	Ample	2	
9. Are there any benches or places to sit (include bus stop benches)?	No	0	MAPS
	Yes	1	Mini
10. Presence of bicycle racks?	Count [0–20+]	-	Authors
11. Is there a designated bike path?	No	0	MAPS
	Sharrow	0	Mini
	Painted line	1	
	Physical barrier - Multi-use path	2	
	Physical barrier – Bollard	2	
	Physical barrier – Concrete/grass buffer	2	
Aesthetic			
12. Are the buildings well maintained?	0–99%	0	MAPS
	100%	1	Mini
13. Is graffiti/tagging present (do not include murals)?	Yes	0	MAPS
	No	1	Mini
14. Cleanliness – is there any litter, rubbish, broken glass, discarded items in the segment?	None or almost none.	-	SPACES
	Yes, some.		
	Yes, lots.		
Sidewalks			
15. Is a sidewalk present?	No	0	MAPS
	Yes, on one side	1	Mini
	Yes, on both sides.	2	
	Pedestrian Street	2	
15.1 Are there poorly maintained sections of the sidewalk that constitute major trip hazards?	Any	0	MAPS
	None	1	Mini
15.2 Is a sidewalk buffer present?	No	0	MAPS
	Yes, on one side	1	Mini
	Yes, on both side	2	
16. What percentage of the length of the sidewalk/walkway is covered by trees, awnings or other overhead coverage?	0–25%/no sidewalk	0	MAPS
	26–75%	1	Mini
	76–100%	2	
Subjective scores			

(*continued on next page*)

Table 1 (*continued*)

Questions	Responses	Score	Source
17.1 On a scale of 1–10, how walkable would you rate this segment for travel?	0–10	-	Authors
17.2 On a scale of 1–10, how walkable would you rate this segment for leisure?	0–10	-	Authors

segment.

3.2. Network analysis

Locations for each of the 26 stations were acquired from the REM website (Réseau Express Métropolitain, 2021) while road network data was downloaded from Open Street Map, and the Quebec Road Network was obtained from Statistic Canada (Statistics Canada, 2021). Highways, highway access ramps, alleyways, and private roads were removed as they were deemed inaccessible and recently built streets around the REM stations were manually added. Additionally, proposed pedestrian connections to each station (documented in the stations' implementation plans) were drawn to all connecting streets. Pre-existing pedestrian paths present in the Open Street Map data were kept as they provide linkages between streets for pedestrians. Using ArcGIS's network analyst, a 500 m service area was generated from the stations' location through the modified road network for each station (Fig. 1). Because ESRI's Network Analyst Service Area Tool can result in inconsistencies (Forsyth et al., 2012; Frank et al., 2017), when the service area boundary fell before the end of a street segment, the entire street segment was included. In future work, the 'sausage' buffer methodology may help avoid this issue (Forsyth et al., 2012; Frank et al., 2017). All 26 REM stations were audited, with one exception: the station that serves the airport.

To generate the street segments to be audited, the Quebec Road Network was used as it already contains streets as segments and does not include any pedestrian paths, unlike Open Street Map. As the goal of the present audit was to assess the built environment at the street level, pedestrian paths were excluded. The segments to be audited were found by spatially joining the generated service areas to the Quebec Road Network. All streets that intersected with the service area were considered, not solely those fully comprised within it. The Quebec Road Network contained segments that differed from the definition of a segment used for the audit. Those segments were manually changed to fit audit parameters; most segments were left intact. Segments were defined as street section falling between two intersections. In a grid system, like typical urban downtown cores, identifying segments is rather straightforward (Fig. 2, left). However, in suburban areas with uneven street pattern this is more difficult. As a result, exceptions were made for complex suburban streets such as displayed in Fig. 2 (right).

In the Quebec Road Network, large boulevards or roads with a median were drawn as two separate lines. For the purpose of the audit, large boulevards were still considered to be a single segment. Modifications conducted on such segments are displayed in Fig. 3. Only if the street was separated by a park or buildings, was it considered to be two separate segments.

Following these guidelines, a total of 951 street segments were identified. Each segment was assigned a unique alpha-numerical code comprising of a suffix indicating the station to which they are attached (i.e., PAN for Panama, DM for Deux-Montagnes) and a randomly generated number. Segments that fell within the service areas of multiple stations were given codes that reflected that (i.e., MG-CS for McGill – Central Station).

3.3. Data collection

A total of 848 of the 951 segments were audited. The remaining 103 segments were deemed either unsafe due to lack of sidewalks, high volume and/or speed of traffic (n = 27) or were under construction and could not be audited (n = 76). Data was collected using the ArcGIS Survey 123 and the ArcGIS Field Map apps (Fig. 3). Audit data was collected on weekdays only, between May 25th and July 1st, 2021. It took an estimated 240 h of field work – excluding transportation – distributed amongst 14 auditors to complete data collection. The time taken to audit each station was, on average, 9.6 h. However, there was great variation across stations with suburban stations taking considerably less time to audit than those located in the downtown core. The fastest station took 10 min (for

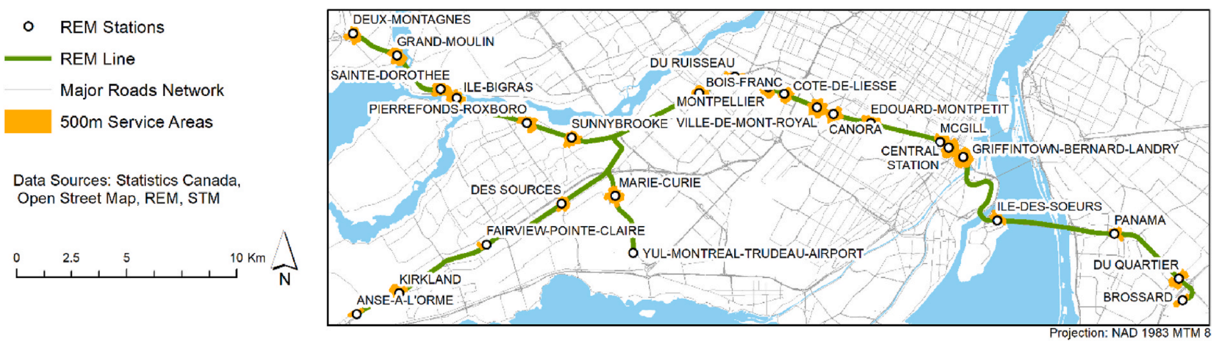

Fig. 1. Map of the REM network with 500 m service areas.

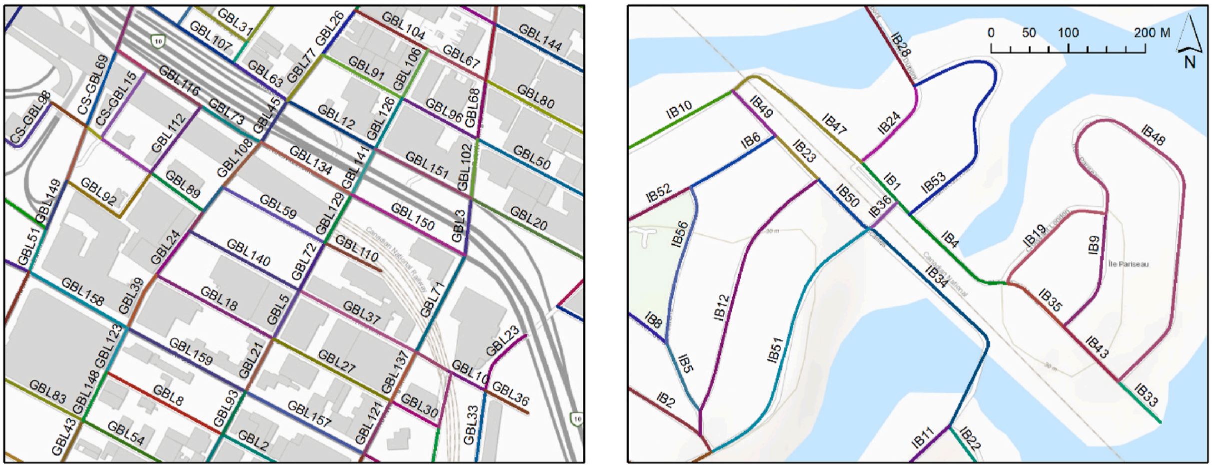

Fig. 2. Segment design in urban (left) versus suburban (right) settings.

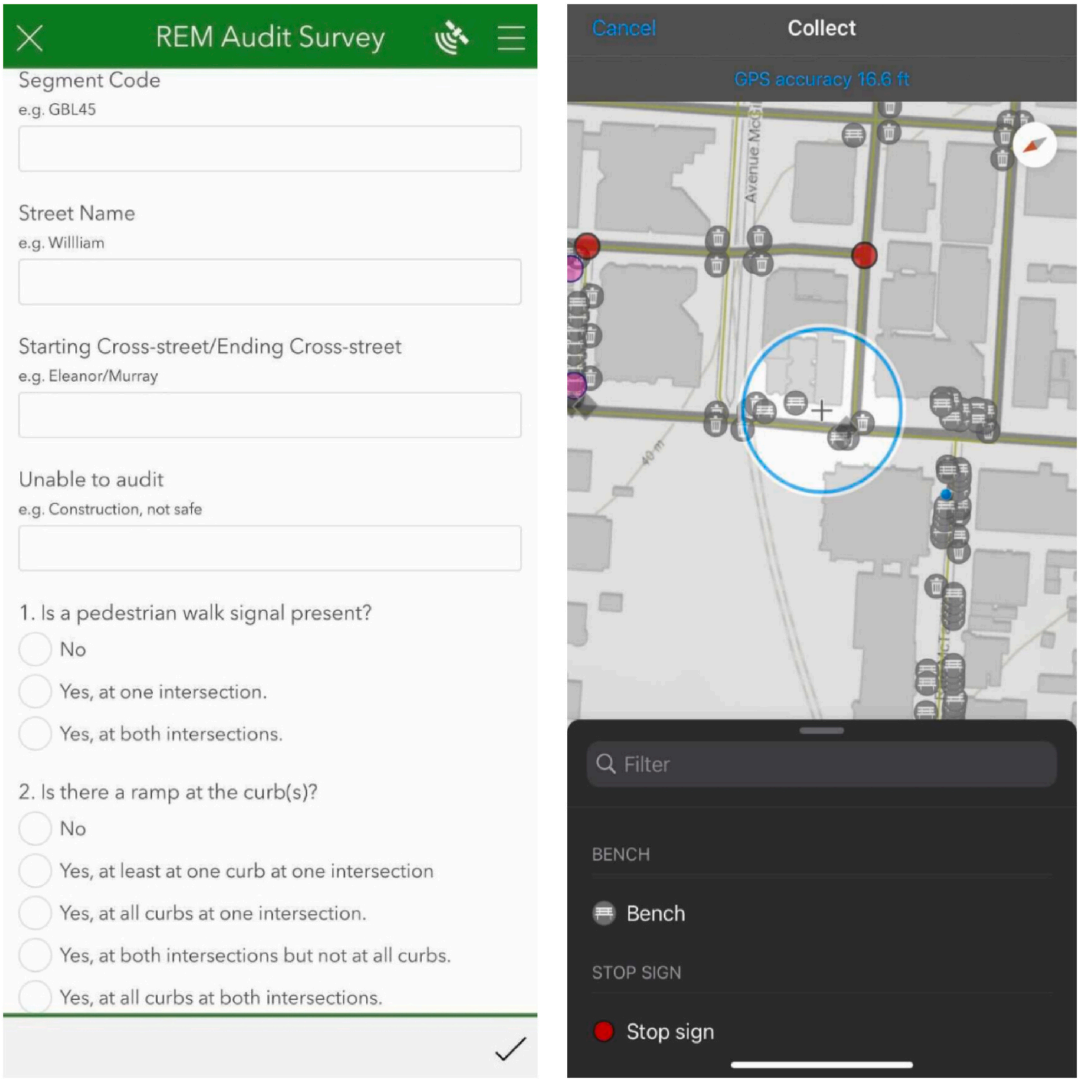

Fig. 3. Screenshots of survey 123 (left) and field maps (right).

one short segment) to audit while the longest took approximately 26 h. Auditors were aged between 21 and 31 years, had completed or were in the progress of completing a university level degree and reported to be physically active. All auditors were employed by McGill University's School of Urban Planning. Gender parity was also present amongst auditors. Each segment was audited by a pair of auditors: one filling out the survey component and the other one mapping the required elements. Only one survey entry was filled for each segment, except for 33 segments which were audited twice by separate teams of auditors. This was done for validation purposes, to further account for interpersonal differences between auditors which could otherwise skew the data.

Audit sessions were generally organized into 3–4 h shifts covering on average around 30 segments. The number of segments assigned per audit session was dependent on the stations with suburban stations being faster to audit than downtown or industrial ones. All assignments were prepared in advance and uploaded data was cross-referenced with the assignments after every audit session to confirm that all required segments had been audited.

All auditors were trained prior to the audit. Online sessions were held to present each survey question in detail with guidelines on how to answer them. Following this, a field trial was conducted using a subset of 10 segments that were audited by all auditors. Training data was used to assess inter-rater reliability using percentage of agreement (Table 2). Questions with percentage of agreements below 80% (i.e., walk signals, crosswalks, streetlights, and sidewalk cover) were directly addressed and re-explained to auditors. Other questions for the audit survey which are not present in the table below were not from the MAPS mini audit tool, some of these questions were significantly modified after the training following feedback from the auditors and analysis of the results.

External data was also collected to supplement the audit-derived data. Walk Score was collected using an API with the geographical location of the centroids of each segment. Speed limits were derived from municipal speed limit maps from the cities of Montreal, Laval, Pointe-Claire, Kirkland and Town of Mont-Royal, with a limited number of segments confirmed through Google Street View. Transit stop locations and the lines serving each stop were collected from transit agencies (i.e., STM, RTL, STL, EXO). Each point was linked to the nearest segment using the snapping tool in ArcGIS with a maximal 30-m buffer while making sure not to pick up stops that were on non-audited street segments. Parking poles with bike racks were obtained from the Agence de Mobilité Durable (AMD). These were then snapped onto each segment in ArcGIS, as was the case for the transit stops. Lastly, mapped data for benches, trash cans, drinking fountains, public toilets and speed bumps were also snapped to the nearest segments using the same method. Fig. 4 shows a sample of the mapped data for the Town of Mont-Royal station.

3.4. Data cleaning and verification

The first step of data cleaning was to verify the segment codes downloaded from Survey 123 to make sure that they were entered consistently. A table join was then performed between the collected survey entries and the attribute table from the segments shapefile to confirm that all segments deemed safe to audit (n = 924) had a survey entry. Mapping and external data as well as a dichotomous cul-de-sac designation were then added to the dataset for each segment. All audited segments that presented empty cells for required questions were completed using a combination of photos taken during the audit and Google Street View.

Following formatting, primary data verification was conducted. Segments identified as cul-de-sacs were verified for questions pertaining to the intersections (i.e., walk signal, ramp, and crosswalk). Answers for these questions that indicated "both intersections" were modified for "one intersection" to reflect the presence of only one intersection on the segment. Official transit stop data was compared with the results of the corresponding survey question. Several discrepancies were discovered in the survey data and thus the decision was made to completely replace audited transit stop location with the more accurate official data from the transit authority. A similar process was conducted for the bicycle rack data collected through the survey and the official data on parking poles with bicycle racks from AMD. As the survey input for individual bike parking counted both parking poles with bicycle racks and other individual bicycle racks, any entries that had a number in the survey less than the official AMD data was adjusted to match the official count. Any cases where the survey data was higher than the official data was assumed to come from the presence of standard individual bicycle

Table 2
Inter-rater reliability scores for the REM built environment audit training session.

Question	%
1. Is a pedestrian walk signal present?	69.23
2. Is there a ramp at the curb(s)?	84.62
3. Is there a visible marked crosswalk?	74.36
5. Parks	92.31
6. Main type of land use	87.18
7. How many public transit stops are present?	87.18
8. Are streetlights installed?	79.49
9. Are there any benches or places to sit (include bus stop benches)?	87.18
11. Is there a designated bike path?	100
12. Are the buildings well maintained?	84.62
13. Is graffiti/tagging present (do not include murals)?	82.05
14. Cleanliness – is there any litter, rubbish, broken glass, discarded items in the segment?	97.44
15. Is a sidewalk present?	100
15.1 Are there poorly maintained sections of the sidewalk that constitute major trip hazards?	94.87
15.2 Is a sidewalk buffer present?	92.31
15.3 What percentage of the length of the sidewalk/walkway is covered by trees, awnings or other overhead coverage?	66.67

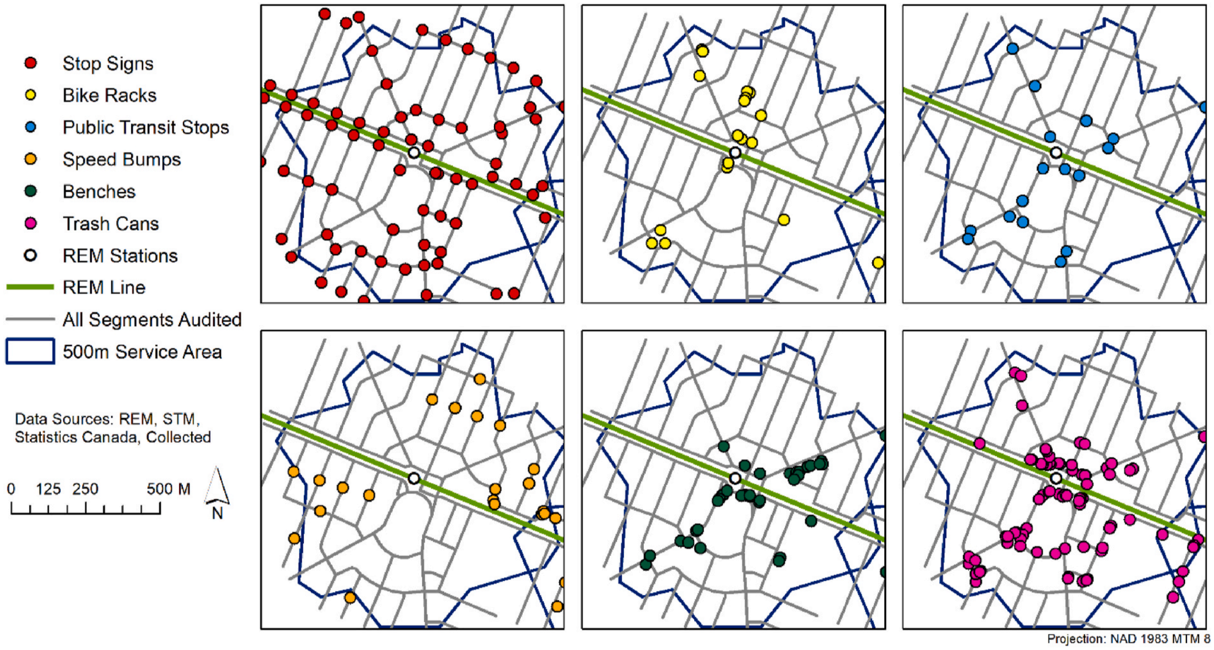

Fig. 4. Elements mapped along audited segments in Ville-de-Mont-Royal service area.

racks that were not accounted for in the AMD's data. Once all primary verifications were conducted, scores from the MAPS mini audit tool (out of 21) were calculated using the scoring grid in Table 1. Unsafe segments were given a score of 0 to reflect their poor conduciveness to walking while segments that were not auditable due to major construction were not given a score (i.e., not applicable).

With the score calculated, a secondary verification process using online methods was applied to further minimize potential discrepancies arising from individual auditors. This process included conducting inter-rater analysis post-audit using the 33 segments with two survey entries. Discrepancies were defined as being a difference of more than one on 21 for the MAPS-Mini audit tool score. Two auditors were highlighted as having recurrent inaccuracies. To account for that, survey entries from these auditors (n = 101) were confirmed using online methods described earlier. When that was not possible, segments were audited again in the field by the best performing auditors. Then, one entry for each of the 33 segments was selected to be kept in the main database. If one of the entries was filled out by one of the two poorly performing auditor, then the other entry was automatically selected, otherwise the process was randomized. In addition to post-audit inter-rater reliability testing, one random segment amongst those with only one entry was selected for each auditor and each station and verified using the same online methods. Inaccuracies were detected through this method for specific questions: main land use, streetlights, sidewalk buffer and sidewalk cover. As a result, all audited entries (n = 848) were revised for those four questions using online verification. At the end of the verification process, final MAPS-Mini audit tool scores were generated once more.

3.5. Analysis

The length, in meters, of each segment with an associated MAPS-Mini audit tools score (n = 875) was calculated using ArcMap's *Calculate Geometry*. To calculate an average score for each station, weights were given to longer segments as they represented a larger portion of the built environment around the station. The weights were generated from calculating quartiles for each station. The length of each segment was compared to the quartiles calculated for each station from all the lengths of the segments in that station. Lengths that fell below the first quartile were given a weight of one, lengths between the first and second quartiles were given a weight of two, lengths between the second and third were given a weight of three, and finally lengths that were greater than the third quartile were given a weight of four. These calculations were repeated for each station. The weighted scores were then calculated as being the score the segment received multiplied by its corresponding weight. The mean of the weighted scores was calculated for each station.

Socioeconomic data was obtained at the dissemination area (DA) level from the 2016 Canadian Census (Statistics Canada, 2016a; 2016b). This includes population, net median household income, percent of tenants spending more than 30% of income on rent, median rent cost, number of immigrants arriving between 2011 and 2016, number of university degree holders and unemployment rate.

A 500-m network buffer was generated for each station. A spatial join conducted between the buffers and the dissemination areas grouped all the socioeconomic variables with their respective stations. The mean of each socioeconomic variable was calculated for each station. For variables containing total numbers (immigrants and degree holders), the percent was first determined from the population variable. The number of benches, bike racks, bike paths, trash cans, transit stops, speed bumps, speed limit, parks, vacant lots, sidewalks, sidewalk cracks, sidewalk buffers, percentage of shade were calculated for each station. This data was plotted to visually assess potential relationships between socioeconomic factors and both mapped amenities as well as average weighted scores per station.

Table 3
Descriptive statistics of audit outputs.

Characteristics	Mean	St. dev	Min	Max
Station level				
Weighted Average Score	5.90	3.05	0	10.67
Street level				
Score	7.51	3.22	0	18
Walk Signal				
No	0.67	0.47	0	1
One intersection	0.2	0.4	0	1
Two intersections	0.13	0.34	0	1
Ramps at the curbs				
No	0.15	0.35	0	1
At least one curb at one intersection	0.06	0.24	0	1
At all curbs at one intersection	0.08	0.28	0	1
At least one curb at both intersection	0.19	0.4	0	1
At all curbs at both intersection	0.51	0.5	0	1
Visible crosswalk				
No	0.44	0.5	0	1
One intersection	0.3	0.46	0	1
Two intersections	0.26	0.44	0	1
Parks	0.13	0.37	0	2
Main Land use				
Residential	0.52	0.5	0	1
Vacant	0.03	0.17	0	1
Greenspace	0.02	0.16	0	1
Industrial	0.03	0.17	0	1
Commercial	0.22	0.41	0	1
Mixed	0.18	0.38	0	1
Transit stops	0.39	0.8	0	7
Streetlights				
None	0.07	0.25	0	1
Some	0.77	0.42	0	1
Ample	0.16	0.36	0	1
Benches				
Yes	0.25	0.43	0	1
No	0.75	0.43	0	1
Bicycle path				
No	0.85	0.36	0	1
Sharrow	0.04	0.18	0	1
Painted lines	0.06	0.24	0	1
Multi-use path	0.02	0.14	0	1
Physical barrier - Bollard	0.02	0.12	0	1
Physical barrier - Concrete/Grass buffer	0.02	0.14	0	1
Building maintenance				
0–99%	0.33	0.47	0	1
100%	0.67	0.47	0	1
Graffiti				
No	0.91	0.28	0	1
Yes	0.09	0.28	0	1
Sidewalks				
No	0.18	0.39	0	1
One side	0.16	0.36	0	1
Two sides	0.65	0.48	0	1
Pedestrian street	0.01	0.1	0	1
Sidewalk maintenance				
No poorly maintained sections	0.64	0.48	0	1
Any poorly maintained sections	0.36	0.48	0	1
Sidewalk buffer				
No	0.73	0.44	0	1
One side	0.09	0.29	0	1
Two side	0.17	0.38	0	1
Sidewalk tree cover				
0 - 25% - no sidewalk	0.73	0.44	0	1
26–75%	0.22	0.41	0	1
76–100%	0.05	0.21	0	1

4. Results

The results of the audit led to an examination of the scores for each station. Four stations representing differing scores are examined at the segment level. This inequity analysis of the scores led to an analysis of socioeconomic inequity between stations. Finally, a case study is presented of two suburban stations with disparate scores despite similar macro environments.

4.1. Audit results

Descriptive statistics for each segment level and station level outputs of the audits are displayed in Table 3. The mean unweighted MAPS-Mini audit tool score for the audited segments was 7.51 and the median unweighted score was 7. The highest score was 18 (out of a maximum score of 21) and lowest score of 0 was registered once for segments around Central Station and Ile-Bigras respectively.

For intersection characteristics, 67% of segments did not have any walk signal and just over half of all segments (51%) had ramps at all curbs. When it came to crosswalks, 44% of segments did not have any, 30% had a visible crosswalk at one intersection, and 26% had once at both intersections. Moving on to land-use data, the average park count per segment was 0.13. For main land use, 52% of segment were characterized as residential followed by 22% as commercial, 18% as mixed, 3% as industrial and vacant each and 2% as dominated by greenspaces. Segments had on average 0.39 transit stops. The majority of segments (77%) were reported to have some streetlights, followed by 16% with ample and 7% with none. Of the audited segments, 75% did not have any benches. Lastly, 85% of the segments did not have a bicycle path, followed by 6% with painted lines, 4% with sharrows and 2% each for multi-use paths, physical barriers with bollards and physical barrier with a concrete or grass buffer.

For aesthetic elements of the MAPS-Mini audit tool, 67% of segments had uniformly well-maintained buildings while 33% had at least one building that was not properly maintained. Most segments (91%) did not have any graffiti. In term of sidewalk characteristics, 65% of segments had sidewalks on both sides, followed by 18% that did not have any, 16% that had a sidewalk on one side and 1% that were pedestrian streets. Most segments (64%) were well maintained. In term of physical separations, 73% of street segments had no sidewalk buffer, 17% had a buffer on both sides and 9% had a buffer on both sides. Lastly, 73% of segments had less then 25% of tree cover over the sidewalk or did not have sidewalks.

Overall, the audit revealed that the main points of improvement for street segments around the new REM stations are bicycle paths, benches, sidewalk buffers and sidewalk tree cover. Conversely, the best performing items from the MAPS-Mini audit tool were graffiti, building maintenance, sidewalk maintenance and the presence of ramps at the curbs at intersections.

At the station level, the average weighted score had a mean of 5.90 points on 21 with two stations receiving a score of 0 (Anse-à-l'Orme and Brossard) and one station receiving a score of 10.67 (Central Station). Both stations with zero points are located at the extremity of the new transit network. These two stations along with the third lowest scoring station, Fairview-Pointe-Claire, do not have any residents within their service areas and only had one auditable street segment connecting to the station (Fig. 5). Additionally, they are all located in suburban areas next to highways. This impedes riders' ability to walk to and from the station. Conversly, the highest scoring stations tend to be located towards the center of the island with the exception of Du Quartier station. The outlying nature of the later station will be explored latter on as a case study.

While variety was observed for all socioeconomic indicators between stations (Fig. 6), no relationships were visually observed with mapped amenities or average weighted station scores. However, differences were visually observed between the average SES indicators across all stations and those of the Greater Montréal Area (GMA) with the average median household income of all stations ($74,545) being higher than the GMA average ($61.790) (Table 4).

Fig. 7 shows the detailed Maps-Mini audit tool scores for segments around four different stations. The first station Anse-à-l'Orme is at the end of the line with one segment scoring at zero due to absence of almost all kind of aminites for a walkable street. The second station we are looking at is the Deux-Montagnes station, which is a suburban station but its score lies near the mid-range point. Almost half of its segments had sidewalks and almost a third had a bicycle path of some form. Unlike the three lowest scoring stations, it is

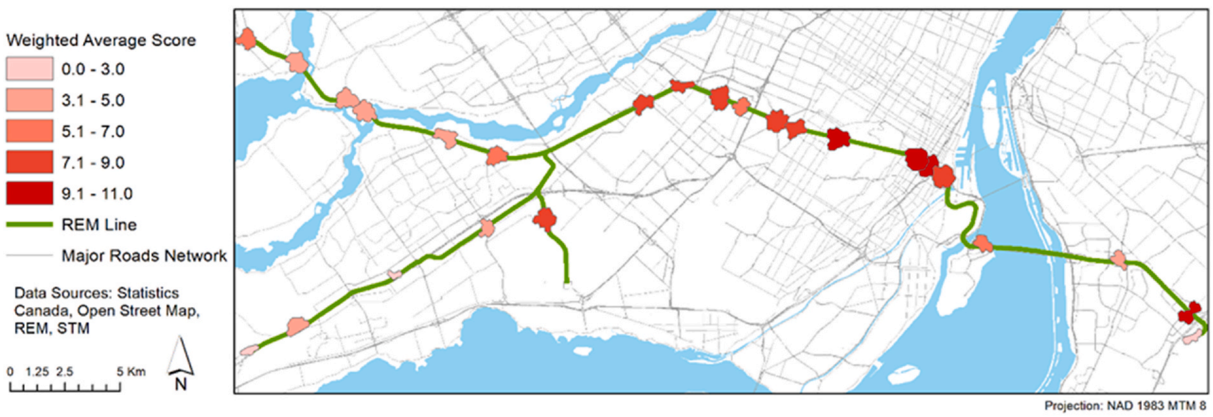

Fig. 5. MAPS-Mini audit tool average weighted score for each station.

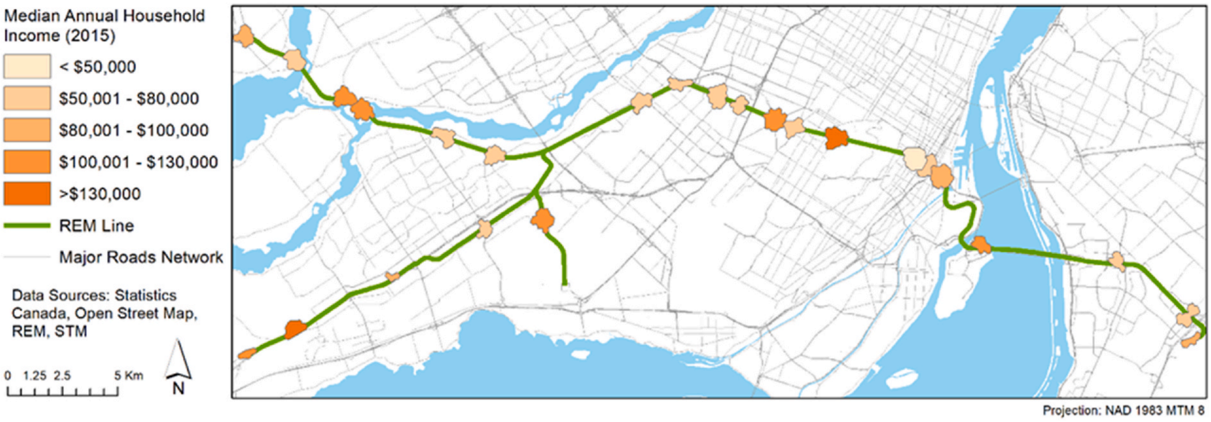

Fig. 6. Median annual household income for each station.

Table 4
SES indicators across MAPS-Mini audit tool station scores.

SES indicators	Station Average	GMA
Median household income ($)	74,545	61,790
Median value of dwellings ($)	441,734	300,794
Median rent ($/month)	976	777
Households paying over 30% on shelter costs (%)	29.73	24.56
Unemployment rate (%)	8.50	7.50
Individuals holding a university degree (%)	40.19	25.54
Immigrants from 2011 to 2016 (%)	7.76	4.47

embedded in a residential area giving it a larger service area with more segments. The third station, Ville-de-Mont-Royal is an inner suburban station. It has a denser street network than the other two suburban stations and no highway in close proximity, allowing for a large service area. Many street segments in Ville-de-Mont-Royal had a high shade percentage and sidewalks on both sides of most streets. Streelighting was also ample along most major streets. Many micro-geography features are present in this service area (Fig. 4). However, there were few transit stops, pedestrian crossing signals, bike parking poles, or bike paths in the service area which reduced the average score.

Finally, Central Station is an urban station located in the downtown core, where the street network is densest. It has the highest average weighted score of all the stations. Central station like many of the downtown stations had a high number of pedestrian cross signals at intersections. This feature is largely absent in most suburban stations. The highest scoring segment in the entire audit was in the Central Station service area. It only lost points because it did not have a park or a bike path. It's high number of amenities, transit stops, often ample streetlights, sidewalks with both shade and buffers, and bike paths propel it to number one.

4.2. Case study

Building stations next to highways comes with benefits, including the low-cost of empty land, and challenges, such as difficulties in encouraging active travel modes. However, the second highest scoring station, Du Quartier, shares many of the same characteristics as the lowest scoring stations: it is in a suburban area located right next to a highway. The difference between these two stations is the micro-geographies and the well-designed highway overpass that connects directly to the station. Perhaps building near highways provides a blank canvas on which transit-oriented villages can be developed. Then again, Panama station scores considerably less than Du Quartier even though they are adjacent stations in the same neighbourhood, straddling the same highway (Fig. 8).

The main two streets next to Panama station are Panama Street and Taschereau Boulevard, both have 50 km/h speed limits. The main street that Du Quartier station connects to is Du Quartier Boulevard which also has a 50 km/h speed limit. Taschereau Boulevard and Du Quartier Boulevard are both large streets with many lanes and high speed limits but only Du Quartier has a sidewalk buffer and a bike path with a physical barrier on each side of the street (Fig. 8). Du Quartier station benefits from the direct connection of the station to Du Quartier Boulevard. The station has three points of pedestrian access compared to two at Panama station. The greater access affords it a larger service area than Panama station, helping to boost its average score with the inclusion of more street segments. Furthermore, both points of access to Panama station are far from streets, requiring a tunnel under the highway to connect surface pedestrian access to the station. One side deposits riders in a large parking lot, part of a bus terminus. The other side, once a pedestrian path is built, will take riders along an embankment adjacent to the highway, behind a residential neighbourhood, then end in another parking lot. This proposed path, when manually drawn into the road network of the network analyst tool in ArcMap, did not manage to bring pedestrian riders to Taschereau Boulevard within 500 m. The long walk to any streets from either access point shrunk the service

Fig. 7. Four stations with differing average scores with each segment's score shown.

area of the station.

The Du Quartier station service area has many microscale features that Panama station does not and of the features they do have in common, Du Quartier has them in higher numbers (Fig. 8). Seven of the Du Quartier street segments also had ample streetlights (ample being the maximum, Table 3). Panama had zero segments with ample streetlights. Du Quartier had 14 segments with a sidewalk buffer on at least one side of the street. Panama, once again, had zero segments with a sidewalk buffer.

5. Discussion

The results of this audit demonstrate the inequities between stations' walkability. Not all light rail transit (LRT) stations necessarily encourage utilitarian walking, some were even impossible to walk to. The case study offers some potential lessons to other LRT stations as the Du Quartier station, in theory, will be able to encourage utilitarian walking despite being a suburban, sparsely populated, car-centric area. The reasons behind the high score of Du Quartier are also easily replicable in other stations. The addition of sidewalks with buffers and shade, and bike paths could go a long way to improving the walkability of stations in similar milieus.

While no relationship was observed between walkability of the station and socioeconomic factors, the analysis still allowed us to highlight that the average median income of all the stations is above the GMA average. Past research has highlighted that in order to build a resilient transit network, rail systems should provide service to low-income population. This is especially important as the substantial investments that light-rail or other types of rail network require can often lead to service cuts in buses which tend to be used by younger and less wealthy people (Pendall et al., 2012). The subject of socioeconomic inequalities between stations could be better framed in future research as being an issue of access to these stations being conferred to wealthier areas.

The audit process also provided insight on the capabilities of the tools used. Despite the MAPS-Mini audit tool's reduced number of items, auditors found the questions to be repetitive in areas with little variation in the built environment such as large suburban neighborhoods with a single land use type. This highlights the importance of audit tools to take into account functionality and efficiency in their design. In this case, while some repetitiveness was observed, the succinct nature of the MAPS-Mini audit tool still allowed for the completion of the audit in a reasonable time (i.e., 9.6 h/station on average). The scores the MAPS-Mini audit tool generated were also sufficient to spotlight certain stations as being poorly or well designed for walkability.

Other methodological findings pertaining to audits indicate the need for added verification of the data collected. For instance,

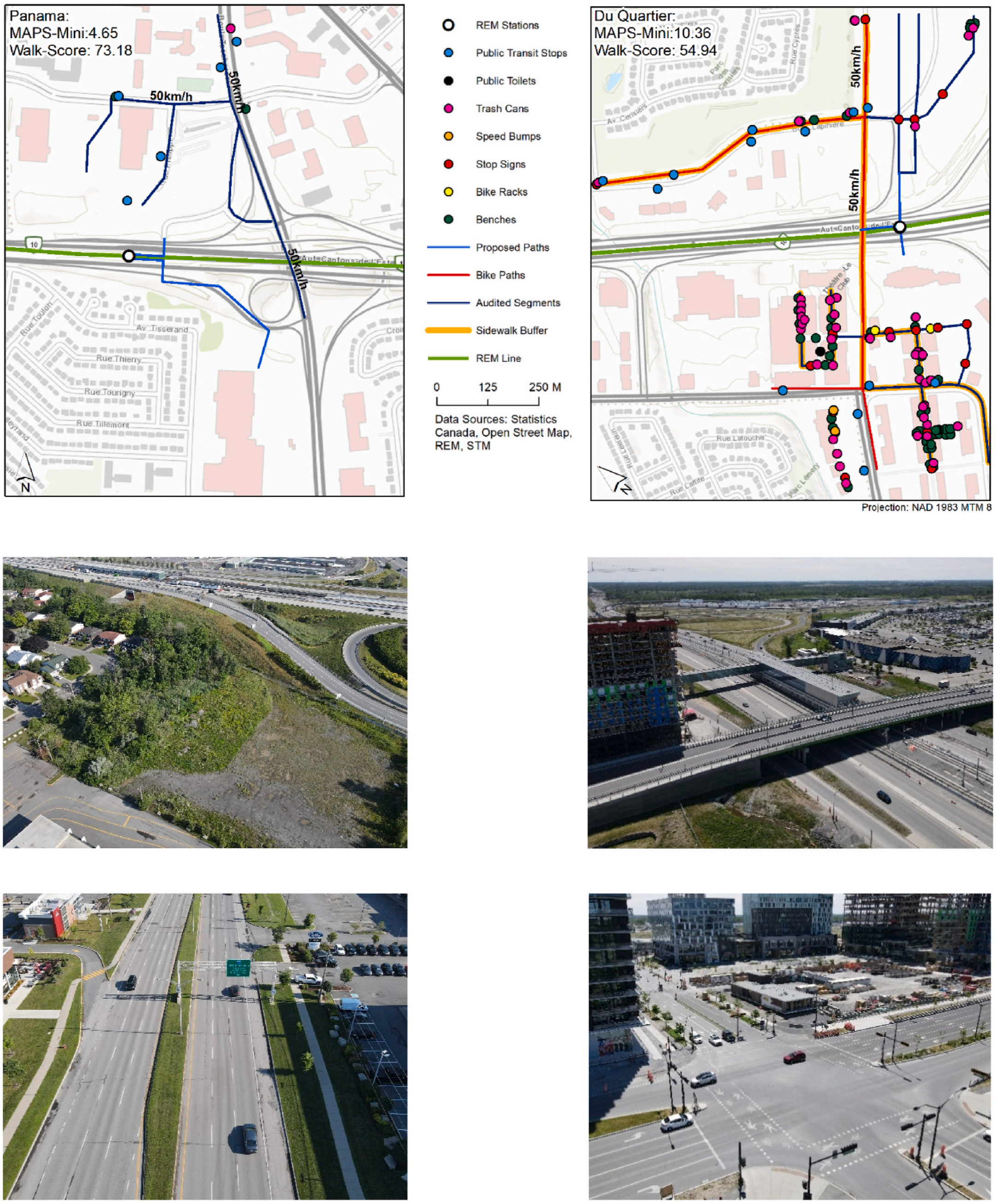

Fig. 8. Comparison of Panama station with Du Quartier station, both in Brossard.

regular discrepancies and errors in the answers of four questions were found in the verification process. While two of these items – streetlights and sidewalk cover – had been flagged with percentage of agreement lower than 80% in the pre-audit inter-reliability testing, the other two – sidewalk buffers and main land use – performed well with percentage of agreements above 85%. Additionally, two auditors were highlighted as having regular significant discrepancies in the information entered. This highlights that the training of auditors is not enough to ensure a thorough audit output. As such we recommend the use of both the secondary verification methods used in this audit: the collection of overlapping segments to use for post-audit inter-rater reliability testing as well as random segment verifications using GSV and/or photos taken by auditors. Such methods have been used for audits strictly conducted via online methods but not as a verification tool for those conducted by foot (Bartzokas-Tsiompras et al., 2020). Another strategy used in past research to examine inter-rater reliability is to use interclass correlation coefficients (Cain et al., 2018; Fox et al., 2021); this may be another useful tool to assess this methodological issue.

The usage of recent applications such as Survey 123 and Field Maps for this audit present opportunities to modify the auditing process. Such tools made it efficient to store data offline during an audit session while also providing both a location and a time stamp for survey submission providing proof of auditors' location, a further verification measure. Given that the tools are new, some bugs were encountered but easily solved. For instance, Survey 123 had difficulties properly downloading the totality of the data often omitting recent inputs. It is also sensitive to changes made after the publication of surveys meaning that it will report answers based on the order in which they were in the original version of the questionnaire. Therefore, if any modifications need to be made to the survey after publication, questions should be entirely replaced by new ones to avoid data corruption. For Field Maps the apps do not always function optimally when installed on moderately older phone models.

A limitation to this paper is the lack of data on walking patterns around each station. Since most of the stations were still under construction, there was no way to assess how much utilitarian walking the built environment around these stations really encouraged. All the findings of this paper rely on theoretical links to walking. Future research should evaluate the actual walking patterns of these stations to discover if the audit scores served as reliable predictors of walking. Also, though no clear station-level relationship between socioeconomic variables and walkability was identified, stations seem to be built in higher SES areas of the city, Future work can further parse out the relationship between socioeconomic factors and walkability. Further, only segments within a 500 m service area of the REM stations were considered in this study. While this service area size has been used in past research auditing LRT stations (Oluyomi et al., 2019), future work may want to use a larger service area as people may be willing to walk further then 500 m to reach an LRT station.

6. Conclusion

This paper provides a new approach to foot-based audits, by employing the latest technology in the form of ArcGIS's Field Maps and Survey 123, using the less cited but most efficient MAPS-Mini audit tool, and highlighting the importance of multiple verification methods for audit data – an often-overlooked component to audits. The implementation of this audit, more often used in public health circles, to evaluate a new light-rail network gives another example of the importance of integrating public health into public transport work.

Sidewalks, sidewalk buffers, sidewalk shade, benches and bike paths were found to be the micro-scale features from the MAPS-Mini audit tool that contributed the most to differences in the average scores of stations. These leverage points could serve as jumping off points for future policy around new light rail infrastructure.

As LRTs grow in popularity, results from this paper can inform transportation planners, engineers, and other city-building officials on how to design LRT stations that support physical activity. Further, the exemplary Du Quartier station design presented in this paper is a concrete example of what cities can aspire to when developing stations in suburban environments, environments renown for discouraging physical activity.

No relationship was visually observed between socioeconomic indicators and station-level walkability in this study. However, the neighbourhoods that stations are built in to begin with were found to have higher median household incomes than the Greater Montreal Area average. This finding raises important questions regarding who benefits from large-scale public transit investments such as LRTs. It is recommended that a more in depth statistical analysis to be conducted in the future to link socioeconomic indicators and segment-level walkability.

Authors contribution

The authors confirm contribution to the paper as follows: study conception and design: Daley, Rodrigue, Ravensbergen, DeWeese, Butler, Kestens & El-Geneidy; data collection: Daley, Rodrigue, Ravensbergen, DeWeese & El-Geneidy; analysis and interpretation of results: Daley, Rodrigue, Ravensbergen, DeWeese, Butler, & El-Geneidy; draft manuscript preparation, Daley, Rodrigue, Ravensbergen, DeWeese, Butler, Kestens & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

Declaration of competing interest

A conflict of interest may exist when an author or the author's institution has a financial or other relationship with other people or organizations that may inappropriately influence the author's work. A conflict can be actual or potential. At the end of the text, under a subheading 'Disclosure Statement', all authors must disclose any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three (3) years of beginning the work submitted that could inappropriately influence (bias) their work. Examples of potential conflicts of interest which should be disclosed include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding.

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