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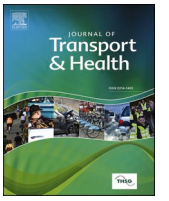

Can 20mph speed limit interventions influence liveability? A natural experiment using the Microscale Audit of Pedestrian Streetscapes Liveability (MAPS-Liveability) and Google Street View

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ABSTRACT

Background: A recent meta-narrative review investigating 20mph speed limits on public health outcomes reported inconclusive findings and the limited scope of liveability investigations. Consequently, we investigated the impact of 20mph speed limit interventions on liveability using the Microscale Audit of Pedestrian Streetscapes Liveability (MAPS-Liveability) via Google Street View (GSV).

Methods: MAPS-Liveability provides a quantitative assessment of liveability and its constructs (i.e., safety, health, sustainability, inclusivity, places, education, traffic/transport, roads, and pavements) at the micro-level (i.e., street). Google Street View enabled pre- and post-implementation data collection for Belfast (n = 68 streets) and Edinburgh (n = 76 streets) by two independent raters, with scores calculated for total liveability and nine liveability constructs. Wilcoxon signed-rank tests (changes pre-to post-implementation), cluster analysis (identification of discrete street clusters), analysis of variance (differences within clusters) and analysis of covariance (differences between clusters) were undertaken. Clusters were mapped, street types identified, and clusters named by determining the predominant street type.

Results: In Belfast and Edinburgh, there were significant increases post-intervention for total liveability, with 57.4% (n = 39) of streets in Belfast and 75% (n = 57) in Edinburgh seeing positive changes. Both cities also saw significant positive increases in the liveability constructs of traffic/transport (e.g., speed signage) and places (e.g., presence of shops); with Edinburgh also

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seeing a significant positive increase post-intervention for pavements (e.g., quality). Cluster analysis identified three clusters *"Mixed land use", "Central Business District"* and *"Residential"* with each showing positive changes for total liveability and the construct of traffic/transport.
Conclusion: 20mph speed limit interventions were found to positively contribute to total liveability and the specific liveability construct of traffic/transport. This was particularly the case when 20mph speed limits were implemented on streets with dense mixed land use.

1. Introduction

Liveability is a multi-faceted concept, which informs the work of a variety of fields (e.g., public health, urban planning, infrastructure, and transport) (Adam et al., 2017; Higgs et al., 2019; King et al., 2020). Current investigations working to disentangle the complexities of liveability are timely, considering the potential impact of the environment (both built and social) on health and well-being (United Nations, 2018; Cleland et al., 2021a). A liveable place is one which is: *"safe, attractive, socially cohesive and inclusive, and environmentally sustainable; with affordable and diverse housing linked to employment, education, public open space, local shops, health and community services, and leisure and cultural opportunities;* via *convenient public transport, walking and cycling infrastructure*" (Lowe et al., 2013, page 11). This definition also highlights the interaction and interlinkage of the nine constructs of liveability (i.e., places, health, inclusivity, sustainability, roads, pavements, traffic/transport, safety, and education) as presented by Cleland et al. (2021a).

When considering the challenges of liveability and its improvement over time, it is plausible to hypothesize that by aiming to influence positively a single construct of liveability (e.g., traffic/transport), there is the potential that this will have a ripple effect and beneficially influence liveability as a whole (Lowe and Giles-Corti, 2015; Turner et al., 2018; Cleland et al., 2019; Cleland et al., 2021b; Nobles et al., 2022). Consequently, if successful, 'improved liveability' may also have the capacity to act as a mechanism in numerous other public health pathways resulting in beneficial physical and mental health outcomes, and thereby reducing the burden of health and social and environmental inequalities (Lowe and Giles-Corti, 2015; Turner et al., 2018; Cleland et al., 2019; Cleland et al., 2021b).

One construct which has been reported to detrimentally impact liveability is traffic/transport. Specifically, Hart et al. (2011) highlighted that residents of roads which have large volumes of traffic were found to have significantly fewer friendships than residents on streets with smaller volumes of traffic. It is likely that the mechanism responsible for this outcome is low social connectedness, with it also being reported as an issue on streets with high traffic flows in multiple cities within the United Kingdom (UK) (Hart and Parkhurst, 2011). In addition, speeding behaviour has also been reported as having a detrimental impact on liveability, as it is anti-social and results in noise pollution and contributes to stress-related illness in residents (Poulter and McKenna, 2007; Cohen et al., 2014).

Taking these findings into consideration Dorling and colleagues (2014) indicated that a method to improve and increase liveability through indirect and direct traffic/transport effects would be to lower speed limits to 20 miles per hour (mph). Dorling (2014) proposed that when lower speed limits are implemented traffic can travel safely using less road space which in turn can free up space, enabling the environment to be reimagined and redesigned (e.g., inclusion of more seating and planting) to enhance pleasantness and overall liveability for residents. The reduction in traffic speed to 20mph also has the potential to provide pedestrians and those who wish to travel actively (e.g., walking, cycling, or jogging/running) with increased personal safety in turn encouraging them to be more physically active. In support of this Turner et al. (2018) through their work on 20mph speed limit interventions also proposed mechanistic pathways and suggested that liveability could be improved by roads being 'easier for vulnerable groups to judge speeds and the availability of 'more pleasant road-crossing conditions' (Turner et al., 2018). In addition, a recent qualitative exploration of the mechanisms, pathways, and public health outcomes of 20mph speed limit interventions also highlighted that improved liveability was perceived and experienced through the mechanism of 'reduced driving speed' (Cleland et al., 2021b). Therefore, considering the popularity of 20mph speed limit interventions in both the UK and continental Europe (30 km per hour), due to their ability to operate at a population level (i.e., Traffic Orders, signage, enforcement and awareness and educational campaigns) and at a relatively low cost, there has been an increasing interest in 20mph 'limits' (which rely on signs, awareness raising and enforcement) as opposed to 'zones' (which also involve physical infrastructure such as speed humps, chicanes, or road narrowing), and implementing them as a potential method to influence a range of public health outcomes (e.g., liveability, collisions and casualties, active travel) (Department for Transport, 2007; Toy et al., 2014; Cairns et al., 2015; Bornioli et al., 2018; Turner et al., 2018; Cleland et al., 2019; Jepson et al., 2022).

However, a recent meta-narrative review investigating the effect of 20mph speed limits deemed the evidence base to be 'insufficient', particularly for outcomes beyond traffic speed and volume (i.e., liveability, inequalities, and pollution) (Cleland et al., 2019). Only two studies were eligible for inclusion in that review and of those two studies, only one reported finding relating to liveability (Cleland et al., 2019). However, the findings emphasized the need to assess the impact of 20mph speed limit interventions on liveability and its constructs (Cleland et al., 2021a).

1.1. MAPS-liveability

Regardless of the upward trajectory of the inclusion of liveability in research, policy and practice, the evidence on liveability measurement tools, particularly at the micro-level (i.e., street, neighbourhood), is sparse (Atkins and Maher, 2018; Cleland et al., 2021a). We recently adapted the Microscale Audit of Pedestrian Streetscapes (MAPS) to enable investigations that focus on the assessment of liveability at lower geographical scales (i.e., street or neighbourhood) via Google Street View (GSV) or walking in person

(Cleland et al., 2021a). MAPS-Liveability provides a reliable method of gaining a quantitative insight into total liveability (i.e., excellent inter-class correlations (ICC) of 0.916–0.929) and the nine liveability constructs (i.e., safety, health, sustainability, inclusivity, places, education, traffic/transport, pavements, and roads) (good to moderate ICC 0.550–0.885) (Cleland et al., 2021a). In addition, testing also showed that MAPS-Liveability is capable of reliably using comprehensive liveability data via GSV to capture change over time and it was found to have strong inter-rater agreement on sensitivity to change and/or following the implementation of an environmental intervention (Cleland et al., 2021a). Details relating to the nine constructs of liveability (i.e., safety, health, sustainability, inclusivity, places, education, traffic/transport, roads, and pavement) and interventions that could impact them (e.g., speed signage, traffic calming measures, bicycle lanes, benches) can also be collected for sub-analysis (Cleland et al., 2021a).

1.2. Aims

The aim of this study was to determine whether 20mph speed limit interventions can contribute to improved liveability as assessed using MAPS-Liveability via GSV. The objectives were to assess liveability both pre- and post-implementation of the Belfast (City Centre) and Edinburgh (Citywide) 20mph speed limit interventions.

2. Methods

The Moray House School of Education Ethics Committee at the University of Edinburgh provided ethical approval (no. 762, 29/03/17).

2.1. Context

This investigation is a sub-study of the "is 20 plenty for health?" evaluation (funded by National Institute for Health and Care Research, https://fundingawards.nihr.ac.uk/award/15/82/12). The "is 20 plenty for health?" evaluation aimed at evaluating the effects of 20mph legislation in both Belfast (City Centre) and Edinburgh (Citywide) to determine and understand the health-related outcomes, pathways and processes that contribute to public health benefits (Jepson et al., 2022). As the aim of this study was to determine whether 20mph speed limit interventions can contribute to improved liveability we reviewed findings from previous research and supplemented the evidence base by producing a model depicting potential mechanistic pathways that could lead to an improvement in liveability following the implementation of a 20mph speed limit intervention (Fig. 1) (Department for Transport, 2007; Toy et al., 2014; Cairns et al., 2015; Bornioli et al., 2018; Turner et al., 2018; Cleland et al., 2019; Jepson et al., 2022).

2.1.1. Intervention implementation – Belfast, Northern Ireland, UK

Within Belfast City Centre, the Department for Infrastructure invested £9935 to implement a 20mph speed limit intervention (i.e., signage, a Traffic Limit Order, an awareness and education campaign and enforcement) during February 2016, across 76 streets and operating 24 h per day, seven days per week. Intervention was put in place where land use mix would be considered predominantly commercial (i.e., shops, offices), with a limited number of student and residential properties. The streets range from 1 to 4 lanes in width and prior to the implementation of the 20mph speed limit intervention, none of the streets had a speed limit of less than 30mph

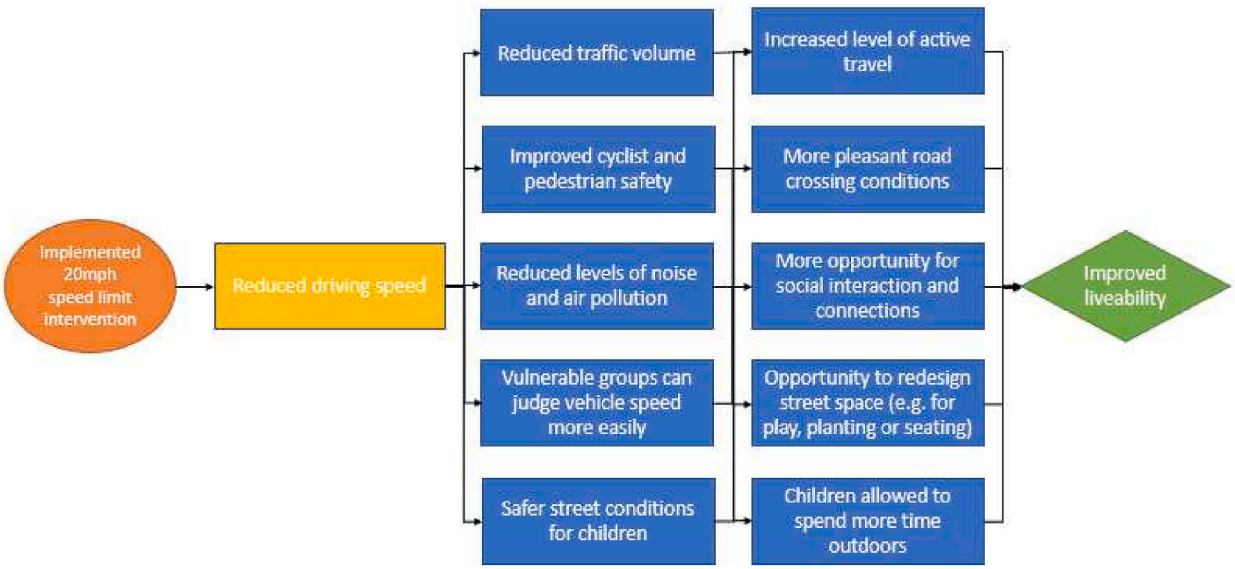

Fig. 1. Potential mechanistic pathways leading to an improvement in liveability.

(Fig. 2).

2.1.2. Intervention implementation – Edinburgh, Scotland, UK

Between 2016 and 2018, the City of Edinburgh Council invested £2.22 million to implement a Citywide 20mph speed limit intervention (i.e., signage, a Traffic Limit Order, an awareness and education campaign and enforcement). At the time of the intervention, 50% of streets in Edinburgh already had a 20mph speed limit, with the intervention bringing the total to 80%. The intervention was implemented over four phases and included seven implementation areas, with the land use mix being considered varied (e.g., residential, commercial, and industrial) (Fig. 3).

When the implementation of the interventions in the two cities are compared, the Edinburgh intervention was implemented on a greater scale (City Centre versus Citywide), with a higher level of investment (£9935 versus £2.22 million) and more intensive intervention activities (i.e., additional signage and more educational and awareness campaigns).

2.2. MAPS-liveability

Data were collected using the MAPS-Liveability (see Cleland et al., 2021a) for the MAPS-Liveability tool). Three trained raters for each city walked the streets (76 streets within Belfast City Centre where 20mph limits were implemented between April and July 2019, and 100 streets in Edinburgh where 20mph speed limits were implemented between February and March 2020) via GSV. For Edinburgh, a proportional (based on length of new 20mph street) stratified sampling approach selected streets at random from each of the seven implementation areas. As liveability is a concept and the MAPS-Liveability tool are relatively new developments, there is no agreement about what defines a meaningful change in liveability to use within sample size calculations. However, sample size calculations based on data from the development of MAPS-Liveability (mean = 67, standard deviation = 16) identified that a sample of approximately 60 streets would provide 90% power to detect changes around 1.5 points (sensitivity 0.05) using pairwise tests.

Data for both cities were collected pre-implementation of the 20mph speed limit interventions (i.e., Belfast, pre-February 2016 and

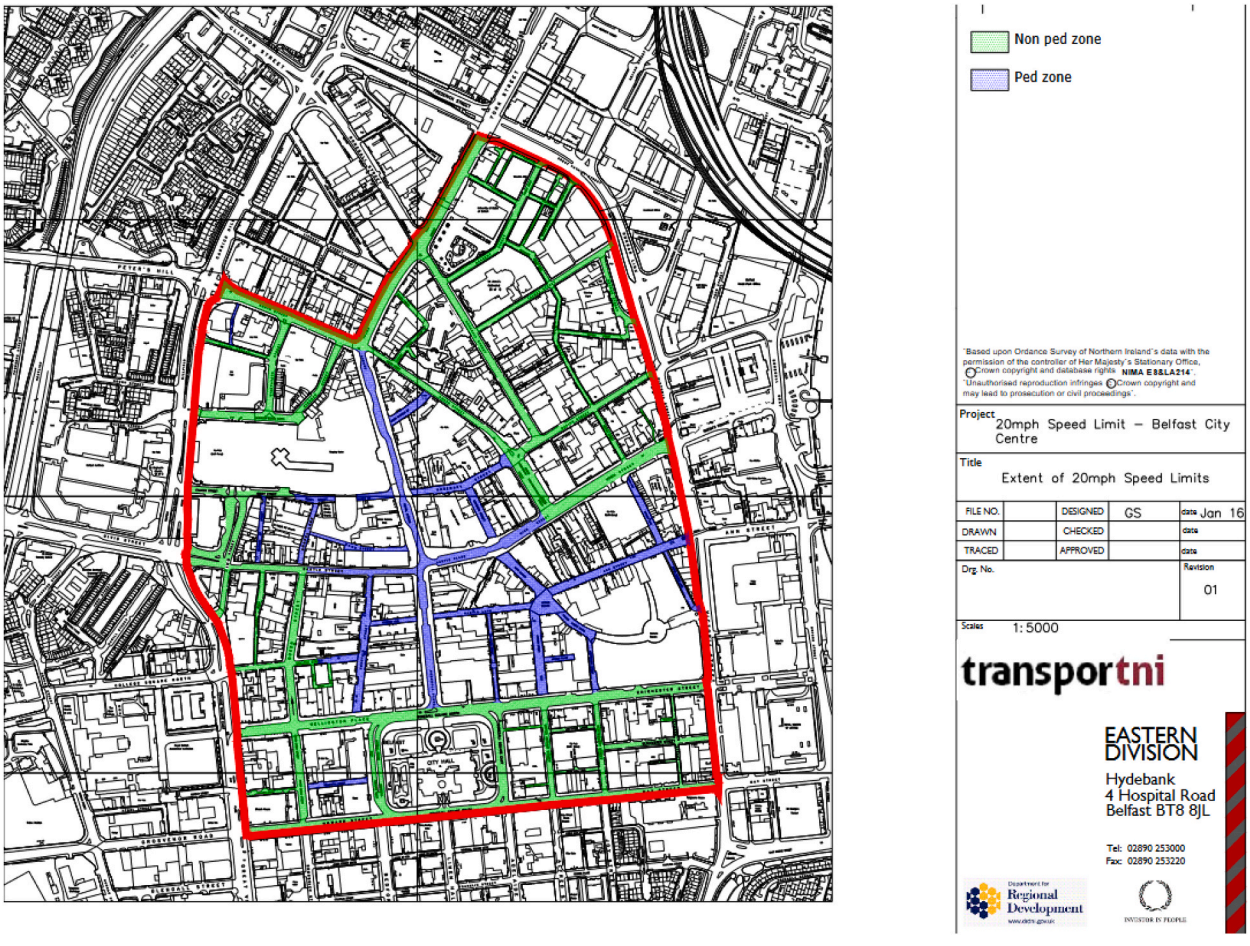

Fig. 2. Map of the 20-mph implementation zones in Belfast. Provided by the Department for Infrastructure, Northern Ireland (https://www.infrastructure-ni.gov.uk/sites/default/files/publications/drd/belfast-city-centre-20mph-zone.pdf).

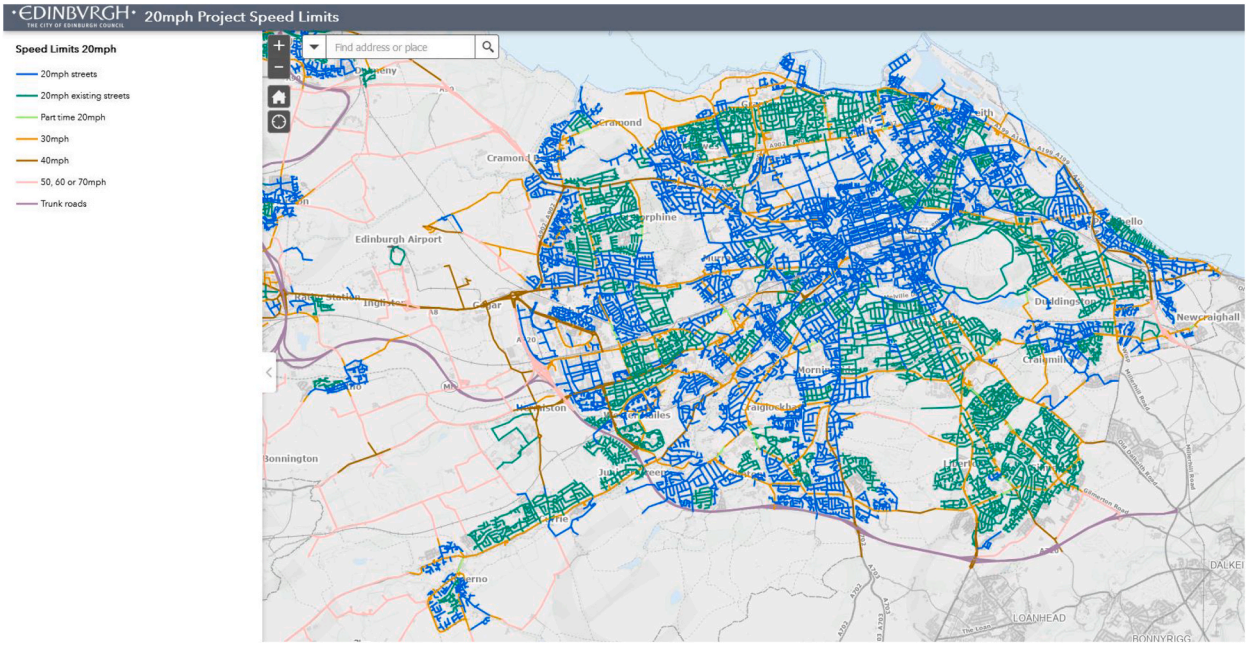

Fig. 3. Map of the 20-mph implementation zones in Edinburgh. Provided by the City of Edinburgh Council (https://cityofedinburgh.maps.arcgis.com/apps/webappviewer/index.html?id=556714cbde034313b0efd04b7fde1700).

Edinburgh, pre-July 2016). For post-implementation data collection, the most recent Google images were used (i.e., those that were after the implementation of the 20mph speed limits and closest to the day of the audit). The approximate time between audits pre-to post-implementation of the 20mph speed limit interventions was 37 months in Belfast and 59 months in Edinburgh.

Data collected in both cities were then scored in line with the MAPS-Liveability scoring protocol (Appendix 1).

2.3. Statistical analysis

The data were processed and scored (i.e., total liveability and nine constructs of liveability) based on the scoring protocol detailed within Cleland et al. (2021a) (Appendix 1). Streets were only included in the analysis if images were available on GSV pre- and post-implementation, to enable pairwise comparisons. Across the entire sample, analysis was performed in SPSS (version 29) for total liveability and the liveability construct scores (Table 1) to include: 1) descriptive statistics for pre- and post-implementation and change following the implementation of the intervention (i.e., post-implementation minus pre-implementation); and 2) Wilcoxon signed-rank tests to determine the level of significance for change pre-to post-implementation. Significance was set at $p < 0.05$ (two-tailed).

In addition, to identify similar groupings of streets we performed cluster analysis of the baseline liveability scores in Stata (version 15) combining data from both Belfast and Edinburgh. This enabled us to observe how liveability might change because of the implementation of a 20mph speed limit intervention and whether it was related to road type. As two cities in the UK with the same Highway Code and regulations, it was considered appropriate to combine the data for the cluster analysis. Furthermore, the data being analysed having been collected using the MAPS-Livability tool (Table 1) did not reflect broader cultural or population differences between the cities, but the street environments. The unsupervised machine learning technique, k-medians analysis was used as some of the individual scores calculated from MAPS-Liveability were highly skewed. The elbow method did not give a strong indication of the optimum number of clusters, and subsequently it was decided to derive three clusters and review the results. Using this technique, three of the streets were randomly selected as cluster exemplars, and then every other street initially allocated to its nearest exemplar (Brusco et al., 2017). Subsequently the exemplars and cluster allocations are switched until across all the streets the sum of the squared Euclidean distances of each object to the cluster exemplar is minimised (Brusco et al., 2017). Initial clusters' centers are randomly generated and iteratively updated, until the differences between the streets and their allocated cluster centre are minimised. The elbow method did not give a strong indication of the optimum number of clusters, and subsequently it was decided to derive three clusters and review the results. Following cluster analysis, we mapped the streets in each cluster to enable the identification of both the geographic location and type of street, naming the clusters by determining the predominant street type (Williams et al., 2021). Analysis of variance (ANOVA) tests were then performed in SPSS (version 29) for liveability (and the individual constructs) to: 1) examine which clusters were associated with greater levels of liveability; and 2) examine change (i.e., pre-to post-implementation) within each cluster. Finally, an Analysis of Covariance (ANCOVA) test was performed to 3) examine change (i.e., pre-to post-implementation) between clusters controlling for pre-implementation scores.

Table 1
Liveability construct definitions.

Safety	Safety buttons (+)
	Neighbourhood watch signs (+)
	Physical disorder (±) (graffiti/tagging (not murals or street art), abandoned cars, buildings with broken/boarded windows, drug paraphernalia, broken glass, beer/liquor bottles/cans, litter in yards, noticeable/excessive litter in street/pavement, neighbourhood watch signs, signage for commercial destinations or parks, safety button connecting to police)
	Extent of physical disorder (−)
	Presence of people (+) (presence of anyone walking, running, cycling, performing other physical activity, or exercising)
	Streetlights (+)
	Telephones (+)
	Information kiosks or booths (+)
	Eyes on the street (+) (proportion of street segment that has ground floor or street-level windows within 40 feet of the pavement/walkway (or street if no pavement/walkway))
Health	Pharmacy (+)
	Health centre (+) (health-related professional, health, or social services)
	Alcohol (−) (liquor/alcohol store)
	People performing activity (+) (presence of anyone walking, running, cycling, performing other physical activity, or exercising)
	Smoking areas (−)
	Water (+) (working drinking fountain)
	Bicycle racks (+)
	Leisure facilities (+) (private indoor, public indoor, private outdoor, public outdoor pay)
	Green & open space (+) (public park, public walking trail, community garden)
	Hardscape & softscape features (+) (e.g., fountains, sculptures, or art (public or private), gardens or landscaping)
	Landscaping maintenance (+)
	Obstructions to walking (−) (railroad tracks, highway nearby, other)
	Bicycle lane/use (+) (marked bicycle lane, does the marked bicycle lane run for the entire route, a marked bicycle track separated from traffic and pedestrians, does the marked bicycle track run for the entire route, are there any signs indicating bicycle use)
Sustainability	Rubbish bins (+)
	Physical disorder (±) (graffiti/tagging (not murals or street art), abandoned cars, buildings with broken/boarded windows, drug paraphernalia, broken glass, beer/liquor bottles/cans, litter in yards, noticeable/excessive litter in street/pavement, neighbourhood watch signs, signage for commercial destinations or parks, safety button connecting to police)
	Extent of physical disorder (−)
	Public transport (+)
	Car charging points (+)
	Green & open space (+) (public park, public walking trail, community garden)
	Hardscape & softscape features (+) (e.g., fountains, sculptures, or art (public or private), gardens or landscaping)
	Landscaping maintenance (+)
	Benches (+)
	Trees (+) (how many trees exist within 5 ft of either side of the pavement/pathway, how are the trees generally spaced, what percentage of the length of the pavement/walkway is covered by trees, awnings, or other overhead coverage)
Inclusivity	Mix of residential and non-residential (+)
	Residential houses (+) (single family homes, multi-unit homes, apartments or flats, apartments/flats above street retail, retirement/senior living facility, other
	Places of work/commercial (+)
	Education (+)
	Place of worship (+)
	Senior Centre
Places	Shops (+) (grocery/supermarket, convenience store, big box store, specialty food store, other retail, shopping centre (No = 0, Yes = 1), strip mall (No = 0, Yes = 1), shopping arcade)
	Restaurants (+) (fast food restaurant, sit-down restaurant, café, or coffee shop)
	Culture (+) (library/museums, are there observable historic or cultural features along the route (statues, murals etc.))
	Post office (+)
	Car parks (±) (on-street, parallel, small lot, or garage (<30 spaces), medium to large lot or garage)
	Bank or credit union (+)
	Other land use (−) (warehouse/factory/industrial, abandoned building, unmaintained lot/field)
	Entertainment (+)
	Green & open space (+) (public park, public walking trail, community garden)
	Leisure facilities (+) (private indoor, public indoor, private outdoor, public outdoor pay)
	Other services (+)
	Building maintenance (+)
	Aesthetics (+) (different predominant building façade colors, different building accent colors, different predominant building materials)
Education	Education (+)
	Library/Museums (+)
Traffic/transport	Public transport (+)
	Speed signs (+)
	Speed calming measures (+) (traffic calming: signs; circles; speed tables; speed humps; curb extension. Instructional signs for pedestrian's, crosswalk signage or other pedestrian signage)
	Traffic lanes (−) (number of traffic lanes, is the street predominantly one-way to two-way)
Pavements	Street amenities (+) (building overhangs that provide shelter from inclement weather in public space, rubbish bins (public), benches or other places to sit, bicycle racks, working drinking fountain, working public telephones, kiosks or information booths, car charging points
	Litter in street/pavements (−)

(*continued on next page*)

Table 1 (*continued*)

	Obstructions to walking (−) (railroad tracks, highway nearby, other) Streetlights (+) Crossings (+) (mid-segment street crossing where an individual could safely cross (marked by a sign or crosswalk)) Pavements (+) (pavement present (over 50% of the route), width of pavement, continuous pavement (over 50% of the route), no pavement is there any other place to walk safe from traffic) Buffers (+) (buffer present, buffer over 50% of the route, how wide is the majority of the buffer) Pavement quality (−) (poorly maintained sections of pavement that constitute trip hazards) Pavement obstructions (−) (permanent obstructions, temporary obstructions)
Roads	Crossings (±) (mid-segment street crossing where an individual could safely cross (marked by a sign or crosswalk), intersection control, signalization, pre-crossing curb, post-crossing curb, gutters present in crossing, other characteristics, temporary obstructions, crossing aids, crosswalk treatment, high-visibility stripping, stop lines on road or additional crosswalk warnings, raised crosswalk, different material than road, features, protected refuge islands, one-way streets through crossing, curb extension, miscellaneous problems, poor condition of crossing surface, poor visibility at corners, faded or worn crosswalk markings Obstructions to walking (−) (railroad tracks, highway nearby, other) Bicycle lane/use (+) (marked bicycle lane, does the marked bicycle lane run for the entire route, a marked bicycle track separated from traffic and pedestrians, does the marked bicycle track run for the entire route, are there any signs indicating bicycle use)
Overall score	A summed score can be produced for liveability (Safety + Health + Sustainability + Inclusivity + Places + Education + Traffic/Transport + Pavements + Roads (except for those variables that are doubled scored in attributes (only counted once))

+: considered as a positive construct when investigating liveability; -: considered as a negative construct when investigating liveability.

3. Results

3.1. Belfast (city centre)

GSV data were available for 68 of the 76 streets (89.5%) pre-intervention, 73 of the 76 streets (96.1%) post-intervention and for 68 streets (89.5%) at both time points (i.e., pre-, and post-intervention).

Overall, results for the 68 streets showed a mean liveability score of 65.93 (standard deviation (*SD)* 18.31), increasing significantly to 67.31 (*SD*18.32) following the implementation of the 20mph speed limit intervention (Table 2).

The mean change between time-points was 1.38 (*SD*3.08) which was found to be significant at the level of $p < 0.001$ (Table 2). Of the streets audited, 57.4% (n = 39) were found to have a positive change (pre-to post-intervention) in total liveability, with 30.9% (n = 21) having no change and 11.8% (n = 8) having a negative change.

Table 2
Results for total liveability and the nine constructs of liveability.

	Belfast (n = 68 streets)			Edinburgh (n = 76 streets)		
	Pre-implementation	Post-implementation	Change	Pre-implementation	Post-implementation	Change
	Mean (SD)					
Total liveability	65.93 (18.31)	67.31 (18.32)	1.38 (3.08)*	56.97 (8.69)	59.11 (8.78)	2.38 (3.31)*
Safety[a]	11.07 (2.66)	11.16 (2.66)	0.09 (0.73)	12.78 (1.62)	12.84 (1.83)	0.07 (1.15)
Health[b]	7.72 (2.56)	7.78 (2.52)	0.06 (0.49)	6.50 (2.61)	6.59 (2.58)	0.08 (0.76)
Sustainability[c]	11.22 (4.74)	11.22 (4.50)	0.00 (0.79)	13.59 (3.00)	13.74 (2.98)	0.14 (1.22)
Inclusivity[d]	1.25 (0.74)	1.25 (0.74)	0.00 (0.00)	4.01 (1.07)	4.04 (1.16)	0.03 (0.28)
Places[e]	12.68 (5.11)	12.97 (5.44)	0.29 (1.43)*	10.89 (3.07)	11.11 (3.30)	0.21 (0.75)*
Education[f]	0.13 (0.38)	0.13 (0.38)	0.00 (0.00)	0.13 (0.38)	0.12 (0.36)	−0.01 (0.12)
Traffic/transport[g]	1.63 (1.37)	2.59 (1.83)	0.96 (1.09)*	3.13 (1.46)	4.58 (1.24)	1.45 (0.93)*
Roads[h]	12.96 (5.06)	12.93 (4.97)	−0.03 (0.55)	12.39 (3.90)	12.50 (3.74)	0.11 (0.58)
Pavements[i]	25.16 (6.92)	25.24 (6.43)	0.09 (2.58)	24.29 (3.44)	24.74 (3.50)	0.39 (1.43)*

SD: standard deviation; * significant difference between pre- and post-intervention scores $p < 0.05$.

[a] Safety: safety buttons, neighbourhood watch signs, physical disorder (presence and extent), presence of people, streetlights, telephones, information kiosks and eyes on the street.

[b] Health: pharmacy, health centre, alcohol outlets, presence of people, smoking areas, water, bicycle racks, leisure facilities, green/open space, hardscape/softscape features, landscaping, obstructions to walking and bicycle lane/use.

[c] Sustainability: rubbish bins, physical disorder (presence and extent), public transport, car charging points, green/open space, hardscape/softscape features, landscaping, benches, and trees.

[d] Inclusivity: mix of residential and non-residential, residential housing, places of work/commercial, education, places of worship and senior centre.

[e] Places: shops, restaurants, culture, post office, car parks, bank or credit union, other land use, entertainment, green/open space, leisure facilities, other services, building maintenance and aesthetics.

[f] Education: education and library/museum.

[g] Traffic/transport: public transport, speed signs, speed calming measures and traffic lanes.

[h] Pavements: street amenities, litter, obstructions to walking, streetlights, crossings, pavements, buffers, pavement quality and pavement obstructions.

[i] Roads: crossings, obstructions to walking and bicycle lane/use (Table 1).

When analysis was performed to determine change over time for each of the nine constructs of liveability, five were found to increase (i.e., safety, health, places, traffic/transport, and pavements) three remained the same (i.e., sustainability, inclusivity, and education) and one decreased (i.e., roads). However, only the constructs of traffic/transport (i.e., presence of public transport facilities, speed signage, speed calming measures and traffic lanes) ($p < 0.001$) and places (i.e., presence of amenities and facilities and building maintenance and aesthetics) ($p = 0.041$) increased significantly, pre-to post-intervention (n = 68 streets) (Table 2).

3.2. Edinburgh (Citywide)

Data from GSV was available for 91 of the 100 streets (91.0%) pre-intervention, 80 of the 100 streets (80.0%) post-intervention and for 76 streets (76.0%) at both time-points (i.e., pre-, and post-intervention).

Overall, results for the 76 streets showed a mean liveability score of 56.97 (*SD*8.69), which increased significantly to 59.11 (*SD*8.78) following the implementation of the 20mph speed limit intervention (Table 2). The mean change between time-points was 2.38 (*SD*3.31) (n = 76 streets) which was significant at the level of $p < 0.001$ (Table 2). Of the streets audited, 75% (n = 57) had a positive change (pre-to post-intervention) in total liveability, with 14.5% (n = 11) having no change and 10.5% (n = 8) displaying a negative change.

For each of the nine constructs of liveability: eight increased (i.e., safety, health, sustainability, inclusivity, places, traffic/transport, pavements and roads), although only three showed significant change (pre-to post-intervention): Places (as above) ($p = 0.017$); traffic/transport (as above) ($p < 0.001$); and pavements (i.e., street amenities, litter, obstructions to walking, street lights, crossings, pavement presence and quality, buffer presence and quality and pavement obstructions) ($p = 0.036$) (Table 2). One construct, education, was found to decrease.

3.2.1. Cluster analysis (Belfast and Edinburgh)

Across both cities, three clusters of varying sizes (31–73 streets, n = 144) were found. When mapped and the predominant street type identified the clusters were labelled as: *"Mixed land use"* (C1, n = 40) this cluster included streets with a variety of properties occupying the land (e.g., commercial, residential, business etc.); *"Central business district"* (C2, n = 31) streets within this cluster consisted of predominantly commercial and business properties; and *"Residential"* (C3, n = 73) properties within this cluster were predominantly residential.

1) Level of liveability post-implementation by cluster

The *"Central business district"* (C2) had significantly higher levels in comparison to *"Mixed land use"* (C1) and *"Residential"* (C3) for: total liveability, safety, health, places, road, and pavements ($p < 0.05$) (Table 3). In addition, *"Mixed land use"* (C1) had significantly higher levels in comparison to *"Residential"* (C3) for: total liveability, safety, health, sustainability, inclusivity, places, traffic/transport, roads, and pavements) ($p < 0.05$) (Table 3).

Table 3
Results for cluster analysis – Belfast and Edinburgh.

	C1: Mixed land use			C2: Central Business District			C3: Residential		
	n = 40 streets			n = 31 streets			n = 73 streets		
	Mean (SD)								
	Pre-	Post-	Change	Pre-	Post-	Change	Pre-	Post-	Change
Total liveability	60.95 (10.45)	62.83 (9.82)[b]	1.88 (3.37) *	80.45 (9.01)	82.06 (9.65)[a]	1.61 (2.16) *	53.16 (10.61)	54.96 (10.63)	2.05 (3.55) *
Safety	12.58 (1.69)	12.60 (1.68)[b]	0.03 (1.14)	12.68 (1.54)	12.94 (1.95)[a]	0.26 (1.09)	11.34 (2.72)	11.37 (2.72)	0.03 (0.80)
Health	7.28 (2.64)	7.30 (2.53)[b]	0.00 (0.85)	9.55 (2.38)	9.58 (2.41)[a]	0.03 (0.18)	5.92 (1.93)	6.04 (1.97)	0.12 (0.64)
Sustainability	13.58 (3.15)	13.68 (3.07)[b]	0.10 (1.19)	14.10 (4.18)	14.32 (3.72)[b]	0.23 (1.48)	11.18 (4.11)	11.18 (4.06)	0.00 (0.67)
Inclusivity	3.68 (1.59)	3.73 (1.66)[c]	0.05 (0.32)	1.81 (1.35)	1.84 (1.46)	0.03 (0.18)	2.56 (1.58)	2.55 (1.57)	−0.01 (0.12)
Places	12.18 (3.34)	12.35 (3.24)[b]	0.18 (0.87)	16.71 (3.13)	17.45 (3.56)[a]	0.74 (1.84) *	9.38 (3.03)	9.47 (3.20)	0.08 (0.72)
Education	0.18 (0.38)	0.15 (0.36)	−0.02 (0.16)	0.16 (0.37)	0.16 (0.37)	0.00 (0.00)	0.10 (0.38)	0.10 (0.38)	0.00 (0.00)
Traffic/ transport	3.08 (1.67)	4.35 (1.33)[b]	1.27 (0.96) *	2.71 (1.92)	3.84 (2.07)	1.13 (0.99) *	1.95 (1.25)	3.16 (1.85)	1.22 (1.10) *
Roads	12.80 (3.24)	12.85 (3.19)[b]	0.05 (0.50)	17.16 (3.53)	16.97 (3.41)[a]	−0.19 (0.60)	10.67 (4.02)	10.81 (3.97)	0.14 (0.56) *
Pavements	24.78 (3.18)	25.23 (2.71)[b]	0.37 (1.50)	29.52 (2.67)	29.35 (2.93)[a]	−0.16 (1.10)	22.62 (5.86)	22.97 (5.61)	0.36 (2.56)

[a]Significantly higher than both C1 and C3; [b]Significantly higher than C3; [c]Significantly higher than C2 and C3; *significant increase pre-to post-implementation ($p < 0.05$).

2) Changes (i.e., pre-to post-implementation) in liveability within clusters

When analyzing changes pre-to post-implementation of the 20mph speed limit interventions within each cluster, total liveability and the construct of traffic/transport were found to increase significantly over time for each of the three clusters ($p < 0.05$) (Table 3). With the constructs of places and roads also significantly increasing for the "*Central business district*" (C2) and "*Residential*" (C3) clusters consecutively ($p < 0.05$) (Table 3)

3) Changes (i.e., pre-to post-implementation) in liveability between clusters

When the changes that were observed within each cluster (pre-to post-implementation) for total liveability and the liveability constructs were assessed between clusters, analysis showed that the magnitude of the changes did not differ significantly across clusters ($p > 0.05$) (Table 3).

4. Discussion

To our knowledge, this study is the first to investigate the impact of 20mph speed limit interventions on total liveability and the nine constructs of liveability using MAPS-Liveability via GSV (Cleland et al., 2021a). Our results highlight that whilst 20mph speed limit interventions have been conceptualized as transport/built environment interventions with the aim of directly impacting traffic speed and the rate and severity of collisions and casualties, they may also have the capability to positively impact liveability. This study adds to the limited evidence base, as it demonstrates that 20mph speed limit interventions (i.e., city centre and citywide), can positively contribute to total liveability and the liveability construct of traffic/transport. The significant findings from two UK cities support the hypothesis that by implementing an intervention specifically aimed at improving one construct of liveability (i.e., traffic/transport) it may also be possible to positively contribute to improved total liveability. The findings also support a previous study that demonstrated how 20mph speed limit interventions were perceived to result in the outcome of improved liveability through the mechanism of reduced driving speed and the implementation of 20mph speed limit interventions (i.e., Traffic Orders, signage, enforcement and awareness and educational campaigns) (Cleland et al., 2021b).

In addition, the potential to impact positively on total liveability and the liveability construct of traffic/transport is promising, particularly from a public health perspective. The current evidence base demonstrates that when places are 'liveable' they can facilitate the uptake and maintenance of healthy behaviours, including a reduction in sedentary time and increased levels of active travel (i.e., walking and/or cycling), physical activity (e.g., outdoor play) and socializing (Giles-Corti et al., 2014; Cleland et al., 2019). Consequently, the implementation of 20mph speed limit interventions may have the capacity to contribute positively to various aspects of physical and mental health through the mechanism of improved liveability. This could include the promotion and uptake of active travel (i.e., walking and/or cycling) through safer street conditions, particularly for cyclists, and a reduction in the severity of collisions and casualties (Cleland et al., 2021b). Furthermore, 20mph speed limit interventions may also provide support for better mental health and well-being through decreased levels of stress and reduced social isolation and loneliness when traffic speed, volume, and pollution (i.e., noise and air) are reduced (Hart and Parkhurst, 2011; Giles-Corti et al., 2014; Holt-Lunstad et al., 2015).

4.1. Cluster analysis

Cluster analysis (k-medians) successfully identified three clusters which differentiated the following types of streets based on the baseline MAPS-Liveability data: "*Mixed land use*" (C1), "*Central business district*" (C2) and "*Residential*" (C3). These clusters demonstrated meaningful variability in relation to total liveability and the nine liveability constructs following the implementation of 20mph speed limit interventions. When reviewing the clusters, those with the dense mixed land use (i.e., "M*ixed land use" (C1)* and *"Central business district" (C2)*) were found to have the highest levels of liveability and presented the greatest level of services, amenities, and facilities, with good quality roads and pavements. Following the implementation of the 20mph speed limit interventions, the construct of traffic/transport increased significantly for each of the clusters. These findings in combination indicate that 20mph speed limit interventions could contribute to improved total liveability and the construct of traffic/transport when they are implemented as a blanket intervention across a city or within a city centre. The differing nature of the three identified clusters has also shown that regardless of street type (e.g., busy streets with dense and mixed land use that are highly accessible by various modes of transport (e.g., public transport, active travel) versus residential streets), 20mph speed limits may have the capacity to instigate significant positive changes to liveability and the construct of traffic/transport.

However, when reviewed by magnitude of effect, the *"Residential"* cluster *(C3)* had the lowest levels of liveability in comparison to (*"Mixed land use"* (C1), *"Central business district"* (C2)). Therefore, it could be surmised that to instigate greater changes in liveability and the consequential intended public health outcomes on residential streets, it may require more than one standalone intervention (i.e., 20mph speed limit intervention). This finding is supported by previous research which highlighted that 20mph speed limit interventions as stand-alone interventions have yet to demonstrably facilitate healthful and sustainable changes in mode of transport (i.e., shifting from driving a private motorized vehicle to cycling) therefore, other forms of environmental regeneration/rejuvenation and interventions should be considered in combination with 20mph speed limit interventions for the greatest effect (Cleland et al., 2021b). For instance, as *"Residential"* streets (C3) are used by both pedestrians and motorized vehicles, there is the potential to repurpose these streets by segregating walking and cycling routes and designating activity spaces. Interventions such as this have been implemented in parts of London where the concept of cycle superhighways is emerging and in Barcelona where the strategic superblock plan aims to

turn 1 in 3 streets green by implementing traffic calming measures, and spaces for play and recreation. If implemented multi-faceted approaches which include 20mph speed limit interventions on *"Residential"* streets may have the greatest impact by challenging perceptions, generating healthful and sustainable modal shifts, and ultimately improving health and well-being. By linking 20mph speed limit interventions with other environmental and traffic/transport interventions, this may have the greatest impact on a range of public health outcomes through direct and indirect mechanistic pathways and avoid the occurrence of unintended consequences (Cleland et al., 2021b).

4.2. Implications for future research, policy, and practice

Considering that transport related accidents contribute 2.3% yearly (1.3 million deaths per year, averaging 2500 deaths per day) to the global causes of death the implementation of 20mph (30 km per hour) speed limit interventions could directly impact a range of public health outcomes (Roser, 2021). In addition, 20mph speed limit interventions should also be considered for implementation globally due to their potential to improve public health through mechanistic pathways such as improved liveability, particularly the liveability construct of traffic/transport. Furthermore, when aiming to achieve the greatest impact in relation to liveability, implementation priority should be given to streets that have dense mixed land use, to witness the greatest levels of change. For streets that have limited land use mix (e.g., residential streets) it is recommended that 20mph speed limit interventions be implemented in combination with other traffic/transport or environmental interventions (e.g., segregated bicycle lanes).

When the implications of MAPS-Liveability are considered in relation to future research, policy, and practice, it is plausible to suggest that those aiming to investigate streetscapes should contemplate its use. MAPS-Liveability has not only demonstrated excellent inter-rater reliability for total liveability, but it has also shown that it is sensitive to change and can capture change in liveability over time following the implementation of an environmental intervention (Cleland et al., 2021a). Therefore, it is possible to recommend the use of MAPS-Liveability via GSV as a reliable, acceptable, and feasible method of assessing total liveability and the constructs of liveability following the implementation of environmental interventions (e.g., 20mph speed limits intervention, street rejuvenation projects, school streets) or when aiming to carry out assessments at one point in time (e.g., low traffic neighbourhoods).

4.3. Strengths and limitations

Strengths of our study include the implementation of MAPS-Liveability via GSV. This newly developed tool was specifically designed to assess liveability at the level of the street and to provide an assessment of micro-level environmental attributes that contribute to liveability. In addition, MAPS-Liveability was found to have good-excellent reliability for use with GSV and the capability of offering a quantitative assessment of liveability and its constructs over time at lower geographical levels (i.e. the street). It also facilitated pre-intervention data to be collected, allowing pre- and post-intervention comparisons to be made (Cleland et al., 2021a). Furthermore, where available, data for each of the 20mph streets in Belfast and a stratified sample of 20mph streets in Edinburgh were assessed for liveability and the nine liveability constructs.

A notable limitation of the current study is the lack of control area data. In addition, limitations of the study and the use of GSV include: the impossibility of assessing attributes such as air or noise pollution, or perceived safety; temporality (i.e. an image is one point in time and it is not possible to know the exact time, day or date); contemporality (i.e., time lapses between GSV images and data collection); and the inability to match time-points by time, day, month etc. Finally, when performing evaluations such as this, that consider a traffic/transport intervention that sits within the complex transport/environmental system, caution should be exercised when interpreting the results. For example, the improvements in liveability may not solely be attributable to the 20mph speed limit intervention. During the course of both the Belfast and Edinburgh 20mph speed limit interventions, other transport/environmental changes occurred in each city (i.e., increases in the quality and quantity of cycle lanes; pedestrianisation; the implementation of a rapid transport system (the Glider); development of public transport infrastructure (i.e., bus (Belfast) and tram (Edinburgh) lanes); and the regeneration of several public amenities and facilities (e.g., a shopping centre, seating areas, artwork).

5. Conclusions

Our findings provide evidence for the contribution of 20mph speed limit interventions to improving liveability and specifically the liveability construct of traffic/transport. Policy makers and practitioners should consider the implementation of 20mph speed limit interventions to improve liveability. For the greatest impact on liveability, 20mph speed limit interventions should be focused on streets that have dense mixed land use, or when implementing on streets with limited land use (e.g., residential) 20mph speed limits could be implemented in combination with other public health promoting environmental interventions.

CRediT authorship contribution statement

Claire L. Cleland: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Andrew J. Williams:** Formal analysis, Funding acquisition, Investigation, Methodology, Writing – review & editing. **Frank Kee:** Funding acquisition, Writing – review & editing. **Ruth Jepson:** Funding acquisition, Writing – review & editing. **Michael P. Kelly:** Funding acquisition, Writing – review & editing. **Karen Milton:** Funding acquisition, Writing – review & editing. **Glenna Nightingale:** Writing – review & editing. **Andy Cope:** Funding acquisition, Writing – review & editing. **Ruth F. Hunter:** Conceptualization, Funding acquisition, Methodology, Project

administration, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix 1. MAPS-Liveability Scoring Protocol

MAPS-Liveability	Characteristics	MAPS-Liveability subscale	Liveability attribute scores	Liveability total score (adjusted)
Safety	**A6 -** Safety buttons (+)	Safety button connecting to police (No = 0, Yes = 1)	**21**	**21**
	A6 - Neighbourhood watch (+)	Neighbourhood watch signs (No = 0, Yes = 1)		
	A6 – Physical disorder (±)	Graffiti/tagging (not murals or street art) (No = 1, Yes = 0) + Abandoned cars (No = 1, Yes = 0) + Buildings with broken/boarded windows (No = 1, Yes = 0) + Drug paraphernalia (No = 1, Yes = 0) + Broken glass (No = 1, Yes = 0) + Beer/liquor bottles/can (No = 1, Yes = 0)		
	A7 – Physical disorder (−)	Rate the extent of physical disorder (None = 3, A little = 2, Some = 1, A lot = 0)		
	A9-12 - Presence of people (+)	Presence of anyone walking (No = 0 Yes = 1) + Presence of anyone running (No = 0, Yes = 1) + Presence of anyone cycling (No = 0, Yes = 1) + Presence of anyone performing other physical activity or exercising (No = 0, Yes = 1)		
	SS6 - Street lights (+)	Are street lights installed (No = 0, Some = 1 (e.g., overhead street lights on utility poles with wide spacing) or Ample = 2 (e.g., regularly spaced pedestrian lampposts)		
	SS8 – Telephones (+)	Working public telephones (No = 0, Yes = 1)		
	SS8 – Information (+)	Kiosks or information booths (No = 0, Yes = 1)		
	P19 – Eyes on the street (+)	Estimate the proportion of street segment that has ground floor or street-level windows within 40 feet of the pavement/walkway (or street if no pavement/walkway) (No windows – 25% = 0 26%–75% = 1 > 76% = 2)		
Health	**LU5 -** Pharmacy (+)	Pharmacy or drug store (No = 0, Yes = 1)	**35**	**31**
	LU5 - Health centre (+)	Health-related professional (No = 0, Yes = 1) + Health or social services (No = 0, Yes = 1)		
	LU5 - Alcohol (−)	Liquor/alcohol store (No = 1, Yes = 0)		
	A9-12 – People performing activity (+)	Presence of anyone walking (No = 0, Yes = 1) + Presence of anyone running (No = 0, Yes = 1) + Presence of anyone cycling (No = 0, Yes = 1) + Presence of anyone performing other physical activity or exercising (No = 0, Yes = 1)		
	SS8 - Smoking areas (−)	(No = 1, Yes = 0)		
	SS8 – Water (+)	Working drinking fountain (No = 0, Yes = 1)		
	SS8 – Bicycle racks (+)	Bicycle racks (No = 0, Yes = 1)		
	LU5 – Leisure facilities (+)	Private indoor (No = 0, Yes = 1) + Public indoor (No = 0, Yes = 1) + Private outdoor (No = 0, Yes = 1) + Public outdoor pay (No = 0, Yes = 1)		
	LU5 – Green & open space (+)	Public park (No = 0, Yes = 1) + Public walking trail (No = 0, Yes = 1) + Community garden (No = 0, Yes = 1)		
	A1-2 – Hardscape & softscape features (+)	Do you observe pleasant hardscape features such as fountains, sculptures or art (public or private (No = 0, Yes = 1) + Do you observe softscape features such as gardens or landscaping (e.g., Public: bodies of water, designated viewpoints; Private: retaining walls, bark, ponds) (No = 0, Yes = 1)		
	A5 – Landscaping maintenance	Is landscaping well maintained (0–99% = 0, 100% = 1)		

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MAPS-Liveability	Characteristics	MAPS-Liveability subscale	Liveability attribute scores	Liveability total score (adjusted)
	A8 – Obstructions to walking (−)	Railroad tracks (No = 1, Yes = 0) + Highway nearby (No = 1, Yes = 0) + Other (No = 1, Yes = 0)		
	P14, 15 – Bicycle lane/use (+)	Is there a marked bicycle lane marked with a lane (No = 0, Yes = 1) + Does the marked bicycle lane run for the entire route (100% = 4; 75–99% = 3; 51–75% = 2; 25–50% = 1; 1–25% = 0) + Is there a marked bicycle track separated from traffic and pedestrians (No = 0, Yes = 1) + Does the marked bicycle track run for the entire route (100% = 4; 75–99% = 3; 51–75% = 2; 25–50% = 1; 1–25% = 0) + Are there any signs indicating bicycle use (No = 0, Yes = 1)		
Sustainability	**SS8 –** Rubbish bins (+)	Rubbish bins (public) (No = 0, Yes = 1)	**33**	**14**
	A6 – Physical disorder (±)	Graffiti/tagging (not murals or street art) (No = 1, Yes = 0) + Abandoned cars (No = 1, Yes = 0) + Buildings with broken/boarded windows (No = 1, Yes = 0) + Drug paraphernalia (No = 1, Yes = 0) + Broken glass (No = 1, Yes = 0) + Beer/liquor bottles/can (No = 1, Yes = 0) + Litter in yards (No = 1, Yes = 0) + Noticeable/excessive litter in street/pavement (No = 1, Yes = 0) + Neighbourhood watch signs (No = 0, Yes = 1) + Signage for commercial destinations or parks (No = 0, Yes = 1) + Safety button connecting to police (No = 0, Yes = 1)		
	A7 – Physical disorder (−)	Rate the extent of physical disorder (None = 3, A little = 2, Some = 1, A lot = 0)		
	SS1 - Public transport (+)	If answered 1 or more to **SS1a-c** (No = 0, Yes = 1 (**SS1a or SS1b or SS1c),** Yes = 2 **(two from SS1a-c**) or Yes = 3 (**each of SS1a-c)**		
	SS8 - Car charging (+)	Car charging points (No = 0, Yes = 1)		
	LU5 – Green & open space (+)	Public park (No = 0, Yes = 1) + Public walking trail (No = 0, Yes = 1) + Community garden (No = 0, Yes = 1)		
	A1-2 – Hardscape & softscape features (+)	Do you observe pleasant hardscape features such as fountains, sculptures or art (public or private (No = 0, Yes = 1) + Do you observe softscape features such as gardens or landscaping (e.g., Public: bodies of water, designated viewpoints; Private: retaining walls, bark, ponds) (No = 0, Yes = 1)		
	A5 – Landscaping maintenance (+)	Is landscaping well maintained (0% = 0, 1–49% = 1, 50–99% = 2, 100% = 3)		
	SS8 - Benches (+)	Benches or other places to sit (No = 0 Yes = 1)		
	P23–25 – Trees (+)	How many trees exist within 5 ft of either side of the pavement/ pathway (No pavement/NA = 0, 0–1 trees = 0, 2–10 trees = 1, >11 trees = 2) + How are the trees generally spaced (Irregular or no sidewalk/NA = 0, Evenly = 1) + What percentage of the length of the pavement/walkway is covered by trees, awnings or other overhead coverage (No coverage or no sidewalk/NA and ≤25% = 0, 26%–75% = 1, >75% = 2)		
Inclusivity	**LU2 -** Mix of residential and non-residential (+)	If answered Yes to any of LU2a-f plus any of LU5 a-ae or LU6 a-c No = 0, Yes = 1)	**11**	**11**
	LU2 - Residential houses (+)	Single family homes (No = 0 Yes = 1) + Multi-unit homes (No = 0 Yes = 1) + Apartments or flats (No = 0, Yes = 1) + Apartments/ flats above street retail (No = 0, Yes = 1) + Retirement/senior living facility (No = 0, Yes = 1) + Other (No = 0, Yes = 1)		
	LU5 - Places of work/ commercial (+)	If answered 1 or 2+ to any of LU5 or LU6 (No = 0, Yes = 1) (excluding LU5v,w,y,ae)		
	LU5 - Education (+)	School (No = 0, Yes = 1)		
	LU5 - Place of worship (+)	Place of worship (No = 0, Yes = 1)		
	LU5 – Senior Centre (+)	Senior Centre (No = 0, Yes = 1)		
Places	**LU5 and LU6 -** Shops (+)	Grocery/supermarket (No = 0, Yes = 1) + Convenience store (No = 0, Yes = 1) + Big box store (No = 0, Yes = 1) + Specialty food store (No = 0, Yes = 1) + Other retail (No = 0, Yes = 1) + Shopping centre (No = 0, Yes = 1) + Strip mall (No = 0, Yes = 1) + Shopping arcade (No = 0, Yes = 1)	**40**	**33**
	LU5 - Restaurants (+)	Fast food restaurant (No = 0, Yes = 1) + Sit-down restaurant (No = 0, Yes = 1) + Café or coffee shop (No = 0, Yes = 1)		
	LU5/A3 - Culture (+)	Library/Museums (No = 0, Yes = 1) + Are there observable historic or cultural features along the route (statues, murals etc.) (No = 0, Yes = 1)		
	LU5 - Post office (+)	Post office (No = 0, Yes = 1)		
	LU1 - Car parks (±)	On-street, parallel (No = 0, Yes = 1) – Small lot or garage (<30 spaces) (No = 0, Yes = 1) – Medium to large lot or garage (No = 0, Yes = 1)		
	LU5 - Bank (+)	Bank or credit union (No = 0, Yes = 1)		

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MAPS-Liveability	Characteristics	MAPS-Liveability subscale	Liveability attribute scores	Liveability total score (adjusted)
	LU5 – Other land use (−)	Warehouse/factory/industrial (No = 1, Yes = 0) + Abandoned building (No = 1, Yes = 0) + Unmaintained lot/field (No = 1, Yes = 0)		
	LU5 - Entertainment (+)	Entertainment (No = 0, Yes = 1) + Casino (No = 0, Yes = 1)		
	LU5 – Green & open space (+)	Public park (No = 0, Yes = 1) + Public walking trail (No = 0, Yes = 1) + Community garden (No = 0, Yes = 1)		
	LU5 - Leisure facilities (+)	Private indoor (No = 0, Yes = 1) + Public indoor (No = 0, Yes = 1) + Private outdoor (No = 0, Yes = 1) + Public outdoor pay (No = 0, Yes = 1)		
	LU5 – Other services (+)	Other service (No = 0, Yes = 1)		
	A4 – Building maintenance (+)	Are the buildings well maintained (0% = 0, 1–49% = 1, 50–99% = 2, 100% = 3)		
	P20–22 Aesthetics (+)	How many different predominant building façade colors exist on the route (No building/NA or 1 color = 0, 2–3 colors = 1, >4 colors = 2) + How many different building accent colors exist on the route (No building/NA or 1 color = 0, 2–3 colors = 1, >4 colors = 2) + How many different predominant building materials exist along the route (No building/NA or 1 color = 0, 2–3 colors = 1, >4 colors = 2)		
Education	**LU5 -** Schools (+)	School (No = 0, Yes = 1)	**2**	**0**
	LU5 – Library/Museums (+)	Library/Museums (No = 0, Yes = 1)		
Traffic/ transport	**SS1 -** Public transport (+)	If answered 1 or more to **SS1a-c** (No = 0, Yes = 1 (**SS1a or SS1b or SS1c),** Yes = 2 **(two from SS1a-c**) or Yes = 3 (**each of SS1a-c)**	**15**	**12**
	SS3-4 - Speed signs (+)	Posted speed limit signs (No = 0, Yes = 1) + 20mph speed limit signs (No = 0, Yes = 1) + special zone speed limit signs (No = 0, Yes = 1)		
	SS5 - Speed calming measures (+)	Traffic calming signs (No = 0, Yes = 1) + Traffic calming circles (No = 0, Yes = 1) + Traffic calming speed tables (No = 0, Yes = 1) + Traffic calming speed humps (No = 0, Yes = 1) + Traffic calming curb extension (No = 0, Yes = 1) + Instructional signs for pedestrian's (No = 0, Yes = 1) + Crosswalk signage or other pedestrian signage (for drivers) (No = 0, Yes = 1)		
	P10–11 – Traffic lanes (−)	Number traffic lanes (1–4 = 1, >5 = 0) + Is the street predominantly one-way to two-way (One-way = 0, Two-way = 1)		
Pavements	**SS8 -** Street amenities (+)	Building overhangs that provide shelter from inclement weather in public space (No = 0, Yes = 1) + Rubbish bins (public) (No = 0, Yes = 1) + Benches or other places to sit (No = 0, Yes = 1) + Bicycle racks (No = 0, Yes = 1), Working drinking fountain (No = 0, Yes = 1) + Working public telephones (No = 0, Yes = 1) + Kiosks or information booths (No = 0, Yes = 1) + Car charging points (No = 0, Yes = 1)	**42**	**30**
	A6 – Litter in street/ pavements (−)	Noticeable/excessive litter in street/pavement (No = 1, Yes = 0)		
	A8 – Obstructions to walking (−)	Railroad tracks (No = 1, Yes = 0) + Highway nearby (No = 1, Yes = 0) + Other (No = 1, Yes = 0)		
	SS6 - Street lights (+)	Are street lights installed (No = 0, Some = 1 (e.g., overhead street lights on utility poles with wide spacing) or Ample = 2 (e.g., regularly spaced pedestrian lampposts)		
	SS9 - Crossings (+)	Mid-segment street crossing where an individual could safely cross (marked by a sign or crosswalk) (No = 0, Yes = 1)		
	P1-2,4, 12 – Pavements (+)	Pavement present (No = 0, Yes = 1) + pavement over 50% of the route (No = 0, Yes = 1) + width of pavement (<3 ft = 1, 3–5 ft = 2, >5 ft = 3, no pavement = 0) + continuous pavement (No = 0, No pavement = 0, Yes = 1) + pavement over 50% of the route (No = 0, Yes = 1) + If no pavement is there any other place to walk that is safe from traffic (Yes = 1, No = 0, N/A pavement present = 1)		
	P3 – Buffers (+)	Buffer present (No = 0, Yes = 1) + buffer over 50% of the route (No = 0, Yes = 1) + how wide is the majority of the buffer (<3 ft = 1, 3–5 ft = 2, >5 ft = 3, N/A = 0)		
	P5 – Pavement quality (−)	Poorly maintained sections of pavement that constitute trip hazards (e.g., heaves, misalignment, cracks, overgrowth): minor – moderate (none = 4, One = 3, A few = 2, A lot = 1, No pavement = 0) + major (none = 4, One = 3, A few = 2, A lot = 1, No pavement = 0)		
	P8-9 – Pavement obstructions (−)	Permanent obstructions (None = 3, Some = 2, Many = 1, No pavement = 0) + temporary obstructions (None = 3, Some = 2, Many = 1, No pavement = 0)		
Roads	**SS9, C1, 3–7, 10, 11 -** Crossings (±)	Mid-segment street crossing where an individual could safely cross (marked by a sign or crosswalk) (No = 0, Yes = 1) + Intersection control (Yield sign = 1 + Stop signs = 1 + Traffic signal = 1 +	**41**	**26**

(*continued on next page*)

(*continued*)

MAPS-Liveability	Characteristics	MAPS-Liveability subscale	Liveability attribute scores	Liveability total score (adjusted)
		Traffic circle = 1) + Signalization (Green arrows for dedicated vehicle turn = 1 + Pedestrian walk signals = 1 + Push buttons = 1) + Pre-crossing curb (Ramp lines up w/xing = 1, Ramp doesn't line up = 0, No ramp = 0) + Post-crossing curb (Ramp lines up w/xing = 1, Ramp doesn't line up = 0, No ramp = 0) + Gutters present in crossing (No = 1, Yes = 0) + Other characteristics (Steep slope No = 1, Yes = 0) + Temporary obstructions (No = 1, Yes = 0) + Crossing aids (No = 0, Yes = 1) + Crosswalk treatment (Marked crosswalk No = 0, Yes = 1) + High-visibility striping (No = 0, Yes = 1) + Stop lines on road or additional crosswalk warnings (No = 0, Yes = 1) + Raised crosswalk (No = 0, Yes = 1) + Different material than road (No = 0, Yes = 1) + Features (Specifically identified lanes turning into crossing No = 0, Yes = 1) + Protected refuge islands (No = 0, Yes = 1) + One-way streets through crossing (No = 0, Yes = 1) + Curb extension (No = 0, Yes = 1) + Miscellaneous problems (Lack of lampposts or overhead street lamps No = 1, Yes = 0) + Poor condition of crossing surface (No = 1, Yes = 0) + Poor visibility at corners (No = 1, Yes = 0) + Faded or worn crosswalk markings (No = 1, Yes = 0)		
	A8 – Obstructions to walking (−)	Railroad tracks (No = 1, Yes = 0) + Highway nearby (No = 1, Yes = 0) + Other (No = 1, Yes = 0)		
Is there a marked bicycle lane marked with a lane (No = 0, Yes = 1) + Does the marked bicycle lane run for the entire route (100% = 4; 75–99% = 3; 51–75% = 2; 25–50% = 1; 1–25% = 0) + Is there a marked bicycle track separated from traffic and pedestrians (No = 0, Yes = 1) + Does the marked bicycle track run for the entire route (100% = 4; 75–99% = 3; 51–75% = 2; 25–50% = 1; 1–25% = 0) + Are there any signs indicating bicycle use	**P14, 15** – Bicycle lane/use (+)			

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MAPS-Liveability	Characteristics	MAPS-Liveability subscale	Liveability attribute scores	Liveability total score (adjusted)
(No = 0, Yes = 1)				
Overall score	A summed score can be produced for liveability	Safety + Health + Sustainability + Inclusivity + Places + Education + Traffic/Transport + Pavements + Roads (with the exception of those variables that are doubled scored in attributes (only counted once)) (highlighted in grey)	**N/A**	**178**

Items not used in scoring protocol but can be dependent on the study aims and objectives: **LU3** (How many non-residential buildings are adjacent to the pedestrian walkway or sidewalk and/or street? 0% = 1 1–33% = 2 34–66% = 3 67–99% = 4100% = 5 N/A (all residential) = 6 N/A (no walkway) = 7); LU**4** (How many of the non-residential buildings have parking lots or drives between the pedestrian walkway or sidewalk along the street and their entrances? 0% = 1 1–33% = 2 34–66% = 3 67–99% = 4100% = 5 N/A (all residential) = 6 N/A (no walkway) = 7); **SS5f-g** (What other street characteristics are present? Roll-over curbs, drainage ditches; **SS7** (How many driveways or alleys are there? None, 1–2, 3–5 or 6+; **P6a** (How steep is the pavement at the steepest point in the route (_degrees, no pavement)); **P6b** (How much of the route is at or near this level of steepness? Little 1–25%, some 26–75%, most or all 76–100%, no pavement); **P6c** (If answer to 6(b) is "little" provide a steepness measure that represents the majority of the route __degrees, no pavement or N/A); **P7** (What is the steepest unavoidable cross-slope that affects walkers?_ degrees, no pavement); **P13** (If no pavement, what is the width of the place on which one could safely walk? (not in possible path of traffic) None, <4 ft, >4 ft, N/A); **P16 (**Are there any signs or structures discouraging skateboard usage Yes, No); **P17** (Is there an informal path (shortcut), not on a cul-de-sac, which connects to something else Yes, No); **P18a/18b** – (is this a dead-end street Yes, No) Is there a paved or informal path at the end of the cul-de-sac or dead end street that connects to something else (Yes, No, N/A); **P26–28** (What is the smallest building setback from the pavement/What is the largest building setback from the pavement (no building, <10 feet, 10–20 feet, 21–50 feet, 51–100 feet, >100 feet), What is the average height of buildilngs, No building, 1-2 stories, 3-5 stories, 6-10 stories, >10 stories); **C2** (Number of legs at intersection, T-intersection, 4-way intersection, > 4-ways, N/A); **C8** (Bike lane crosses the crossing Yes, No); **C9** (Distance of crossing leg, including all potential parking and turn lanes___ lanes wide); **C11** (Unanticipated mid-segment crossing, Other__), **SS2 –** Public transport facilities (+).

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