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Pedestrian crossings: Design recommendations do not reflect users' experiences in a car-dominated environment in Auckland, New Zealand

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ABSTRACT

Pedestrian crossings are a staple of city design and a key feature both in terms of risk of road trauma and impacts on pedestrian experience. In car-dominated environments, the challenge is in retrofitting existing infrastructure to enable and encourage walking. It is unclear what diverse people might find difficult and to what extent existing design recommendations identify those needs.

This study aims to provide a real-world perspective on local design guidelines and the Healthy Streets metrics, by triangulating them with objective measures of the built environment and users' perceptions of unfeasibility or difficulty. The study builds on previous research having identified non-signalised crossing points experienced by interview participants (half of whom were disabled) as barriers to access. These non-walkable crossings are characterised objectively, using a range of potentially relevant metrics and specific thresholds. The study then sought the simplest way to describe those crossings, identifying the importance of three metrics: (a) peak-hour traffic; (b) complexity; and (c) turning radii for traffic. The results also identified important gaps in local design guidelines and Healthy Streets metrics, which are currently not set up to enable cities to easily identify these difficult crossings.

These findings are important because they can be used to identify crossings that are likely to cause difficulties walking and should be retrofitted to support walking. They also provide indications of complementary information needed to improve local guidelines and Healthy Streets metrics to enable them to support proactive retrofit.

1. Introduction

In an increasingly urbanised world, cities are major actors in climate action, particularly through more sustainable transport systems (C40 Cities, 2018; Masson-Delmotte et al., 2018; United Nations, 2015). A modal shift from driving to walking, public transport, and cycling is a key aspect of addressing global heating (Masson-Delmotte et al., 2018). This shift also presents major and now well understood benefits in terms of public health, well-being, equity of access, and liveability (Haines et al., 2009; Sallis et al., 2016; Woodcock et al., 2009).

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Enabling and encouraging walking requires rethinking and retrofitting street environments (United Nations Environment Programme, 2021, p. 13) to remove existing barriers (Burdett, 2016; Giles-Corti et al., 2016) and redesign environments that can be hostile to or difficult for walking (Bozovic, 2021; Gehl, 2010). Following the SDG "leave no one behind" ethos, change should reduce the inequities of access (UN Sustainable Development Group, n.d.).

Despite a research interest in walkability, especially in the last 15 years, there is to date no consensus on what "walkable" means, who experiences barriers, and what these barriers are (Bozovic et al., 2020; Forsyth, 2015). There is a certain agreement on basic requirements, namely the availability of everyday destinations, the absence of barriers to access, and perceived safety (Forsyth, 2015). The body of evidence also shows a growing acknowledgement of individual experiences and characteristics, suggesting that they moderate the associations between the walking environment, the broader transport system, and walking behaviours (Alfonzo, 2005; Bozovic et al., 2020; Mehta, 2008). The walking environment should be understood beyond sidewalks, to include the street environments including the built features, design and maintenance; the operation systems such as traffic lights; the natural features; and the human presence and activity) and the transport system (encompassing provision for driving, public transport, and bicycle riding) (Alfonzo, 2005; Bozovic, 2021; Herrmann et al., 2017; Mehta, 2008).

Improving the walking environment requires compensating for a historical lack of evidence regarding the barriers to walking experienced by people across age or disability status (Burdett & Thomas, 2020; Meher et al., 2021) and improving the measurement of perceived walkability – to date it is "often inadequate", namely overlooking evidence from demographics groups at risk of transport disadvantage (namely older and disabled people) (De Vos et al., 2023, p. 315) and characterised by uncertainties regarding how environmental features influence experiences and behaviours (Bozovic et al., 2020; Orstad et al., 2017) and how individual characteristics moderate those relationships (Bigonnesse et al., 2018; Eisenberg et al., 2017; Stafford & Baldwin, 2017). Cities manage budgets and workforce dedicated to the design and retrofit of streets, but the evidence status means that it is unclear if the improvements made are addressing the most acutely experienced barriers. A recent study examining the case of Auckland, New Zealand suggested a disconnect between action plans and experienced walkability (Bozovic et al., 2021b).

This study focuses on non-signalised crossings, important both in terms of pedestrian experience (Bozovic et al., 2021a; Meher et al., 2021; Mindell & Karlsen, 2012; Transport for London & Mayor of London, 2018) and road trauma (Howard, 2018; Tse et al., 2023). In Auckland, while the proportion of non-signalised crossings was not identified, it is estimated that they are majority, given that an estimate indicates that over 99 % of intersections are non-signalised (see supplementary file B).

This study was designed to **better understand which features and/or factors make crossings *not* walkable** for adults of diverse ages, disabled or not. The features of the walking environment that are seen by the users as difficult, unpleasant, or non-traversable, in a car-oriented environment are examined and characterised. The study builds on data previously collected through interviews in which 56 participants, half of whom were disabled, reported the specific features of the walking environment they experience as barriers (Bozovic et al., 2021a). Non-signalised crossings were the most frequently noted type of environmental barrier (Bozovic et al., 2021a). This study (a) characterises the non-signalised crossings flagged by participants as difficulties or barriers to walking and (b) explores the appropriateness of guidelines to spot these crossings. Triangulating objective measures, user perceptions, and guidelines, the study aspires to help develop recommendations on the priorities of retrofit for pedestrian crossings, and inform improvement in guidelines and assessment of these. Therefore the aims of the study were to:

1. **Characterise objectively the crossings perceived as difficult or non-walkable**, providing insight for retrofit.
2. **Examine the appropriateness of the local design guidelines and the Healthy Streets design check** for identifying the non-walkable crossings experienced by people.

2. Methods

2.1. Setting

This research is situated in Tāmaki Makaurau Auckland, Aotearoa New Zealand (hereafter: Auckland), a city of 1.5 million residents (2023) with car-oriented land use patterns and transport infrastructure (Nunns, 2014). Road transport is the largest contributor to greenhouse gas emissions (39 %), and 80 % is caused by private vehicles (Auckland Transport et al., 2021). The feedback on the consultation of the regional land transport plan indicated over 90 % support for investment in public transport and active modes (Auckland Transport et al., 2021). The city aims to halve its greenhouse gas emissions by 2030, and the action plan includes a shift to active modes and public transport (Auckland Council, 2020).

2.2. Study design

This is a descriptive study examining a range of non-signalised pedestrian crossings identified as barriers to accessing destinations of importance within walkable distances (hereafter ***problematic non-signalised crossings***). The theoretical model used is the Social Model of Walkability, linking the walking environment to walking behaviours, through the lens of walking experiences (Bozovic et al., 2020).

The study builds on previously gathered insights from 56 interview participants (Bozovic et al., 2021a). Briefly, participants (aged 20 to 89 years), were living in Auckland. Disability was the key socio-demographic characteristic examined, and 27 of the participants (48 %) had at least some difficulty with one or more of the following: walking, seeing, hearing, or remembering or concentrating. Participants reported on the attributes that made walking trips difficult and/or unpleasant or discouraged them from taking walking trips (barriers to access). Each reported barrier included a description, a location, and the reference of the participant who mentioned it. Non-signalised crossings were the most frequent barrier to access mentioned. Included in this study are 31 specific locations that could be measured (excluding instances related to a past or evolving situations – e.g., a worksite with changing layout and vehicle flows).

The study considers local design guidelines and the Healthy Streets framework, briefly described below. **The local design guidelines** considered are (a) the Waka Kotahi/New Zealand Transport Agency (NZTA) Pedestrian Design Guide (Waka Kotahi NZ Transport Agency, 2009); and (b) Auckland's Transport Design Manual (Auckland Transport, 2020c). The local design guidelines support transport professionals by providing both high-level and specific insights (covering for instance the topics of a pedestrian network as a whole, down to the design of kerbs or crossings).

The Healthy Streets framework makes a notable and needed effort to promote a holistic assessment of streets' amenity and supportiveness of public health and provide pragmatic decision-making support for delivering complex policy goals such as health and sustainability (Ede & Morley, 2020; Plowden, 2020). The framework includes 10 indicators based on 19 metrics. The metrics examine either the whole street, the point defined as the "weakest" for that specific metric, or the bus service, if available. Designers are provided with guides to score each of the 19 metrics from 0 (worst) to 3 (best). Alongside the guide developed for the UK, an Australian-specific guide was recently released (Healthy Streets Ltd, 2022). Healthy Streets Design Check Australia was considered in

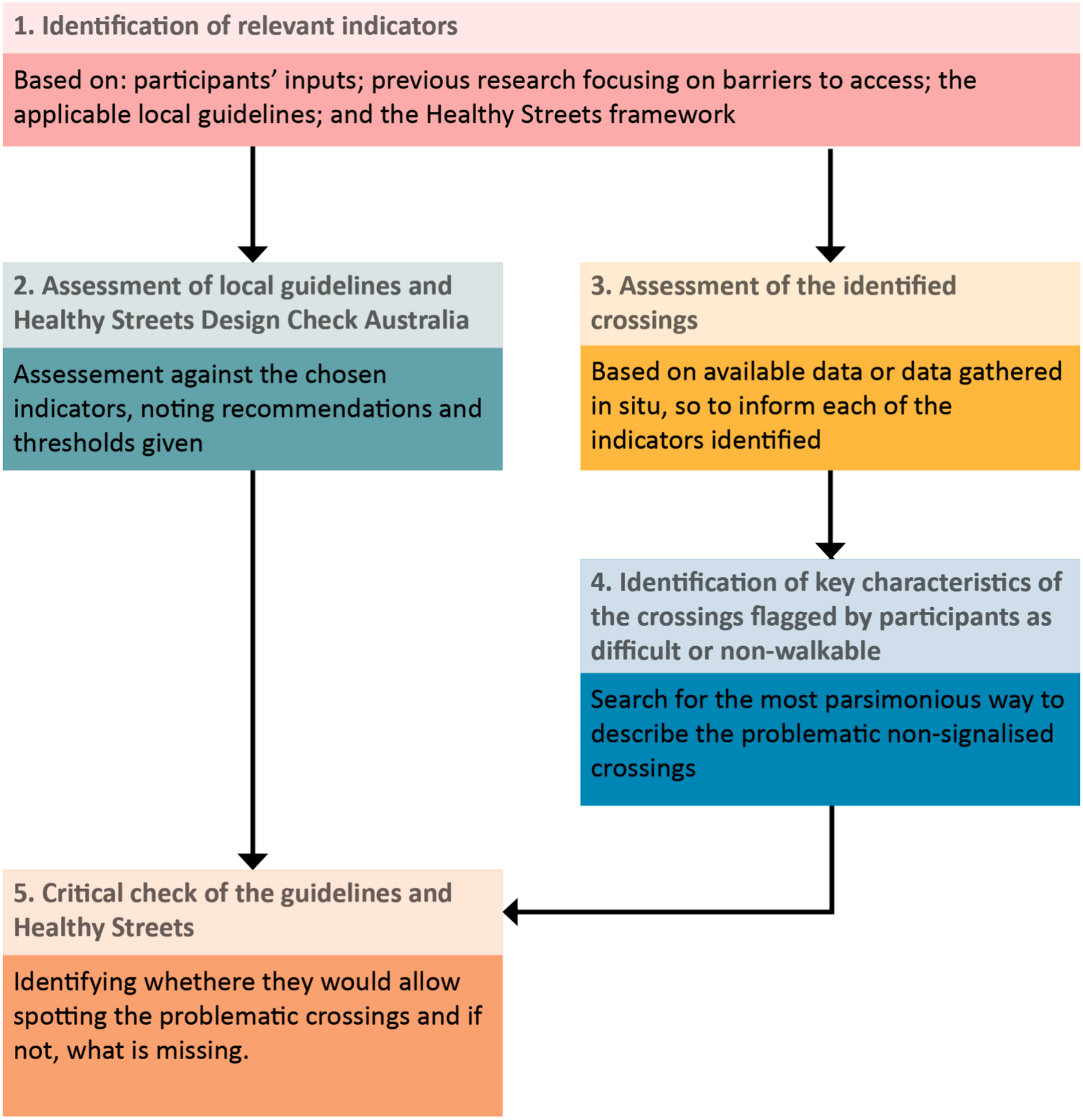

Fig. 1. Process used to characterise the problematic non-signalised crossings and assess them against the considered guidelines.

this study, given the similarities between Australian and New Zealand's urban environments namely in terms of car-oriented design (Laird et al., 2001).

2.3. Data processing and analysis

A five-step process was used to characterise the problematic non-signalised crossings and assess them against the considered documents. The process is illustrated in Fig. 1

(1) **Objective indicators of non-signalised crossing design were identified** based on participants' inputs, existing evidence, and relevant guidelines.
(2) **Recommendations from local guidelines and the Healthy Streets Design Check Australia** (Healthy Streets Ltd, 2022) were assessed against the chosen indicators, noting recommendations and thresholds given;
(3) **The problematic crossings were evaluated against the selected indicators** though data available online and gathered in situ, where required; the sources of data are indicated in Table 1, providing the characteristics of the problematic crossings against each of the indicators.
(4) **Key design characteristics and their thresholds were identified**, searching for the simplest way to describe the problematic non-signalised crossings; and.
(5) **The key characteristics were compared with the recommendations from step 2**, critically examining the technical documents against characteristics users might find difficult.

3. Results

3.1. Identifying objective indicators

Objective indicators were identified from (a) features indicated by participants; (b) previous research having focused on barriers to access (Bozovic et al., 2020; Eisenberg et al., 2017; Forsyth, 2015; Hutabarat Lo, 2009); (c) the applicable local guidelines: NZ Transport Agency's Pedestrian Design guideline (Waka Kotahi NZ Transport Agency, 2009) and Auckland's Transport Design Manual (TDM) – Urban Street and Road Design Guide (Auckland Transport, 2020c); and (d)the Healthy Streets framework, laying out the important dimensions to consider (developed in London (Mayor of London, 2017) but employed internationally, including in Australia (Healthy Streets Ltd, n.d.)). Wherever possible, the measures chosen consider metrics that cities routinely collect (for instance, peak hour traffic volumes), with the idea of developing an assessment that answers the research questions while being pragmatic and easy to implement. The selected indicators are presented in Table 1.

3.2. Assessment of technical documents

The local guidelines place emphasis on traffic volumes, traffic speeds, and crossing design. **The NZTA Pedestrian Design Guide** (Waka Kotahi NZ Transport Agency, 2009) focuses mainly on traffic volumes and speed, and physical aids for crossing, part of a tool assessing the crossing level of service (Abley et al., 2015). The acceptable or desirable levels of service are set by local authorities. While the guideline notes that cornering radii should be minimised, it is strongly dominated by traffic-related engineering (e.g., design based on vehicle tracking and road network hierarchy, and not pedestrians (p. 15–23), or suggestion of slip lanes "if large kerb radii are required" (p. 15–23)). **The Auckland Transport Design Manual** (Auckland Transport, 2020c) similarly focuses on traffic characteristics and certain design features, referring to the same calculation of the levels of service as the national guide (Abley et al., 2015). The manual acknowledges kerb radii as key element for the safety of intersections and is less traffic centric as the national Design

Table 1
Selected indicators.

Indicator		Description
1	**Number of traffic movements in conflict with the pedestrian crossing**	Traffic movements across the pedestrian crossing – sum of movements from all directions (see illustration Fig. 2)
2	**Traffic volume**	Number of vehicles across the pedestrian crossing, in both directions, for the peak hour
3	**Proportion of heavy vehicles**	Proportion of large vehicles including public service vehicles, public transport and vehicles servicing properties on the street and other large vehicles
4	**Traffic speed (85th percentile) and turning radii**	85th percentile speeds of unimpeded vehicles (i.e. not circulating behind another vehicle and having their speed influenced by it). The turning radii are measured for the direct left hook, i.e. for the movement across the pedestrian crossing coming from the adjacent lane (in New Zealand circulation is on the left)
4	**Type of crossing**	Noting the presence or not of a zebra crossing and the possible presence of crossing aides (e.g., pedestrian refuge)
6	**Distance to cross**	Distance in meters, at the middle of the painted or suggested crossing (see Fig. 2 below and arrow A-B).
7	**Number of lanes to cross**	Number of lanes in both directions (regardless of the presence of a pedestrian refuge)
8	**Presence of constraints to traffic movements and speeds**	Presence of design elements to slow the traffic down (e.g. raised tables) and/or signs indicating traffic rules or restrictions (e.g. stop sign, dead end street, or "residents only")

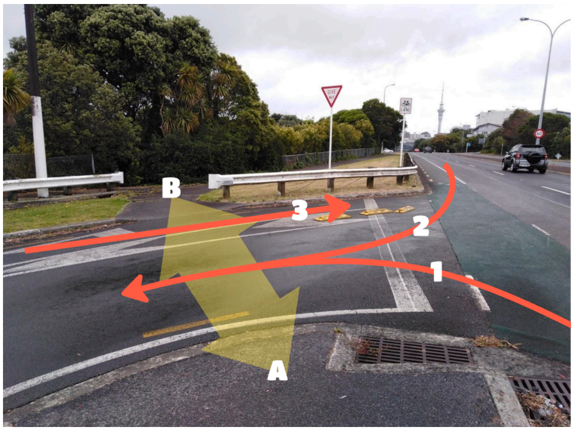

Fig. 2. Counting the traffic movements in conflict with the pedestrian crossing, example: here, the informal crossing across the side street is indicated as the double arrow A-B. The pedestrian needs to watch three movements, here: from A: the left- and right-turning flows from the main road (noted 1 and 2), as well as the traffic exiting the side street (noted 3).

Guide: it is stressed that not every intersection needs to cater for every vehicle, and that occasional difficult turns are acceptable (p. 160). Neither of the documents provide specific support for designers for planning or retrofitting cornering radii (e.g., an overview of radii to consider and their relationship to speed).

The Healthy Streets Design Check (Healthy Streets Ltd, 2022) makes a notable and needed effort to promote a holistic assessment of environments and provides pragmatic decision support for delivering complex policy goals such as health and sustainability (Ede & Morley, 2020; Plowden, 2020). The metrics assess a street's amenity and supportiveness of public health. Eight of the metrics capture aspects relevant to non-signalised crossings. These are: traffic speed (85th percentile); volume of motorised traffic; proportion of large vehicles in the traffic mix; intersections geometry (e.g. cornering radii) and design; level of pedestrian priority and presence of crossings, for intersections and midblock crossings; and levels of traffic filtering. The assessment of the three documents against the indicators chosen is presented in Table 4.

3.3. Characterisation of the problematic non-signalised crossings

From the 46 problematic non-signalised crossings reported by interview participants, 31 instances were included after filtering (eliminating 9 duplicates and 6 non-specific instances or relating to an evolving situation). The problematic non-signalised crossings examined were mostly informal (not marked across the carriageway but only indicated to the pedestrian through lowered kerbs and tactile pavers, in most cases). Traffic volumes ranged widely, with number of instances of "low" volumes (≤500 vehicles per day in 11 cases, corresponding to the second highest score for the metric #2 (traffic), in the Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022)). The presence or absence of crossing aids was not an obvious explanation: five of the instances with "low" traffic also have pedestrian refuges, four of them with a STOP sign, and one has a zebra crossing (a marked crossing, while other non-signalised crossings in New Zealand are by default non-marked). An overview of the types of crossings and respective values of

Table 2
Overview of the included crossings.

		Peak hour traffic [vehicles/h]		Width to cross [m]		Cornering radius (direct left hook) [m]	
Type of crossing	**n**	**median**	**IQR**	**median**	**IQR**	**median**	**IQR**
casual	19	1,050	1,075	12	3	12	13
casual + platform	1	580	0	27	0	22	0
casual + refuge	5	1,450	750	14	1	11	1
casual + STOP & refuge	2	150	0	14	3	11	0
casual + STOP, red marks, refuge	2	158	28	17	0	11	0
zebra (slip lane)	2	540	330	6	1	22	4
Total (n) and weighted averages	**31**	**951**	**803**	**13**	**2**	**13**	**8**

peak hour traffic, widths to cross, and cornering radii is presented in Table 2.

The cornering radii and speeds appear to be particular because while they are understood to be important in terms of ease of crossing and crash risk, evidence associating cornering radii and vehicle speeds appears limited, in urban environments. Evidence gathered within this study is presented below. The overall findings are presented in Table 3.

3.4. Cornering radii and speed

Turning radii appear to be an important parameter, interesting also because this factor was acknowledged but not strictly prescribed in the guidelines or the best practice. While road geometry is associated with driving speeds, in road design manuals, the existing empirical evidence is limited and not directly applicable here, because it focused on curves away from intersections (Turner et al., 2009) or intersections with dedicated turning lanes, in the US (Fitzpatrick & Scheider, 2005). Therefore, measures were taken in the field for a sample of locations presenting a range of radii corresponding to those indicated by the participants. A total of 966 measures were taken and examined. The methodology is presented elsewhere (Bozovic, 2021 Appendix 6C).

The measures of speed relative to each radius band are presented in Table 3 and the distributions are shown in Fig. 3. The speeds were predominantly above 20 km/h, and even above 30 km/h, for the highest examined radius. The regression analysis revealed each additional meter of cornering radius was associated with 0.8 km/h higher cornering speed ($p < 0.001$). The measures indicated that the speed selection could be higher than the theoretical design speed, as calculated according to the AUSTROADS technical design guidelines (Richard Fanning, n.d.). For instance, 78 measures were taken at locations having radii of approximately 8 m, corresponding to a design speed of 20 km/h, and 30 of them (38 %) were above 20 km/h. Despite some important differences between the investigated locations (e.g. some had zebra crossings, one had a raised platform, and the side friction varied), the speeds for each radius had approximately normal distributions centred around increasing median values.

3.5. Key characteristics of problematic non-signalised crossings

The search for the simplest way to describe the problematic non-signalised crossings involved a screening of their characteristics, against all the indicators considered. This process identified three indicators helping explain the difficulty for pedestrians in these problematic non-signalised crossings: (a) traffic volume; (b) turning radii; and (c) number of traffic movements in conflict with the pedestrian crossing, as a proxy for the complexity of the crossing.

Problematic non-signalised crossings identified all correspond to one of the following categories: (1) Peak hour traffic > 500 vehicles/h; (2) peak hour traffic < 500 vehicles/h, three or more traffic movements in conflict and left hook radius >= 8 m; or (3) peak hour traffic < 500 vehicles/h and left hook radius >= 18 m (NZ is left hand drive, so left hook corresponds to the nearside turn).

All the problematic crossings situated at intersections had relatively high turning radii (above 8 m) for the direct left hook, allowing relatively high cornering speeds and limited time for pedestrians for deciding whether to cross and performing the crossing. Further, large cornering radii also result in traffic trajectories that are not orthogonal to the pedestrian crossing, and therefore mean a lesser mutual visibility between the pedestrian and the driver. Specifically, in these scenarios, pedestrians can expect traffic to arrive at them almost from behind.

3.6. Assessment of technical documents against the findings

Local design guidelines focus on traffic volume and physical crossing aids, and in doing so, fail to identify instances noted as difficult or non-walkable by people. Turning radii and complexity were identified as key indicators. Failing to consider them results in situations such as side road crossings being overlooked.

The Healthy Streets approach is more nuanced, considering traffic volumes but also cornering speeds and crossing design. The importance of cornering radii is acknowledged but not strictly prescribed, the Design Check indicating that a “tight” geometry (forcing vehicles to slow down to 5 km/h or less) has “generally an internal radius of < 2 m” (Healthy Streets Ltd, 2022). No other measures are given, for instance there is no indication of what would constitute an unacceptably large radius.

Table3
Speed measures for different cornering radii (direct left hook).

Turning radius	n	median	V85	IQR	min	max
[8–8.5 m]	78	18.7	22.6	4.9	7.6	27.7
[11.5–12 m]	199	20.8	24.8	5.3	11.1	39.7
18 *m*	215	25.8	32.8	6.2	8.3	53.4
22 *m*	238	25.7	32.6	7.4	7.4	46.2
30 *m*	146	36.5	41.8	6.6	20.3	53.5
NA	90	41.1	46.5	6.2	30.9	54.4
all observations	**966**	**25.9**	**38.3**	**13.6**	**7.4**	**54.4**

Table 4
Assessment of the technical documents and characterisation of the problematic crossings presented against the selected indicators.

Selected indicators	Local guidelines – NZTA Pedestrian Design Guide (Waka Kotahi NZ Transport Agency, 2009)	Auckland Transport Design Manual (Auckland Transport, 2020c) and Engineering Design Code (Auckland Transport, 2020a, 2020b)	Best practice recommendation – Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022)	Characteristics of the problematic non-signalised crossings	Characteristics of the problematic non-signalised crossings compared to Auckland's context
1. Number of traffic movements in conflict with the pedestrian crossing	No specific recommendation. General idea that lesser complexity is better.	**No assessment thresholds** (e.g., above which a signalised intersection should be planned) but the Intersection design should aim for intersections to be easy and safe to navigate for all users (p. 159). The number of conflicts is not to be reduced per se, but conflicts need to happen at survivable speeds and users must be able to see each other (p. 158). Geometrical layout can be used to reduce the complexity, namely by allowing pedestrians to cross traffic movements in sequence, and not simultaneously (p. 159). Separation in time and space should be provided "if needed" (p. 158).	No specific recommendation. The Qualitative Assessment document (Healthy Streets Ltd, 2021) talks about the ease of crossing and of assessing if the streets and one of the prompt questions is "Does the street feel dominated by parked or moving vehicles?" (p. 3), but no figures are given regarding conflicting traffic movements.	The number of traffic movements in conflict with the crossing, as a proxy for the complexity, shows no obvious relationship with difficulty: 24 of the instances are exposed to one or two traffic movements, or a relatively low complexity (source: on-site observation).	Not exceptional in Auckland's context (typically: 4-way intersections, 3-way intersections and midblock crossings, respectively 4, 3 and 2 movements in conflict
2. Traffic volume (number of vehicles) across the pedestrian crossing	**No assessment thresholds** (e.g., above which a signalised intersection should be planned): traffic volumes enter a calculation of levels of service, together with the physical aids provided and speed. The acceptable or desirable levels of service are to be set by local authorities. The guideline notes that traffic volume reduction is beneficial (p. 2–4), without quantifying it, but also that "On busier roads, kerb extensions and a raised median or pedestrian island can provide excellent safety benefits and a satisfactory level of service at flows above 1500 vehicles per hour." p. 6–10)	**No assessment thresholds** (e.g., above which a signalised intersection should be planned). Traffic volumes are noted to influence the choice of crossing (p. 170). The manual does not provide thresholds, as it does for bicycle crossing planning (p. 79) but the traffic volumes enter the calculation of levels of service of specific facilities (Australasian Pedestrian Crossing Facility Selection Tool, 2020)	**Metric #2 total two-way traffic, peak hour** Ideal (score 3): <200 vehicles/h (v/h) Score 2: 200–500 v/h Score 1: 500–1,000 v/h Score 0: > 1,000 v/h	Traffic levels measures showed a high dispersion, from 50 to 1,720 vehicles per hour (median: 800, IQR 1,470; source: Auckland Traffic Counts (Auckland Transport, n. d.-c)). Nine of the instances have peak hour traffic below 200 vehicles per day, which would award them the highest score regarding the appropriateness of non-signalised crossings, in the Healthy Streets approach (Mayor of London, 2017). Five of those cases also had pedestrian refuges, four with a stop sign for the traffic exiting the side street.	Traffic volumes higher than 500 vehicles/h are not exceptional for Auckland. This is the case for 58 % of the traffic measures available across the city (see supplementary file A).
3. Percentage of heavy vehicles (HCV) in the traffic across the	**No assessment thresholds**. The guideline examines notes HCV only from the perspective of their requirements regarding road layout	**No assessment thresholds**. The manual acknowledges the impacts of heavy traffic on noise and air pollution and	**Metric #3 vehicles mix and proportion of heavy vehicles** Ideal (score 3): The only heavy vehicles present are service vehicles and public	Heavy vehicle traffic was available as a percentage of total traffic, and not peak hour traffic, for 20 of the 30 instances (source:	The measures were not exceptional for Auckland: heavy vehicles proportions are available in over 3800 recent measures across

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Table 4 (*continued*)

Selected indicators	Local guidelines – NZTA Pedestrian Design Guide (Waka Kotahi NZ Transport Agency, 2009)	Local guidelines – Auckland Transport Design Manual (Auckland Transport, 2020c) and Engineering Design Code (Auckland Transport, 2020a, 2020b)	Best practice recommendation – Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022)	Characteristics of the problematic non-signalised crossings	Characteristics of the problematic non-signalised crossings compared to Auckland's context
pedestrian crossing	geometry, encouraging even to consider slip lanes at intersections with high volumes of HCV (p. 6–24).	recommends taking measures to minimise the impacts – for instance by restricting movements of heavy vehicles through residential areas or putting in place time-specific restrictions (p. 107).	transport (PT) Score 2: <1% heavy vehicles excluding PT Score 1: 1–3 % heavy vehicles excluding PT Score 0: >3% heavy vehicles excluding PT	Auckland Traffic Counts (Auckland Transport, n.d.-c)) Considering the total traffic and the thresholds from the Healthy Streets approach (Mayor of London, 2017), two instances had < 2 % heavy traffic, twelve had less than 5 % and eight >= 5 %.	the city, 73 % are under 5 % and 27 % above.
4. Traffic speed and turning radii	**No assessment thresholds** (e.g., above which a signalised intersection should be planned). Speed enters the calculation of pedestrian levels of service (i.e., waiting time) and influences design (e.g., no zebra crossing or platforms above 50 km/h). The cornering traffic and its speed influence little the scoring: the *risk* of a vehicle cornering at speed is not part of the assessment. The method applied to one of side streets off Dominion Rd (Rowan St) yields the level of service A. Notes that radii should be minimised but also that their calculation is based on vehicle tracking and road network hierarchy, not pedestrians (p. 15–23). Slip lanes are suggested "if large kerb radii are required" (p. 15–23).	**No assessment thresholds** but non-signalised crossings are discouraged if speed is higher than 50 km/h (p. 162). Traffic speeds are noted to influence the choice of crossing (p. 170) but unlike for bicycle crossing planning (p. 79), thresholds are not provided. Kerb radii are acknowledged as key element for the safety of intersections (p. 160). Minimal values allowing the passage of design vehicles should be used – it is stressed that not every intersection needs to cater for every vehicle, and that occasional difficult turns are acceptable (p. 160). Desired cornering speed enters the calculation of levels of service of specific facilities (Australasian Pedestrian Crossing Facility Selection Tool, 2020) but the manual and the engineering design code relative to pedestrian infrastructure do not provide an overview of radii to consider and their relationship to speed.	**Metric #5 Turning speeds at side-street intersections – measure applied to the weakest side-street intersection** Ideal (score 3): "has a narrow, tight geometry such that a turning motorised vehicle must slow down to less than 5 km/hr" and includes a raised platform Score 2: As score 3 but with pram ramps and no raised platform Score 1: Presence of pram ramps only Score 0: None of the features of scores 1–3	The locations were all in 50 km/h speed limit areas, across arterials or their side streets. V85 speed measures are not available from Auckland Transport and were estimated to 47 km/h (N = 90 free vehicles, median: 42 km/h, minimum: 31 km/h; maximum: 54 km/h; IQR 6 km/h)). V85 for the cornering speeds were estimated between 23 km/h (8 m radius) and 42 km/h (30 m radius). Source: on-site speed measurements; see point Cornering radii and speed, above.	All the cases were in areas limited to 50 km/h, which is the typical speed limit in Auckland's urban areas (Auckland Transport, n.d.-b). The radii measures are not readily available, and it wasn't possible to produce a distribution of the levels found on Auckland's network. It is however expected that the vast majority will be above 3.5 m, as this corresponds to typical road design standards for a 50 km/h environment (highways manual).
5. Type of crossing / provision	**No strict rules.** Aids enter the calculation of levels of service (i.e.,	**No strict rules.** Choice of crossing is presented as dependent on traffic	**Metric # 7 Priority at intersections** Ideal (score 3): Flush	Eighteen crossings were casual without any physical aid; two were	An overview of the numbers of crossings by types has not been

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Table 4 (*continued*)

Selected indicators	Local guidelines – NZTA Pedestrian Design Guide (Waka Kotahi NZ Transport Agency, 2009)	Auckland Transport Design Manual (Auckland Transport, 2020c) and Engineering Design Code (Auckland Transport, 2020a, 2020b)	Best practice recommendation – Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022)	Characteristics of the problematic non-signalised crossings	Characteristics of the problematic non-signalised crossings compared to Auckland's context
of crossing aids	waiting times) and improve it (p. 6–9) and notes that non-signalised crossings with physical aids can be satisfactory even above 1,500 vehicles/h (p. 6–10). The guideline warns also about the delays for traffic when zebra crossings or signalised crossings are installed (p. 6–11)	speed and volume, pedestrian volumes, and street layout (p. 170) but thresholds are not given.Intersection redesign should examine current pedestrian behaviour, including informal crossings; participation (older, younger, disabled people); crash history; and safety of existing conflict points (p. 185) but the manual does not provide assessment thresholds.	pedestrian priority zone or raised zebra (1 lane of traffic per direction max) Score 2: Pedestrian priority zone without ramps or zebra with "tight geometry" and 1 lane of traffic per direction max Score 1: Zebra with 1 lane of traffic per direction max, geometry "not tight" OR crossing with 2 m + wide pedestrian refuge and 1 lane of traffic per direction (side streets) OR 20 km/hr or less speed zone, no formal pedestrian priority (side streets) OR 2 m + wide pedestrian refuge AND speed limit 30 km/h max (main roads) OR raised entry threshold but no priority (AND 30 km/h speed limit for main roads) Score 0: not scoring 1–3 AND presence of a slip lane OR missing dropped kerb OR crossing not on the desire line	zebra crossings across slip lanes; and ten were casual crossings with additional crossing aids and/or traffic management devices: a refuge (five cases); a refuge and a STOP sign (two cases), a STOP sign, refuge and red marks across the carriageway (two cases) and a raised platform (one case). As seen above (point 2), five of the crossings having pedestrian refuges also had peak traffic levels below 200 vehicles/h. Source: on-site observation.	identified. However, it is known that Auckland has just under 200 signalised intersections (Auckland Transport, n.d.-a). Although most of these intersections are assumed to provide signalised pedestrian crossings, the number, spread over Auckland's surface of 1,086 km2, indicates a low density of signalised intersections. These elements support the claim that the casual crossings are typical of Auckland's environment.
6. Distance to cross	**No strict rules.** Distances to cross enter the calculation of levels of service (i.e., delay) and the calculation of the crossing sight distance to provide (p. 15–2).	**No assessment thresholds.** Compact intersections and shorter crossing distances are recommended (p. 159, 195) but the manual doesn't provide thresholds for assessing the level of service, based on crossing distance. The design code specifies the *minimum* width of the carriageway for the mixed use and main street collectors (6.4 m; Footpaths and Public Realm p. 31)	**No specific thresholds,** only the number of lanes per direction (one or more) is considered in metric 7 (see above)	Distances to cross are generally important: All intersections also involve crossing a distance > 10 m (and even > 20 m in three cases), except for one case (slip lane, width = 5.4 m). Ad minima, the crossing distance would be 6 m (two 3 m-wide lanes), but in practice, traffic lanes can be wider than 3 m and carriageways can be widened by the presence of several lanes per direction, on street parking, medians, or bus lanes.	The crossing distances are not exceptional for Auckland, where even residential streets tend to have two lanes of 3 m and above, and roadside parking.
7. Number of lanes to cross	**No strict rules.** The idea is that less lanes is safer. The guideline recommends examining if road space can be reallocated (Table 1).	**No assessment thresholds.** The manual notes that the road layout can and should be reconsidered, to provide for most efficient modes (p. 33), for instance by removing slip lanes and reducing the number of	**Dichotomous assessment:** one lane per direction or more, metric 7 (see above)	With four exceptions, the crossings were across two lanes of traffic; two were zebra crossings across a single slip lane, one crossing was a diagonal across an intersection (two times two lanes) and one crossing was across two	The vast majority of the crossings involved up to two lanes, typical of any residential street. The values are therefore not exceptional.

(continued on next page)

Table 4 (*continued*)

Selected indicators	Local guidelines – NZTA Pedestrian Design Guide (Waka Kotahi NZ Transport Agency, 2009)	Auckland Transport Design Manual (Auckland Transport, 2020c) and Engineering Design Code (Auckland Transport, 2020a, 2020b)	Best practice recommendation – Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022)	Characteristics of the problematic non-signalised crossings	Characteristics of the problematic non-signalised crossings compared to Auckland's context
		single movement lanes (p. 189, 191). Engineering Design Code notes that "Pedestrian signals are required where a footpath route crosses **multiple traffic lanes in one direction** and vehicle speeds exceed 30 km/h." (p. 31)		streets side by side (two plus three lanes).	
8. Presence of constraints to traffic movements and speeds	**No strict rules.** When considering improvements, the guideline recommends questioning traffic volumes and speeds and adapting them if possible (Table 1)	The manual recommends holistic design principles by type of street, with typically a high pedestrian focus on main streets and local streets, coupled with an adequate (re)allocation of road space to encourage active modes and measures to reduce traffic volumes and speeds (p. 123). The used of filtered permeability is considered for a network that prioritises walking "as the fundamental unit of movement" p. 38 without necessarily allowing all traffic movements.	**Metrics # 3** considers the ban of heavy vehicles other than services and public transport (see above) **Metrics # 5 and 7** relate to "tight" geometries and raised platforms (see above)	The crossings didn't present traffic constraints other than the STOP signs and red markings mentioned above (point 5, type of crossing and crossing aids). As is usual in New Zealand, all traffic movements were allowed.	The identified cases are typical of Auckland's context, where traffic access constraints are few, and usually limited to the city centre. The typical intersection allows all traffic movements.

4. Discussion

While people's walking experiences are important for understanding walking behaviours (Alfonzo, 2005; Middleton, 2010), there is a lack of experiential data on the associations between objective features of the walking environment and experiences (Andrews et al., 2012; Bigonnesse et al., 2018; Eisenberg et al., 2017). This research gap is important when considering the need to identify and re-design the features of the built environment that can be perceived as non-walkable or hostile for walking (Burdett, 2016; Gehl, 2010; Giles-Corti et al., 2016).

Acknowledging this problem, this study focused on one type of barrier to walking: non-signalised pedestrian crossings Instances flagged by pedestrians as difficult or non-walkable were characterised in objective terms, and these findings were used to provide a real-world perspective on local design guidelines (Auckland Transport, 2020c; Waka Kotahi NZ Transport Agency, 2009) and the Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022).

Objective indicators; users' perceptions of feasibility or difficulty; and guidelines' recommendations were triangulated. The findings highlight the importance of cornering radii, complexity, and traffic volumes, for which specific thresholds are suggested. Further, the assessment of the technical documents considered outlines that they are not set up to help professionals identify the most critical crossing points, those that require immediate attention.

The contribution of this study was not about identifying what causes barriers, but in characterising previously identified barriers and exploring the appropriateness of guidelines against users' perspectives of difficulty. Finally, the usefulness of the findings for the urban retrofit and future research are recommended.

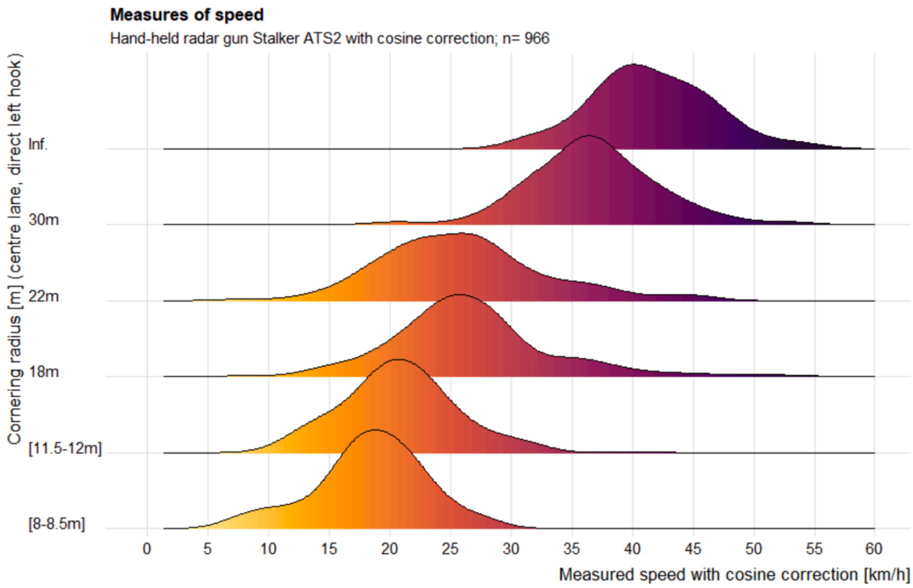

Fig. 3. Distributions of speeds for different cornering radii (direct left hook).

4.1. *Findings in the light of previous research*

A previous systematic literature review showed low levels of agreement between measures of environmental features and users' perceptions of those same features (Orstad et al., 2017). Primary studies tended to pre-define measures, often in non-comparable ways, and examine the associations with users' perceptions captured in diverse ways. For instance, Michael and colleagues examined footpath obstruction as an environmental attribute, finding a poor level of agreement between the presence or not of obstructions, as observed by trained surveyors and users' agreement or not with the statement that the footpaths are unsafe to walk (Michael et al., 2006). Analysing the evidence, the review authors noted that "[t]he perceived neighborhood environment and objectively measured neighborhood environment are related but distinct constructs […]" (Orstad et al., 2017, p. 905).

The present study took a different approach, starting from users' inputs (i.e., crossings perceived as difficult to navigate) and striving to find what measures could help explain these perceptions. The methodology allowed associating difficulties perceived by people of diverse ages, abilities, and backgrounds to real-world infrastructure characteristics, and further reality-checking professional guidelines.

Possible interplays between metrics were considered here, and indications of associations were observed, conceptually aligning with previous findings. These interplays stress the importance of considering walkability as a complex, multi-dimensional phenomenon (Forsyth, 2015; Hutabarat Lo, 2009). The problematic non-signalised crossings perceived as difficult or impossible to cross were characterised by an interplay of traffic volume, complexity, and cornering radii.

4.2. *Findings and local guidelines*

Two local design guidelines were considered: the national pedestrian design guide (Waka Kotahi NZ Transport Agency, 2009), that is understood to be under review at the time of the writing, and the Auckland Transport Design Manual (Auckland Transport, 2020c). The available guidelines mostly focus on best practice, naming all the aspects that should ideally be in place for a "walkable" environment, with the caveat of not necessarily identifying those aspects that could be perceived as barriers. In the case of inherited, car-dominated environments, the gap between what is on the ground and what is ideal could seem overwhelming, and the difficulty of knowing what should be improved first is real.

Identifying problematic non-signalised crossings using existing guidelines is challenging in three ways: firstly, advice given regarding identifying issues often requires data that are not available (e.g., pedestrian desire lines and suppressed demand, to assess the network completeness. Second, recommendations tend to be qualitative, for instance not providing measures for cornering radii. Third, thresholds that are available or embedded into assessment tools of non-signalised crossings relate to vehicle and pedestrian flows and crossing distances, giving a form of "hydraulic" vision of walking, mirroring the vehicular traffic modelling by emphasising the throughput and waiting times, and leaving aside aspects that might add to perceived barriers.

The findings of this study were at odds with the guidelines regarding non-signalised crossings, for which the guidelines refer to a sophisticated tool estimating levels of service based on traffic, crossing distances, physical crossing aids (e.g., refuges) and the vehicle speed (Australasian Pedestrian Crossing Facility Selection Tool, 2020). While the tool provides some support in comparing variants, it assesses intersections one at a time requiring data that is often not available (e.g., traffic speed as measured or pedestrian flows). Conceptually, the idea of producing a single output, or level of service, can also be problematic, as it arguably does not reflect the diversity of users' needs. Namely, blind users do not rely on pedestrian refuges (Bozovic, 2021; Bozovic et al., 2021a), and therefore, their effect on the calculation of the level of service is debatable.

The national guideline provides one illustrative threshold, stating that "On busier roads, kerb extensions and a raised median or pedestrian island can provide excellent safety benefits and a satisfactory level of service at flows above 1500 vehicles per hour." (Waka Kotahi NZ Transport Agency, 2009, pp. 6–10). The eight cases with built crossing aids and traffic below 1500 vehicles per hour were at odds with this statement. As seen above, participants reported that pedestrian refuges were at best not satisfying and at worst not usable at all (blind participants, not knowing if a refuge will be available and feeling exposed while standing in the middle of fast-moving traffic). All the problematic crossings at intersections had radii higher than 8 m, over two times higher than the recommended "tight radius" of 3.5 m (from Auckland Transport's Transport Design Manual (Auckland Transport, 2020c)).

The findings of this study suggest assessing the appropriateness of non-signalised crossings based on traffic volume, complexity, and speeds, considered simultaneously (low complexity can be an issue if high speed, and vice versa).

4.3. Findings and the Healthy Streets design Check

The present study showed the problematic non-signalised crossings would fail the Healthy Streets Design Check's (Healthy Streets Ltd, 2022) assessment of turning speed, when situated at intersections, because they do not include "tight" cornering radii. It was however identified that the Design Check does not provide objective measures other than an indication of an ideal-case scenario (radius < 2 m). Further, the number of traffic movements the pedestrians are exposed to is not directly considered, suggested here as objective ways of assessing complexity and potential traffic speeds.

4.4. Usefulness of the findings for urban design and transport planning

Study findings can first help identify the least walkable non-signalised crossings of Auckland. Combining the assessment of crossings (e.g., flagging those that might be perceived as difficult or impossible to cross) and the expected local traffic (for instance using tools like Space Syntax (UCL, n.d.)), could provide a draft prioritisation for retrofit, aligning with Universal Design principles. The findings could also be useful for other New Zealand towns and cities, having been designed based on the same national design standards as Auckland and likely to display similar systemic issues regarding crossings.

Two key aspects of this study can also be relevant beyond Auckland and New Zealand: firstly, the methodology of identifying non-walkable crossings could be replicated, through pedestrians' inputs, indicators, and measures. Second, a similar methodology could be applied to investigate other features of the WE that might be perceived as non-walkable (e.g., footpaths perceived as "too narrow"). Thirdly, the findings can be interesting for urban areas having been developed in patterns similar to Auckland, around a car-dominated infrastructure and single-use low density suburbia. The most obvious examples are the United States, Canada or Australia (country with which New Zealand shares design standards).

The identified metrics and thresholds should *not* be used directly for design, given that their purpose is to characterise what crossings are *not* walkable. For instance, it is suggested that some users will not cross at non-signalised intersections with cornering radii above 18 m. A cornering radius below 18 m should therefore not be seen as a "good" radius, because although possibly crossable, it might still correspond to a high level of difficulty and stress for users.

It is however suggested the findings be integrated in design guidelines. The guidelines should provide indications on (1) **identifying the critical features** that have the potential of preventing people from accessing their destinations on foot or by wheelchair; the present study provides insights about non-signalised crossings, but it is understood that people might have difficulties with many other features of the walking environment; (2) **identifying the metrics to be examined**, for each critical feature; in this study, traffic volume, cornering radii and number of traffic movements in conflict with the crossing were identified as key metrics for assessing non-signalised crossings, and indicative thresholds were provided. Most benefit would be gained from metrics that can be operationalised in a systemic way, for instance using an algorithm through an entire urban network, to identify the a priori hot spots.

4.5. Strengths and limitations

This study has two major strengths. Firstly, it contributes to understanding the non-signalised crossings perceived as non-walkable by examining which metrics and thresholds characterise barriers as reported by users. As the inputs stemmed from interviews with people aged 20 to 89, half of whom were disabled, the identified characteristics help understand the lowest common denominators of environmental barriers. In doing so, the study provides a support for systemically assessing walking networks in a way that considers the diversity of users and helps better consider disabled people and their diverse needs (Bigonnesse et al., 2018; Eisenberg et al., 2017; Stafford & Baldwin, 2017). The approach taken responds to the often noted difficulty of measuring environments in a way that is consistent with people's perceived walkability (Orstad et al., 2017).

Second, this study examined the findings against the metrics from the local design guidelines (Auckland Transport, 2020c; Waka Kotahi NZ Transport Agency, 2009) and the Healthy Streets Design Check Australia (Healthy Streets Ltd, 2022), allowing to identify important metrics that had not been directly considered (e.g., cornering radii as a proxy for cornering traffic speed) and specific thresholds (e.g., cornering radii in m or numbers of traffic movement in conflict with the crossing). The findings can complement the best practice and local design guidelines because contrary to those documents, they do not describe what is "ideally crossable" but rather the features of the most non-walkable non-signalised crossings. Moreover, our research provides a foundation for future research, including the identification of key factors related to the user experience to capture in future surveys, and the use of the

Healthy Streets Guide enables comparison with other international studies.

The main limitation of the study is that the characterisation of the problematic non-signalised crossings relied on relatively low numbers of instances. Although the instances were reported by people of diverse ages, disabled or non-disabled, the limited size of the participants' cohort limits insights into the granularity of lived experiences. For instance, none of the participants reported having hearing difficulties, and it is understood that hearing impaired people can experience specific barriers (Payne, 2021). Future research should develop characterisation based on diverse barriers to walking, from more people with diverse ages and disability statuses, residing in different car-dominated cities, and also including children, who can encounter specific barriers to walking (Carroll et al., 2015; Chaudhury et al., 2017; Egli et al., 2020). While this research is not global but focused on Auckland, New Zealand only, the results can have value for countries having seen important car-centric urban development, namely Australia, the United States, and Canada, countries with which New Zealand's transport design practices share similarities (Abley et al., 2015).

5. Conclusion

Walking for transport and walkability are becoming more common in urban development agendas, but face two major difficulties: the lack of consensus around what causes the highest barriers to walking, and the need to prioritise retrofit, especially in car-dominated realms that might be perceived as non-walkable.

A pragmatic approach is needed, and this study offers a possible way forward by triangulating lived experiences of barriers to walking (non-signalised crossings discouraging the access to destinations both desired and perceived as being within walkable distance), objective measures, and technical recommendations and guidelines.

The results provide a minimum definition of non-signalised crossings perceived as non-walkable, based on three factors: cornering radii, complexity, and traffic volumes. A critical assessment of the guidelines suggests a more nuanced approach to crossings, considering the interplay between different parameters, but points also to a need for "non-walkability guidelines" helping professionals in charge of walkability identify the most critical non-walkable features.

Future research should further develop the characterisation of problematic non-signalised crossings, considering the inputs of people with different ages and abilities, living in different car-dominated cities. It is also recommended the methodology developed here be applied to other features of walking environments that are perceived as barriers to walking, such as narrow/obstructed sidewalks, car-dominated streets or roads with limited natural surveilance, or insufficient lighting.

6. Authors' statement

Tamara Bozovic was supported during the realisation of this study by the Auckland University of Technology Doctoral Scholarship. No direct funding was received for this project. The authors do not declare any conflict of interest.

7. Notation

The paper does not use special characters or subscripts.

CRediT authorship contribution statement

T. Bozovic: Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **E. Hinckson:** Writing – review & editing, Supervision, Methodology, Conceptualization. **M. Smith:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

All data collected and used in the analyses are provided in the paper and/or the supplemental materials.

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Appendix A. Supplementary material

Supplementary file A: Overview of Auckland's average daily traffic measures. Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2024.104169.

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