Appendices

CHAPTER 1

1A: Ethics approval, phase 1

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

12 December 2018

Erica Hinckson
Faculty of Health and Environmental Sciences

Dear Erica

Re Ethics Application: **18/431 Research on the quality of your street environment for walking: how easy is it to get around, what are the difficulties, and how do they influence your mobility**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 12 December 2021.

Standard Conditions of Approval

1. A progress report is due annually on the anniversary of the approval date, using form EA2, which is available online through http://www.aut.ac.nz/research/researchethics.
2. A final report is due at the expiration of the approval period, or, upon completion of project, using form EA3, which is available online through http://www.aut.ac.nz/research/researchethics.
3. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form: http://www.aut.ac.nz/research/researchethics.
4. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
5. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.

Please quote the application number and title on all future correspondence related to this project.

AUTEC grants ethical approval only. If you require management approval for access for your research from another institution or organisation, then you are responsible for obtaining it. You are reminded that it is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

For any enquiries, please contact ethics@aut.ac.nz

Yours sincerely,

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: rfq8954@autuni.ac.nz; moushumi.chaudhury@aut.ac.nz

1B: Ethics approval, phase 2

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

31 August 2020

Erica Hinckson
Faculty of Health and Environmental Sciences

Dear Erica

Re Ethics Application: **18/431 Research on the quality of your street environment for walking: how easy is it to get around, what are the difficulties, and how do they influence your mobility**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Phase 11 of your project has been approved for three years until 12 December 2021.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: rfq8954@autuni.ac.nz; moushumi.chaudhury@aut.ac.nz

1C: Walking levels vs WalksScore ™ levels for Auckland

What was done

New Zealand Household Travel Survey (HTS)[1] data for 2015-17 was obtained from the Ministry of Transport. The anonymised dataset contains residential addresses as well as information regarding trips made in the previous week and individual characteristics.

For participants living in Auckland, the correlation was sought between walking levels (trips legs walked for transport, in the previous week) and the WalkScore ™ scores. The WalkScore ™ scores were automatically retrieved for each address, using R software[2] and its packages opencage[3] (geocoding addresses into longitude and latitude) and walkscoreAPI[4] (retrieving the WalkScore scores based on coordinates).

The dataset contained 1678 home addresses in Auckland, corresponding to 2711 respondents (1.62 per household), and a total of 5,171 trip legs made by any mode. 776 of the respondents (28.6%) had walked at least 1 trip leg in the previous week.

A trip leg is defined as a segment of a journey not including a change of mode[5]. For instance, walking to the bus stop, taking the bus, and walking to the end destination corresponds to two walking trip legs and one bus trip leg. Walked trip legs exclude:

- Trip legs shorter than 100 m and not crossing a road
- Walks on private property
- And off-road round trips

A linear model was computed, expressing weekly trips walked as a function of the WalkScore scores. The slope (0.04) and the R2 coefficient (0.01) indicated a very poor fit.

The code is provided in the following pages.

---

[1] Ministry of Transport. (2017). New Zealand Household Travel Survey 2015-2017. Retrieved from https://www.transport.govt.nz/mot-resources/household-travel-survey/results-from-household-travel-survey-2015-2017/

[2] R Core Team. (2019). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

[3] . Possenriede, D., Sadler, J., Salomon, M., Ross, N., Russ, J., & Silge, J. (2020). opencage: Geocode with the OpenCage API version 0.2.2 from CRAN. Retrieved from https://rdrr.io/cran/opencage/

[4] Whalen, J. (2012). walkscoreAPI: Walk Score and Transit Score API. Retrieved from https://CRAN.R-project.org/package=walkscoreAPI

[5] NZ Ministry of Transport. (2015). Walking New Zealand Household Travel Survey 2011 - 2014 (p. 21). Wellington, Aotearoa New Zealand: Ministry of Transport. Retrieved from https://www.transport.govt.nz/assets/Uploads/Report/Walking-2015-y1012.pdf

Code

```
# Setup ---------------------------------------------------------------------
library(tidyverse)
library(walkscoreAPI)
library(opencage)

setwd("C:/Users/tbozovic/OneDrive - AUT University/a1_STUDY_1_quant/Part-1-HTS")


# Import addresses, 2016-19 -------------------------------------------------
ad_y14y16_19SEP19 <- read.csv("C:/Users/tbozovic/OneDrive - AUT
University/a1_STUDY_1_quant/Part-1-HTS/HTS-15-17/ad_y14y16_19SEP19.csv")
addresses <- ad_y14y16_19SEP19
# 204,669 obs

# Create unique ID, format yy_samno
addresses <- addresses %>% mutate(
  UniqueID = str_c(Year, samno, sep = "_", collapse = NULL))



# Filter --------------------------------------------------------------------

# Only Auckland, address= home
# adType = Address Type H=Home, E=Education Facility, W=Work, O=Other
addresses <- addresses %>% filter(Town=="Auckland") %>% filter(adType=="H")
# 1,678 addresses


# Retrieve Walkscores -------------------------------------------------------

result <- list() # Empty list to store results

for (i in 1:nrow(addresses)){

  year    = as.character(addresses[i,"Year"])
  ID      = as.character(addresses[i,"samno"])
  address = as.character(addresses[i,"address"])


  # Geocode address using opencage and extract useful results
  gc <- opencage_forward(placename = address,
                         key = 'c3b26bb87f224e6885aa77fb7882765e',
                         countrycode = 'NZ',
                         limit = 1)

  res <- data.frame(
    year          = year,
    ID            = ID,
    address       = address,
    gc_time       = gc$time_stamp,
    gc_suburb     = gc$results$formatted,
    gc_lat        = gc$results$geometry.lat,
    gc_lon        = gc$results$geometry.lng,
    gc_confidence = gc$results$confidence,
    gc_url = gc$results$annotations.OSM.url,
    gc_remaining = gc$rate_info$remaining)


  # Find walkscore using the geocoded long lat
  ws <- getWS(res$gc_lon, res$gc_lat,
              'e2e3f2cce96a124a33a4ab346734e598')

  # Add useful walkscore results to df
  res$ws_status      <- ifelse(ws$status == 1, 'Success', 'Fail')
  res$ws_score       <- ifelse(ws$status == 1, ws$walkscore, NA)
  res$ws_description <- ifelse(ws$status == 1, ws$description, NA)
  res$ws_updated     <- ifelse(ws$status == 1, ws$updated, NA)
  res$ws_snaplon     <- ifelse(ws$status == 1, ws$snappedLong, NA)
  res$ws_snaplat     <- ifelse(ws$status == 1, ws$snappedLat, NA)

  # Store results in list
  result[[i]] <- mutate_if(res, is.factor, as.character)}
```

```
result <- bind_rows(result)

# Add identifiers
result_ID <- merge(addresses, result)
# 1,678 observations

# Create unique ID household
result_ID <- result_ID %>% mutate(
  UniqueID = str_c(Year, samno, sep = "_", collapse = NULL))

# Select only variables of interest and filter

result_filter <- result_ID %>%
  dplyr::select(
    UniqueID,
    Year,
    samno,
    address,
    Suburb,
    Town,
    ws_score)

# Join the "trips" dataset, with travel behaviour ----------------------------

tr_y14y15_17OCT18 <- read.csv("C:/Users/tbozovic/OneDrive - AUT
University/a1_STUDY_1_quant/Part-1-HTS/HTS-15-17/tr_y14y15_17OCT18.csv")
tr <- tr_y14y15_17OCT18

# Check total number of trips
table(tr$Newmode)
# Total 218,581 trips; 25,183 trips walked = 11.5%


# Create unique ID household, format yy_samno, id results
tr <- tr %>% mutate(
  UniqueID = str_c(Year, samno, sep = "_", collapse = NULL))

### Attach trip data corresponding to the included results
results_tr <- merge(result_filter, tr, by="UniqueID")
# 39,884 obs, 72 variables
# 5,171 trips

# Create unique ID for each person
results_tr <- results_tr %>% mutate(
  UniqueID_p = str_c(UniqueID, person, sep= "_", collapse = NULL))


# Examine trips walked vs WalkScore ---------------------------------------

# LM equation
m  <- lm(trips_w_count ~ ws_score, results_w)
summary(m)
# (Intercept)    ws_score
# 10.16158514  0.04057022
# Very poor fit (R2 =0.01)
# Multiple R-squared:  0.009715, ................ Adjusted R-squared:  0.009512
```

1D: Engagement with local stakeholders done within the scoping phase

Name	Role and Organization	Date	Notes
Sam Bourne	National Urban Design and Landscape Advisor, NZ Transport Agency	Feb. 18	(Colleague, at that time; several discussions on this topic at different dates). Transformation of the urban environments: a systemic challenge. Research can contribute to better systems approaches.
Claire Pascoe	Lead Advisor, Urban Mobility	Feb. 18	(Colleague, at that time; several discussions on this topic at different dates). Research can contribute highlight diverse experiences of the built environment. Recent focus was rather on cycling behaviour.
Darren Davis	Transport & Land Use Integration Manager, Auckland Design Office (ADO)	20.4.18	Research can contribute to needed prioritised action to improve walking environment. It can also highlight "invisible" difficulties (e.g., arm in scarf making it painful to rush to cross during the green phase).
Lily Linton	Road Safety Policy Analyst, Auckland Transport (AT)	15.5.18	System design issues, namely regarding pedestrian safety. Value in providing insights regarding lived experiences (in particular perceptions of safety) and the choice of (not) walking. Interesting also in public transport as a potential enabler of walking.
Dr Haydn Reid	Head of Infrastructure Programme - Digital City, Auckland Council	18.5.18	Interesting if research can provide inputs for liveability indicators.
Ben Ross	Geographer, South Auckland Urban Champion	9.6.18	Important to inform future deliveries; identify the "why" of the barriers – for whom? Who chooses to drive the first/last mile?
Frith Walker	Head of place-making, Panuku (Auckland Council)	18.6.18	Outcomes would be useful for targeted walking action plan (not existing at the moment)
Irene Tse	Road Safety Engineering Team Leader, AT	18.6.18	System design is part of the current safety problem – 70% of vulnerable road users are killed or seriously injured on arterial roads. Elderly are particularly exposed. Needs: evidence regarding users' needs by age, ability, etc. What do they see as difficult or risky? How does it look like? How can improvements reduce the perceived risks?
Samuel Murray	National Policy Coordinator, CCS Disability Action National Office, and member of the Disability Data and Evidence Working Group	20.9.18	Research could contribute to current data gaps, namely disability lens on the four dimensions of well-being (social, economic, environmental, cultural). Namely from the perspective of access.
Vivian Naylor	Barrier Free Advisor & Educator at CCS Disability Action	27.9.18	A major issue noted: disabled people are questioned about their needs but do not see resulting improvements. Research needs to have practical outcomes.
Brian Coffey	Director, Office for Disability Issues	10.10.18	Letter of support to this research received http://bit.ly/support-ODI
Dr Catherine Brennan	Advisor, Office for Disability Issues	10.10.18	Evidence seen as positive to help prioritise needed improvements of the built environment.
Mary A. Schnackenberg	Chair of the Disability Advisory Panel - Auckland Council, and Hon. Secretary, Auckland Branch, Association of Blind Citizens	12.10.18	Data on difficulties faced by disabled people is inconsistent. For instance, a study by PwC was contracted by Auckland Transport but not published. The problem is important, barriers to access impact negatively on wellbeing.

Name	Role and Organization	Date	Notes
	of New Zealand Incorporated		
Jade Farrar	Member of the national leadership team, Enabling Good Lives, member of the Disability Advisory Panel - Auckland Council, former Strategic Disability Advisor, Te Pou o te Whakaaro Nui, Improving the workforce performance of mental health, addiction and disability services	25.10.18	There is a lack of richness in data relative to disabled people. Data tend to be aggregated, anecdotal, estimated. There is a need for new ways of understanding how disabled people move. Disabled people are tired of being interviewed but not heard. Research should lead to practical recommendations.
Professor Valerie Wright St-Clair	Department of Occupational Science and therapy, and Co-director, AUT Centre for Active Ageing	29.10.18	Importance of considering older people’s perspectives, and intersectionality (e.g., age and not having English as the first language). Own research on older migrants indicated number of traffic-related topics.
Elise Copeland	Principal Specialist Universal Access and Design	31.10.18	There is no overview of the barriers faced by disabled people. Pedestrians overall not much valued. Need to better understand the diversity of disabled people – e.g. neuro divergence, experiencing very specific barriers. The interviews should ask if anything has improved the access. Value in interviewing care-givers.
Olivia Haddon	Māori design specialist, Auckland Design Office, Auckland Council	31.10.18	Importance of including ethnicity lens, engaging with Maori communities. Importance of investing time into building the relationship.

1E: Dissemination of findings with local stakeholders and professionals

Beyond the presentations at peer-reviewed conferences, cited at the start of the thesis, effort was made to share findings with the local professionals and stakeholders. These include namely:

- Presentations to:
    - Auckland Council design strategy team
    - Auckland Transport (lunchtime learnings series)
    - Waka Kotahi / NZ Transport Agency
    - The Ministry of Transport (joint Ministry of Transport / Waka Kotahi Workshop)
- A short article for transport professionals' magazine (Roundabout)
- Meetings with
    - Tiffany Robinson, Senior Active Modes Coordinator Sustainable Mobility
    - Roselle Thoreau and Shrividya Vadi, Ministry of Transport
    - Representatives of Connect Wellington and Living Streets Aotearoa
- Summaries shared with the Transport Knowledge Hub and local stakeholders

A technical report is also being prepared for local practitioners.

CHAPTER 2

2A: Reviews and scopes

Information on the codes used to characterise the scopes of the examined reviews

Code	Meaning	Values
Publ	N publications assessed	N
Examined determinants of walking (specifying correlations)		
3D	Destinations availability and other high-level metrics, as determinants to walking (destinations, distance, density; street connectivity is indirectly part)	1 (yes) / 0 (no) If yes: aspects assessed
3D-	.... Objectively assessed (e.g. GIS)	1 (yes) / 0 (no)
3D-	.... Users' perception (e.g. survey)	1 (yes) / 0 (no)
3D-	.... Objective OR users' perceptions, used interchangeably	1 (yes) / 0 (no)
3D-	.... Objective AND users' perceptions, correlation	1 (yes) / 0 (no)
Q	Qualities of the street environment as determinants to walking (walking infrastructure, traffic, aesthetics, etc.)	1 (yes) / 0 (no) If yes: aspects assessed
Q-	.... Objectively assessed (e.g. number of trees)	1 (yes) / 0 (no)
Q-	.... Users' perception (e.g. survey)	1 (yes) / 0 (no)
Q-	.... Experts' perception (e.g. audit)	1 (yes) / 0 (no)
Q-	.... Objective OR users' perceptions, used interchangeably	1 (yes) / 0 (no)
Q-	.... Objective AND users' perceptions, correlation	1 (yes) / 0 (no)
I	Individual characteristics - were the results presented for population sub-groups?	1 (yes) / 0 (no)
I-	.... Disabililty	1 (yes) / 0 (no) If yes: aspects assessed
I-	.... Old age	1 (yes) / 0 (no) If yes: age limit considered
I-	.... Self-selection	1 (yes) / 0 (no)
Walking as an outcome (correlated with walkability features)		
w-Lev	.... Walking levels (number of trips per day/week, etc., or time walked)	1 (yes) / 0 (no)
w-Sev	.... Severance, trips not made	1 (yes) / 0 (no)
Theoretical framework (development or testing)		
Model-dvpt	Develops a theoretical model?	1 (yes) / 0 (no)
Model-dvpt-detail	Name, background, objective of development	text
Model-test	Tests a theoretical model?	1 (yes) / 0 (no)
Model-test-detail	Name, what is tested, objective	text
Critical appraisal of walkability		
Walkability	Questions the meaning of walkability, takes a broader perspective	1 (yes) / 0 (no)

Authors	Year	syst	Title	Examined	Objective, quote	Population	Setting	Analysis of evidence
Andrews G.J., Hall E., Evans B., Colls R.	The built environment and the walking behaviours: A critical review of reviews and new social model of walka	n	Moving beyond walkability: On the potential of health geography	what the sub-discipline of health geography might be able to contribute, beyond what it currently does, to existing debates	*[not clearly stated]; In the context of the substantial volume of research focused in recent years on the walkability of the built environment, this report presents some initial thoughts on what the sub-discipline of health geography might be able to contribute, beyond what it currently does, to existing debates.*	na	(does not apply)	Critical review
Barnett D.W., Barnett A., Nathan A., Van Cauwenberg J., Cerin E.	Additional file A: Studies' scopes and focus		Built environmental correlates of older adults' total physical activity and walking: A systematic review and meta-analysis	BE correlates of older adults' PA and differences by type of PA and environmental attribute measurement, quantitative evidence; ! Urban OR rural; 56 studies urban., 3 rural, 32 mixed, 9 not reported (p. 5); 22 stratified neighbourhood recruitment by urbanization (p. 6)	*The aim of this study was to first systematically review and quantify findings on built environmental correlates of older adults' PA and, second, investigate differences by type of PA and environmental attribute measurement.*	Adults, mean age 65+	Urban OR rural	Meta-analysis
Cerin E., Nathan A., van Cauwenberg J., Barnett D.W., Barnett A.	2017		The neighbourhood physical environment and active travel in older adults: A systematic review and meta-analysis	BE and active travel in older adults, quantitative evidence only; ! Urban OR rural; 34 studies urban, 4 mix - Urban, suburban and/or rural; 3 not reported;	*We systematically reviewed the literature on neighbourhood physical environmental correlates of AT in older adults and applied a novel meta-analytic approach to statistically quantify the strength of evidence for environment-AT associations.*	Adults, mean age 65+	Urban OR rural	Meta-analysis
Eisenberg, Vanderbom, Vasudevan	2017	y	Does the built environment moderate the relationship between having a disability and lower levels of physical activity? A systematic review	role of the built environment as a moderator of the relationship between having a disability (physical, sensory or cognitive) and lower levels of physical activity		Adults with disabilities	Urban OR rural	
Ewing, Cervero	2010		Travel and the built environment: a meta-analysis	Associations between quantitative BE characteristics and use of travel modes, amongst which walking	*The purpose of this meta-analysis is to summarize empirical results on associations between the built environment and travel, especially nonwork travel.*	Not clear, a priori adults ("We excluded many studies because they dealt with limited populations or trip purposes […]. Notably, several recent studies of student travel to school cannot be generalized to other populations and trip purposes.	Urban or suburban	Meta-analysis
Forsyth, A.	2015	n	What is a walkable place? The walkability debate in urban design	Analysis of the concept of walkability, its different dimensions and definitions	*This review both problematizes the idea of walkability and proposes a conceptual framework distinguishing these definitions. This matters for urban design, because what is considered a walkable place varies substantially between definitions leading to substantially different designs. By mapping the range of definitions, this review highlights potential conflicts been forms of walkability.*	All	(does not apply)	Critical review
Grasser G., Van Dyck D., Titze S., Stronegger W.	2013	y	Objectively measured walkability and active transport and weight-related outcomes in adults: A systematic review	GIS-based measures of walkability (density, land-use mix, connectivity and walkability indexes) in urban and suburban neighbourhoods, walking for transports & weight in adults; 34 publications, from 19 studies;	*The aim of this study was to investigate which GIS-based measures of walkability (density, land-use mix, connectivity and walkability indexes) in urban and suburban neighbourhoods are used in research and which of them are consistently associated with walking and cycling for transport, overall active transportation and weight-related measures in adults.*	adults "healthy, white (!) adults, older than 19 years"	Urban or suburban	Descriptive
Haselwandter	2014		The Built Environment, Physical Activity, and Aging in the United States: A State of the Science Review	BE - PA in older adults	*This paper aims to: (1) review the current literature to determine what relationships exist between the built environment and physical activity in older adults; (2) identify features that may act as barriers or enablers among older adults in senior-specific housing; and (3) identify areas of future research for this population*	Adults, 65+	! Not specified	Descriptive
Hutabarat Lo	2009		Walkability: what is it?	Definition of walkability	*In order to understand walkability, it is important to consider how pedestrians are defined and the discourses that shape the development of pedestrian space. This paper examines both these issues and identifies points of agreement and disagreement between metrics for walkability.*	na	(does not apply)	Critical review
Kashef M.	2011	n	Walkability and residential suburbs: A multidisciplinary perspective	Determinants of walkability, examining (1) evidence from environmental health fields, and (2) results from planning, design and transportation studies	*This study develops a nuanced understanding of issues related to suburban design and walkability, which have received increased attention over the last two decades. It examines a broad range of environmental health, transportation and design/planning studies.*	na	suburban	Descriptive
McCormack G.R., Shiell A.	2011		In search of causality: A systematic review of the relationship between the built environment and physical activity among adults		*The aim of this study was to review quantitative studies examining associations between the built environment and physical activity that either used a 1) statistical design to adjust for neighborhood self-selection or 2) experimental or quasi-experimental design with assessment of change in both the built environment and physical activity.*	Adults	Urban	Descriptive
Mindell J.S., Karlsen S.	2012	y	Community severance and health: What do we actually know?	what is known about severance, i.e. lack of walkability, difficulty to access destinations; considered different ages & abilities	*Community severance occurs where road traffic (speed or volume) inhibits access to goods, services, or people. […] Based on a systematic literature search [papers 2000- March 2010], we discuss what is actually known about community severance.*	All	Urban OR rural	Descriptive
Salvo G., Lashewicz B.M., Doyle-Baker P.K., McCormack G.R.	2018	y	Neighbourhood built environment influences on physical activity among adults: A systematized review of qualitative	Qualitative studies, BE --> PA in adults; 36 peer-reviewed qualitative studies (1998+)	*We undertook a systematized literature review to synthesize findings from qualitative studies exploring how the built environment influences physical activity in adults.*	Adults	Urban OR rural	Descriptive

Authors	Publ	3D	3D-detail	3D-O	3D-P-u	3D-OorP-u	3D-OvsP-u	3D-OvsP-u-detail	Q	Q-detail	Q-O	Q-P-u	Q-P-e	Q-OorP-u	Q-OvsP-u	Q-OvsP-u-detail
Andrews G.J., Hall E., Evans B., Colls R.	na	0		0	0	0	0		0		0	0	0	0	0	
Barnett D.W., Barnett A., Nathan A., Van Cauwenberg J., Cerin E.	100	1	Examined all BE characteristics	0	0	0	1	For those attributes with significant correlation with total walking, objective measures were significant (p<0.05) while perceived were not. However, all had significant numbers of non-significant individual findings, and for residential density/urbanization 3.5 of the findings were counter-intuitive (out of 17).	1	Examined all BE characteristics	0	0	0	0	1	For those attributes with significant correlation with total walking (p<0.05), only the perceived measures were statistically correlated, while the objective were not, for greenery and aesthetics and crime/ personal safety. Infrastructure defined as "walk-friendly" was correlated overall but neither the objective nor perceived measures were correlated at 0.05. Traffic/pedestrian safety showed no correlation overall, but was significantly correlated for the perceived measures. For all aspects, large numbers of findings were not
Cerin E., Nathan A., van Cauwenberg J., Barnett D.W., Barnett A.	42	1	Examined all BE characteristics, 3D, Q, PT	0	0	0	1	For those attributes with significant correlation with total walking (p<0.05), residential density and PT were associated both as objective and perceived measures . Street connectivity, only the objective measure was significant, while for the land use mix / diversity of destinations and for the availability of green areas, only the perceived measures were significant. There were no counter-intuitive individual findings but an important number of non-significant individual findings (69/144). All examined parameters had important numbers of non-significant individual findings, with the exception of presence of PT (1 non-significant /5.	1	Examined all BE characteristics, 3D, Q, PT	0	0	0	0	1	neither objective nor perceived measures were individually significantly associated with total walking (p>0.05)
Eisenberg, Vanderbom, Vasudevan	15	1	high-level indicators, GIS	1	0	0	0		1	NEWS and measures of barriers	0	0	1	1	0	
Ewing, Cervero	50	1	5D (density, diversity, street connectivity + distance to destinations and access to PT)	1	0	0	0		0		0	0	0	0	0	
Forsyth, A.	na	0		0	0	0	0		0		0	0	0	0	0	
Grasser G., Van Dyck D., Titze S., Stronegger W.	34	1	density, destinations, land use mix, connectivity	1	0	0	0				0	0	0	0	0	
Haselwandter		1	Destinations, street connectivity, land use mix	0	0	1	0		1	Aesthetics or safety were considered but results were found for PA, not walking specifically	0	0	0	0	0	
Hutabarat Lo		0		0	0	0	0		0		0	0	0	0	0	
Kashef M.	na	0	discussion on destinations, presence of sidewalks, mixed use, green open spaces, but for PA in general and without a clear overview of the positive/ns/ne	0	0	0	0		0	Safety, aesthetics, convenience of facilities - same issue as for 3D	0	0	0	0	0	P poorly correlated to O (can be a dychotomy presence/absence, and not specify quality
McCormack G.R., Shiell A.	33	1	LU mix, residential density, proximity to destinations, sprawl	1	0	0	0		1	few: furniture, lighting, shading, traffic, aesthetics	1	0	0	0	0	
Mindell J.S., Karlsen S.	6	0		0	0	0	0		1	What characteristics of street environments contribute to severance	0	0	0	0	1	Perception of unpleasant environments has a similar effect than the measured one (travel times) on journeys not made.
Salvo G., Lashewicz B.M., Doyle-Baker P.K., McCormack G.R.	36	1	Presence of PT, shops, parks…	0	1	0	0		1	Perceived barriers and facilitators	0	1	0	0	0	

Authors	I	I-detail	I-dis	Disability aspects	I-old	I-old-age	I-ssel	I-ssel detail	Model-dvpt	Model-dvpt-detail	Model-test	Model-test-detail	w-Lev	w-Sev	Walkability
Andrews G.J., Hall E., Evans B., Colls R.			0	not directly, noting that studies tend to disregard diverse abilities	0		0		0		0		0	0	1
Barnett D.W., Barnett A., Nathan A., Van Cauwenberg J., Cerin E.	1	Study for older people, examining moderating effects of age, sex, functionality or driver status for total PA, not walking (additional table S5); primary data focusing on disabled / chronical conditions /	0	Analysed for total PA, but not walking; being mobility-limited significantly moderated the relationship between the overall availability of destinations and total PA (1 study, [17])	1		0	12% of the studies were adjusted for ssel, and the paucity of data is noted The moderating effects of duration of residency were examined, but not self-selection per se (choice of nbh)	0		0	refers to socio-ecological framework; collects all papers' BE-PA findings, reporting BE against pre-defined categories; there is no guarantee that they are complete, minimal and mutually exclusive	1	0	0
Cerin E., Nathan A., van Cauwenberg J., Barnett D.W., Barnett A.	1	Study for 65+ but examined: disability, driver status, self-efficacy, chronic conditions, age 75+	1	Chronic conditions	1	whole population 65+, but detail for 75+	1	Intended to control but noted the paucity of information - only 4 studies controlled for self-selection; the overall lack of data is considered as a large weakness	0	BE attributes based on NEWS categories, because it is the "most popular measure of perceived neighbourhood environmental attributes worldwide" and some additions from the reviewed papers>>> no guarantee that the categories are complete, minimal and mutually exclusive	0		1	0	0
Eisenberg, Vanderbom, Vasudevan	1	disability	1	"Disability" = broad, "serious difficulties" in one of 6 dimensions (hearing, visual, cognitive, ambulatory, self-care, independent living)	0	Noted that most research on older adults, but results reported overall	0		0		0		1	0	0
Ewing, Cervero	1	Examined effects of self-selection	0		0	Population included but no specific report	1	Notes importance, and effect (attenuation of BE-w relationship), but data not specifically reported	0		0		1	0	0
Forsyth, A.	0		0		0		0		0		0		0	0	1
Grasser G., Van Dyck D., Titze S., Stronegger W.			0	Not directly, noting that many study didn't report age / ability	0	Population >19 but reseults not presented for older people	0		0		1	Walkability as density, connectivity, land use mix; examines which measures are used and how they correlate with walking levels	1	0	0
Haselwandter	1	Older adults	0	Notes importance (e.g. results from Rosenberg et al, 13), but does not include them in the results overview	1	Older adults	0		0	Proposes a conceptual framework, where accessibility to destinations, aesthetics and safety contribute to PA, with moderation through age.	0		1	0	0
Hutabarat Lo	0		0		0		0		0		0		0	0	1
Kashef M.	0	Importance of intention	0		0		0		0		0		0	0	1
McCormack G.R., Shiell A.	1	self-selection effects	0		0		1	Attenuation of the BE-w relationships	0		0		1	0	0
Mindell J.S., Karlsen S.	1	Importance of access to car for the ability to make journeys; importance of old age and ability (e.g. walking speed)	1	Noted overall higher barrier threshold	1	Noted higher odds of being a slow walker and therefore struggling to cross car-dominated			1	Theoretical model for the health effects of community severance, linking traffic with walking outcomes.				1	1
Salvo G., Lashewicz B.M., Doyle-Baker P.K., McCormack G.R.	1	Specifics for "older adults"	0		1		0		0		0		1	1	0

Authors	Year	syst	Title	Examined	Objective, quote	Population	Setting	Analysis of evidence	Publ
Stafford L., Baldwin C.	2017	n	Planning Walkable Neighborhoods: Are We Overlooking Diversity in Abilities and Ages?	"critical review of the literature, highlighting existing research practices, known person–environment influences on walkability, and limitations within current knowledge" --- diverse abilities and ages	*This article demonstrates a need for more inclusion of human diversity in walkable neighborhoods research to better inform policy, planning, and design interventions that are spatially and socially just for all ages and all abilities. Our study addresses this through a critical review of the literature, highlighting existing research practices, known person–environment influences on walkability, and limitations within current knowledge.*	Adults	(does not apply)	Critical review	96
Talen, Koschinsky	2013	n	The Walkable Neighborhood: A Literature Review.	Stocktake of the research on "walkable neighbourhoods", to examine how the delivery of better adapted neighbourhoods is supported by the scholarship.	*We take stock of this literature by linking together the various strands of research in which the "walkable neighborhood" is a primary concern. We organize the literature into three broad categories: measurement, criticism, and tests of the benefits of walkable neighborhoods. Our broader interest is to better understand how a key government policy—the promotion of affordable housing in walkable neighborhoods—is supported by scholarship. We hope to add some measure of clarity to a research landscape now crowded with competing claims about what the walkable neighborhood can be expected to do.*	na	(does not apply)	Critical review	
Vale D.S., Saraiva M., Pereira M.	2016	y	Active accessibility: A review of operational measures of walking and cycling accessibility	Different measures of accessibility on foot (and by bike), for any demographic (some studies included disabled adults)	*In this paper, we review objective active accessibility measures, and deliberately exclude perceived accessibility measures. Thus, it is a methodological review of active accessibility measures that can be applied in a variety of urban contexts. Although there are other reviews of accessibility measures (Geurs and Van Wee 2004; Iacono, Krizek, and El-Geneidy 2010; Maghelal and Capp 2011; Talen and Koschinsky 2013), this analysis fills a gap in the literature as it focuses exclusively on active accessibility and operational measures that can be reproduced in different contexts.*	na	(does not apply)	Methodological review	32
Won et al	2016	y	Neighborhood safety factors associated with older adults' health-related outcomes: A systematic literature review,	Neighbourhood safety and its impacts on health and behaviors, including walking (only 9 studies - frequency or total t), in older adults; disability considered as a health condition	*This systematic literature review, following the PRISMA guidelines, focuses on identifying neighborhood safety factors associated with health-related outcomes and behaviors of older adults in the U.S.*	Adults, 50+	Urban OR rural	Descriptive	32

Authors	3D	3D-detail	3D-O	3D-P-u	3D-OorP-u	3D-OvsP-u	3D-OvsP-u-detail	Q	Q-detail	Q-O	Q-P-u	Q-P-e	Q-OorP-u	Q-OvsP-u	Q-OvsP-u-detail
Stafford L., Baldwin C.	0	Critical appraisal of use of 3D to assess walkability for different groups	0	0	0	0	3D important but not enough No one size fits allImportance of individual characteristics and attitudes Risk of biased measures, e.g. connectivity - streets, or footpaths? e.g. footpath connectivity and NOT street influences walking in impaired children	0	Critical appraisal of use of 3D to assess walkability for different groups	0	0	0	0	0	Importance of better operationalising /measuring aspects of BE, to capture the "what" causes barriers
Talen, Koschinsky	0		0	0	0	0		0		0	0	0	0	0	
Vale D.S., Saraiva M., Pereira M.	0		0	0	0	0		0		0	0	0	0	0	
Won et al	0		0	0	0	0		1	Perceived and measured aspects related to safety	0	0	0	1	0	

Authors	I	I-detail	I-dis	Disability aspects	I-old	I-old-age	I-ssel	Ssel detail	Model-dvpt	Model-dvpt-detail	Model-test	Model-test-detail	w-Lev	w-Sev	Walkability
Stafford L., Baldwin C.	1	Importance of impairments	1	Examining specific requirements But noting lack of evidence re needs of people with disabilities	1	Examining specific requirements	0		0		0		0	0	1
Talen, Koschinsky	0		0		0		0		0		0		0	0	1
Vale D.S., Saraiva M., Pereira M.			0	Not directly. Some studies included it, but review didn't focus on disability-related accessibility measures	0		0		1	Relationship between built environment factors and active accessibility; Specification issues used to evaluate accessibility measures; based on Behavioral Model of the Environment (Lee and Moudon 2004; Moudon and Lee 2003) , socio-	0				1
Won et al	1	Study for 50+, disability-related specific issues noted	1	Physical limitations noted as a factor correlated with poorer perceived safety	1										

2B: Detail findings

(See next pages)

	Barnett D.W., Barnett A., Nathan A., Van Cauwenberg J., Cerin E. ,2017	Cerin E., Nathan A., van Cauwenberg J., Barnett D.W., Barnett A. ,2017	Salvo G., Lashewicz B.M., Doyle-Baker P.K.,	Ewing, Cervero, 2010	Eisenberg, Vanderbom, Vasudevan, 2017	McCormack G.R., Shiell A., 2011
Population	Adults, mean age 65+	Adults, mean age 65+	Adults	Not clear, a priori adults ("We excluded many studies because they dealt with limited	Adults with disabilities	Adults
Area	Urban OR rural	Urban OR rural	Urban OR rural	Urban or suburban	Urban OR rural	Urban
Walking outcome	**Total walking**	**Total walking**	**Total walking**	**Total walking**	**Neighbourhood walking**	"General walking", associated here with total wa
Data reference	Table 5, Associations of environmental attributes/correlates with older adults' physical activity by physical activity and environmental measures (objective	Table 3, Summary table of associations of neighbourhood physical environmental correlates of active travel in older adults (1)	Extracted from 3.1. Summary of Study Methods - see specific sheet for details (1)	Data source: Table A-7 Elasticity of walk trips with respect to density.	(1)	Table 1, Summary of associations between built environmental attributes and physical

				Barnett et al., 2017							Cerin et al., 2017						
				P	**Ø**	**N**	**pa**	**Da (1)**	**% Ø**	**% N**	**P**	**Ø**	**N**	**pa**	**Da (1)**	**% Ø**	**% N**
	(2)	**(3)**	**3D - Destinations availability**														
	P	**!**	Composite walkability index*	4.37	3.63	0	0.001	**P**	45%	0%	8	1	0	<.001	**P**	11%	0%
	P	**!**	Residential density/urbanisation*	8	14.5	3.5	0.036	**P**	56%	13%	7	6	0	<.001	**P**	46%	0%
	P		Land-use mix—destination diversity*	1	8	2	0.439	Ø	73%	18%	10.5	6.5	0	<.001	**P**	38%	0%
	P		Retail floor area ratio	na	na	na	na	na			na	na	na	na	na		
Feasibility	**P**		Street connectivity*	5.71	13.2	2	0.185	Ø	63%	10%	5	10	0	0.014	**P**	67%	0%
	P		Connected pedestrian infrastructure*	na	na	na	na	na			na	na	na	na	na		
	P		Overall access to destinations & services (distance to, availability)*	6.93	25.57	0.5	0.009	**P**	77%	2%	6.5	7.5	0	<.001	**P**	54%	0%
	P		Acess to public transport (distance to, availability)*	5.5	11.5	1	0.011	**P**	64%	6%	8.2	1.8	0	<.001	**P**	18%	0%
	P		Parks/public open space (distance to, availability)*	6.05	23.78	0.17	0.014	**P**	79%	1%	6.93	10.07	0	0.001	**P**	59%	0%
			Detail - availability of specific destinations (distance to, availability)*														
	P		Shops/commercial*	8.58	23.42	0	0.001	**P**	73%	0%	5.33	3.67	0	<.001	**P**	41%	0%
	P		Food outlets*	0.72	6.28	1	0.873	Ø	79%	13%	1	5	0	0.542	Ø	83%	0%
	P		Education*	0.14	2.85	0	0.826	Ø	95%	0%	4	5	1	0.112	Ø	50%	10%
	P		Health & aged care*	3.61	7.39	1	0.191	Ø	62%	8%	2	3	1	0.451	Ø	50%	17%
	P		Recreational facilities*	5.5	11.5	1	0.011	P	64%	6%	0	2	0	1	Ø	100%	0%
	P		Social recreational facilities*	6.05	23.78	0.17	0.014	P	79%	1%	8.2	1.8	0	<.001	P	18%	0%
	P		Jobs*	na	na	na	na	na			na	na	na	na	na		
			Street environment														
Safety from crime	**P**	**!**	Safety from crime*	10.49	28.01	2.5	0.027	**P**	68%	6%	2	15.86	3.14	0.667	Ø	76%	15%
	P		Design - "eyes on the street", active facades*	na	na	na	na	na			na	na	na	na	na		
	P		Lighting* (! Could be also comfort)	na	na	na	na	na			1	3	0	0.29	Ø	75%	0%
	N		Littering, vandalism, decay* (part of "aesthetics", for Haselwandte	na	na	na	na	na			0.72	2.28	3	0.05	**N**	38%	50%
	N		Presence of people seen as threatening*	na	na	na	na	na			2	15.86	3.14	0.667	Ø	76%	15%
	P		Presence of other people walking*	na	na	na	na	na			na	na	na	na	na		
	P		Presence of other people walking OR driving*	na	na	na	na	na			2	1	0	0.024	P	33%	0%
	P		Presence of police*	na	na	na	na	na			na	na	na	na	na		
Accessibility	**N**	**!**	Barriers to walking*	na	na	na	na	na			na	na	na	na	na		
	N		Barriers - incomplete walking infrastructure*	na	na	na	na	na			na	na	na	na	na		
	N		Barriers - not sufficient crossing facilities*	na	na	na	na	na			na	na	na	na	na		
	N		Barriers - footpaths design*	na	na	na	na	na			na	na	na	na	na		
	N		Barriers - footpaths maintenance / cluttering*	na	na	na	na	na			na	na	na	na	na		
	N		Detours, pedestrian network not allowing convenient use*	na	na	na	na	na			na	na	na	na	na		
	P		Absence of physical barriers*	na	na	na	na	na			na	na	na	na	na		
Comfort	**P**		Safety from traffic*	5	25	3	0.705	Ø	76%	9%	3	19.49	1.51	0.484	Ø	81%	6%
	P		Safe and convenient crossing facilities*	na	na	na	na	na			na	na	na	na	na		
	P		Room for walking	na	na	na	na	na			na	na	na	na	na		
	P		Possibility to sit	na	na	na	na	na			2	2	0	0.048	**P**	50%	0%
	P		Availability of public toilets	na	na	na	na	na			0	2	0	1	Ø	100%	0%
	P		Protection from sun/rain/wind	na	na	na	na	na			na	na	na	na	na		
	P		Low levels of noise	na	na	na	na	na			na	na	na	na	na		
	N		Air pollution	na	na	na	na	na			na	na	na	na	na		
	N		Noise	na	na	na	na	na			na	na	na	na	na		
Pleasurability	**P**		Greenery, landscaping, "aesthetically pleasing" scenery*	10.51	19.49	0	0.002	**P**	65%	0%	3.01	11.99	0	0.189	Ø	80%	0%
	P		Attractive zones for sitting / public spaces*	na	na	na	na	na			na	na	na	na	na		
	P		Liveliness, activation, diversity, complexity (interesting walking realm)*	na	na	na	na	na			na	na	na	na	na		
	P	**!**	"Walk-friendly infrastructure" or "pedestrian-friendly features"*	5	15	0	0.042	**P**	75%	0%	6.76	18.24	1	0.024	**P**	70%	4%
	P	**!**	Good design (e.g. human scale, right enclosure)*	na	na	na	na	na			na	na	na	na	na		
	N		Unkeep*	na	na	na	na	na			na	na	na	na	na		
			Total	**93**	**263**	**18**					**95**	**155**	**14**				
			Ratio significant unexpected / expected results	**16%**							**10%**						
			Ratio non-significant results	**70%**							**59%**						
	3D only		**Total**	62.2	175.4	12.3					72.7	63.3	2.0				
			Ratio non-significant results	70%							46%						

	Salvo et al.				Ewing, Cervero, 2010				Eisenberg et al., 2017				McCormack, Shiell, 2011			
	P	**Ø**	**N**	**Da (1)**	**P**	**Ø**	**N**	**Da (1)**	**P**	**Ø**	**N**	**Da (1)**	**P**	**Ø**	**N**	**Da (1)**
3D - Destinations availability																
Composite walkability index*	na	na	na	na	na	na	na	na	1	1	0	Ø	na	na	na	na
Residential density/urbanisation*	na	na	na	na	2	na	1	Ø	1	1	0	Ø	na	na	na	na
Land-use mix—destination diversity*	na	na	na	na	1	na	0	P	na	na	na	na	1	0	0	P
Retail floor area ratio	na	na	na		1	na	0	P	na	na	na		na	na	na	
Street connectivity*	na	na	na	na	6	na	0	**P**	0	1	0	Ø	2	0	0	P
Connected pedestrian infrastructure*	4	na	0	P	2	na	0	P	na	na	na	na	1	0	1	na
Overall access to destinations & services (distance to, availability)*	na	na	na	na	na	na	na	na	1	0	0	P	1	0	0	P
Acess to public transport (distance to, availability)*	4	na	0	P	na	na	na	na	na	na	na	na	0	1	1	Ø
Parks/public open space (distance to, availability)*	2	na	0	P	na	na	na	na	na	na	na	na	1	1	0	Ø
Detail - availability of specific destinations (distance to, availability)*	na	na	na	na	na	na	na	na	0	0	0		na	na	na	na
Shops/commercial*	5	na	0	**P**	na	na	na	na	1	1	0	Ø	na	na	na	na
Food outlets*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Education*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Health & aged care*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Recreational facilities*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Social recreational facilities*	na	na	na	na	na	na	na	na	na	na	na	na	0	1	0	Ø
Jobs*	na	na	na	na	3	na	0	P	na	na	na	na	1	1	0	Ø
Street environment																
Safety from crime*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Design - "eyes on the street", active facades*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Lighting* (! Could be also comfort)	6	na	0	**P**	na	na	na	na	na	na	na	na	1	0	0	P
Littering, vandalism, decay* (part of "aesthetics", for Haselwandte	0	na	5	**N**	na	na	na	na	na	na	na	na	na	na	na	na
Presence of people seen as threatening*	0	na	6	**N**					na	na	na	na	na	na	na	na
Presence of other people walking*	2	na	0	P	na	na	na	na	na	na	na	na	na	na	na	na
Presence of other people walking OR driving*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Presence of police*	4	na	2	Ø	na	na	na	na	na	na	na	na	na	na	na	na
Barriers to walking*	na	na	na		na	na	na		na	na	na	na	na	na	na	na
Barriers - incomplete walking infrastructure*	0	na	4	N	na	na	na	na	na	na	na	na	na	na	na	na
Barriers - not sufficient crossing facilities*	0	na	1	N	na	na	na	na	na	na	na	na	na	na	na	na
Barriers - footpaths design*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Barriers - footpaths maintenance / cluttering*	0	na	4	N	na	na	na	na	na	na	na	na	na	na	na	na
Detours, pedestrian network not allowing convenient use*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Absence of physical barriers*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Safety from traffic*	na	na	na	na	na	na	na	na	na	na	na	na	0	1	0	Ø
Safe and convenient crossing facilities*	1	na	0	P	na	na	na	na	na	na	na	na	na	na	na	na
Room for walking	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Possibility to sit	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Availability of public toilets	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Protection from sun/rain/wind	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Low levels of noise	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Air pollution	0	na	2	N	na	na	na	na	na	na	na	na	na	na	na	na
Noise	0	na	3	N	na	na	na	na	na	na	na	0	na	na	na	na
Greenery, landscaping, "aesthetically pleasing" scenery*	6	na	0	**P**	na	na	na	na	na	na	na	na	na	na	na	na
Attractive zones for sitting / public spaces*	na	na	na	na	na	na	na	na	na	na	na	na	1	0	0	P
Liveliness, activation, diversity, complexity (interesting walking realm)*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
"Walk-friendly infrastructure" or "pedestrian-friendly features"*	na	na	na	na	na	na	na	na	0	1	0	Ø	1	1	2	Ø
Good design (e.g. human scale, right enclosure)*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Unkeep*	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Total	**34**		**27**		**15**		**1**		**4**	**5**	**0**		**10**	**6**	**4**	
Ratio significant unexpected / expected results	**3%**				**6%**				**0%**				**29%**			
Ratio non-significant results	**na**				**na**				**56%**				**30%**			
3D only — Total	15.0		0.0		15.0		1.0		4.0	4.0	0.0		7.0	4.0	2.0	
Ratio non-significant results									50%				31%			

Notes

1 Directions of associations after full adjustment for sample size and study quality; P = positive (p<0.05), Ø = non-significant, N = negative (p<0.05). Bold: 5 or more findings

2 Expected direction of association: P (positive) or N (negative)

3 Sign "!" placed in front of indicators not referring to a specific BE feature but rather a cluster of features; the associations with walking do not allow to assess the relative importance of specific features

***** Indicators reflecting the authors' categories; caution, authors' clustering and primary studies' ways of measuring components might vary, and some overlaps exist (e.g. "safe and convenient crossing facilities" is part of a broader "safety from

			Study	Haselwandter, 2014				TOTAL				TOTAL					TOTAL				Ewing, Cervero, 2010				Grasser G., Van Dyck D., Titze S., Stronegger W., 2013			
			Population	Adults, 65+																	Not clear, a priori adults ("We excluded many studies because they de				adults "healthy, white (!) adults, older than 18 years"			
			Area	! Not specified				Urban or rural				Urban or rural					Urban/suburban only											
			Walking outcome	**Total walking**				**Total walking**				**Total walking**					**Total walking**				Walking for transport				Walking for transport			
			Data reference	Table 1 A Review of Measures and Results in Studies Examining the Built Environment in Seniors p. 225 (1)				All studies				From all studies that reported non-significant results					Only studies focusing on urban realms				Data source: Table A-7 Elasticity of walk trips with respect to density. Table A-8 Elasticity of walk trips				Table 1, Number of studies reporting significant associations in relation to all included studies			
				P	**Ø**	**N**	**Da (1)**	**P**	**Ø**	**N**	**N/(P+N)**	**P**	**Ø**	**N**	**%N**	**%Ø**	**P**	**Ø**	**N**	**N/(P+N)**	**P**	**Ø**	**N**	**Da**	**P**	**Ø**	**N**	**Da**
	(2)	**(3)**	**3D - Destinations availability**																									
	P	!	Composite walkability index*	2.67	0.33	0.00	P	**16.37**		**0**	0%	16	6	0	0%	27%	na		na		na	na	na	na	4	0	0	P
	P	!	Residential density/urbanisation*	na	na	na	na	**18**		**4.5**	20%	16	22	4	9%	52%	**2**		**1**	33%	na	na	na	na	4	0	0	P
	P		Land-use mix—destination diversity*	na	na	na	na	**13.5**		**2**	13%	13	15	2	7%	50%	**2**		**0**	0%	1	na	0	P	2	2	0	Ø
	P		Retail floor area ratio	na	na	na		**1**		**0**	0%	na	na	na	na	na	**1**		**0**	0%	1	na	0	P	na	na	na	na
Feasibility	P		Street connectivity*	0.50	0.50	0.00	Ø	**19.71**		**2**	9%	13	25	2	5%	62%	**8**		**0**	0%	na	na	na	na	4	0	0	P
	P		Connected pedestrian infrastructure*	na	na	na	na	**7**		**1**	13%	1	0	1	50%	0%	**3**		**1**	25%	1	na	0	P	na	na	na	na
	P		Overall access to destinations & services (distance to, availability)*	na	na	na	na	**15.43**		**0.5**	3%	15	33	1	1%	67%	**1**		**0**	0%	na	na	na	na	na	na	na	na
	P		Acess to public transport (distance to, availability)*	na	na	na	na	**17.7**		**2**	10%	14	14	2	7%	48%	**0**		**1**	100%	na	na	na	na	na	na	na	na
	P		Parks/public open space (distance to, availability)*	na	na	na	na	**15.98**		**0.17**	1%	14	35	0	0%	71%	**1**		**0**	0%	na	na	na	na	na	na	na	na
			Detail - availability of specific destinations (distance to, availability)*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Shops/commercial*	na	na	na	na	**19.91**		**0**	0%	15	28	0	0%	65%	**na**		**na**		3	na	0	P	na	na	na	na
	P		Food outlets*	na	na	na	na	**1.72**		**1**	37%	2	11	1	7%	81%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Education*	na	na	na	na	**4.14**		**1**	19%	4	8	1	8%	60%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Health & aged care*	na	na	na	na	**5.61**		**2**	26%	6	10	2	11%	58%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Recreational facilities*	na	na	na	na	**5.5**		**1**	15%	6	14	1	5%	68%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Social recreational facilities*	na	na	na	na	**14.25**		**0.17**	1%	14	27	0	0%	65%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Jobs*	na	na	na	na	**4**		**0**	0%	1	1	0	0%	50%	**4**		**0**	0%	na	na	na	na	1	0	0	P
																								na				na
			Street environment																					na				na
Safety from crime	P	!	Safety from crime*	na	na	na	na	**12.49**		**5.64**	31%	12	44	6	9%	71%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Design - "eyes on the street", active facades*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Lighting* (! Could be also comfort)	na	na	na	na	**8**		**0**	0%	2	3	0	0%	60%	**1**		**0**	0%	na	na	na	na	na	na	na	na
	N		Littering, vandalism, decay* (part of "aesthetics", for Haselwandte	na	na	na	na	**0.72**		**8**	92%	1	2	3	50%	38%	**na**		**na**		na	na	na	na	na	na	na	na
	N		Presence of people seen as threatening*	na	na	na	na	**2**		**9.14**	82%	2	16	3	15%	76%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Presence of other people walking*	na	na	na	na	**2**		**0**	0%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Presence of other people walking OR driving*	na	na	na	na	**2**		**0**	0%	2	1	0	0%	33%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Presence of police*	na	na	na	na	**4**		**2**	33%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
Accessibility	N	!	Barriers to walking*	na	na	na		**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Barriers - incomplete walking infrastructure*	na	na	na	na	**0**		**4**	100%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Barriers - not sufficient crossing facilities*	na	na	na	na	**0**		**1**	100%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Barriers - footpaths design*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Barriers - footpaths maintenance / cluttering*	na	na	na	na	**0**		**4**	100%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Detours, pedestrian network not allowing convenient use*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Absence of physical barriers*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
Comfort	P		Safety from traffic*	na	na	na	na	**8**		**4.51**	36%	8	45	5	8%	78%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Safe and convenient crossing facilities*	na	na	na	na	**1**		**0**	0%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Room for walking	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Possibility to sit	na	na	na	na	**2**		**0**	0%	2	2	0	0%	50%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Availability of public toilets	na	na	na	na	**0**		**0**		0	2	0	0%	100%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Protection from sun/rain/wind	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P		Low levels of noise	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Air pollution	na	na	na	na	**0**		**2**	100%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Noise	na	na	na		**0**		**3**	100%	na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
Pleasurability	P		Greenery, landscaping, "aesthetically pleasing" scenery*	na	na	na	na	**19.52**		**0**	0%	14	31	0	0%	70%	**na**		**na**		na	na	na	na	na	na	na	na
	P		Attractive zones for sitting / public spaces*	na	na	na	na	**1**		**0**	0%	1	0	0	0%	0%	**1**		**0**	0%	na	na	na	na	na	na	na	na
	P		Liveliness, activation, diversity, complexity (interesting walking realm)*	na	na	na	na	**0**		**0**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	P	!	"Walk-friendly infrastructure" or "pedestrian-friendly features"*	na	na	na	na	**12.76**		**3**	19%	13	35	3	6%	69%	**1**		**2**	67%	na	na	na	na	na	na	na	na
	P	!	Good design (e.g. human scale, right enclosure)*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
	N		Unkeep*	na	na	na	na	**na**		**na**		na	na	na	na	na	**na**		**na**		na	na	na	na	na	na	na	na
			Total	**3**	**1**	**0**		**255**		**64**	**20%**	**205**	**430**	**36**	**5%**	**64%**	**25**		**5**	**17%**	**6**		**0**				**0**	
			Ratio significant unexpected / expected results	**0%**				**11%**				**13%**					**17%**				**0%**							
			Ratio non-significant results	**21%**				na				**64%**																
	3D only		**Total**	3.2	0.8	0.0		179.8	0.0	17.3		149.0	247.6	16.3	**0.0**	**0.6**	22.0	0.0	3.0		6.0	0.0	0.0		15.0	2.0	0.0	
			Ratio non-significant results	21%				0%				60%					0%				0%				12%			

**Not
es**

1 Directions of associations after full adjustment for sample size and study quality; F

2 Expected direction of association: P (positive) or N (negative)

3 Sign "!" placed in front of indicators not referring to a specific BE feature but rathe

***** Indicators reflecting the authors' categories; caution, authors' clustering and prima

			Study	McCormack G.R., Shiell A., 2011				TOTAL			
			Population	Adults							
			Area								
			Walking outcome	Walking for transport				Walking for transport			
			Data reference	Table 1, Summary of associations between built environmental attributes and physical activity							
				P	**Ø**	**N**	**Da**	**P**	**Ø**	**N**	**N/(P+N)**
	(2)	**(3)**	**3D - Destinations availability**								
	P	**!**	Composite walkability index*	3	0	0	P	**7**		**0**	0%
	P	**!**	Residential density/urbanisation*	1	0	0	P	**5**		**0**	0%
	P		Land-use mix—destination diversity*	1	0	0	P	**4**		**0**	0%
	P		Retail floor area ratio	na	na	na	na	**1**		**0**	0%
Feasibility	**P**		Street connectivity*	na	na	na	na	**4**		**0**	0%
	P		Connected pedestrian infrastructure*	1	0	0	P	**2**		**0**	0%
	P		Overall access to destinations & services (distance to, availability)*	1	0	3	N	**1**		**3**	75%
	P		Acess to public transport (distance to, availability)*	na	na	na	na	**na**		**na**	
	P		Parks/public open space (distance to, availability)*	na	na	na	na	**na**		**na**	
			Detail - availability of specific destinations (distance to, availability)*	na	na	na	na	**na**		**na**	
	P		Shops/commercial*	na	na	na	na	**3**		**0**	0%
	P		Food outlets*	na	na	na	na	**na**		**na**	
	P		Education*	na	na	na	na	**na**		**na**	
	P		Health & aged care*	na	na	na	na	**na**		**na**	
	P		Recreational facilities*	0	1	0	Ø	**0**		**0**	
	P		Social recreational facilities*	na	na	na	na	**na**		**na**	
	P		Jobs*	na	na	na	na	**1**		**0**	0%
							na				
			Street environment				na				
Safety from crime	**P**	**!**	Safety from crime*	na	na	na	na	**na**		**na**	
	P		Design - "eyes on the street", active facades*	na	na	na	na	**na**		**na**	
	P		Lighting* (! Could be also comfort)	na	na	na	na	**na**		**na**	
	N		Littering, vandalism, decay* (part of "aesthetics", for Haselwandte	na	na	na	na	**na**		**na**	
	N		Presence of people seen as threatening*	na	na	na	na	**na**		**na**	
	P		Presence of other people walking*	na	na	na	na	**na**		**na**	
	P		Presence of other people walking OR driving*	na	na	na	na	**na**		**na**	
	P		Presence of police*	na	na	na	na	**na**		**na**	
Accessibility	**N**	**!**	Barriers to walking*	na	na	na	na	**na**		**na**	
	N		Barriers - incomplete walking infrastructure*	na	na	na	na	**na**		**na**	
	N		Barriers - not sufficient crossing facilities*	na	na	na	na	**na**		**na**	
	N		Barriers - footpaths design*	na	na	na	na	**na**		**na**	
	N		Barriers - footpaths maintenance / cluttering*	na	na	na	na	**na**		**na**	
	N		Detours, pedestrian network not allowing convenient use*	na	na	na	na	**na**		**na**	
	P		Absence of physical barriers*	na	na	na	na	**na**		**na**	
Comfort	**P**		Safety from traffic*	1	0	0	P	**1**		**0**	0%
	P		Safe and convenient crossing facilities*	na	na	na	na	**na**		**na**	
	P		Room for walking	na	na	na	na	**na**		**na**	
	P		Possibility to sit	na	na	na	na	**na**		**na**	
	P		Availability of public toilets	na	na	na	na	**na**		**na**	
	P		Protection from sun/rain/wind	na	na	na	na	**na**		**na**	
	P		Low levels of noise	na	na	na	na	**na**		**na**	
	N		Air pollution	na	na	na	na	**na**		**na**	
	N		Noise	na	na	na	na	**na**		**na**	
Pleasurability	**P**		Greenery, landscaping, "aesthetically pleasing" scenery*	0	1	0	Ø	**0**		**0**	
	P		Attractive zones for sitting / public spaces*	na	na	na	na	**na**		**na**	
	P		Liveliness, activation, diversity, complexity (interesting walking realm)*	na	na	na	na	**na**		**na**	
	P	**!**	"Walk-friendly infrastructure" or "pedestrian-friendly features"*	0	1	0	Ø	**0**		**0**	
	P	**!**	Good design (e.g. human scale, right enclosure)*	na	na	na	na	**na**		**na**	
	N		Unkeep*	na	na	na	na	**na**		**na**	
			Total	**8**		**3**		**29**		**3**	**9%**
			Ratio significant unexpected / expected results	**27%**				**9%**			
			Ratio non-significant results								
	3D only		**Total**	7.0	1.0	3.0		28.0	0.0	3.0	
			Ratio non-significant results	9%				0%			

Notes

1 Directions of associations after full adjustment for sample size and study quality; F

2 Expected direction of association: P (positive) or N (negative)

3 Sign "!" placed in front of indicators not referring to a specific BE feature but rathe

***** Indicators reflecting the authors' categories; caution, authors' clustering and prima

2C: Findings, continued: assessments of parts of the model

First author and year	Aspects of the model tested	Methods and setting	Findings	Limitations
Fancello 2020 [1]	Importance of different levels of the hierarchy of needs and associations with demographic characteristics	Survey (in person and online) of residents of a small Italian town. N = 358	• **Demographic characteristics** associated with the relative importance of different walking needs (e.g. pleasantness very important for a cluster of mostly young, unemployed women engating in PA and living in the city centre, but having low importance for working women not engaging in PA)	• No lens relative to trip purpose (examining walking routes to points of the city suggested by researchers) • No lens relative to types and levels of disability
Nakamura 2020 [2]	Associations between demographic characteristics, P, and willingess to walk	Use of virtual reality and video footage of chosen street environments, and participant rating of different indicators of walkability N = 50	• **Demographic characteristics** associated with P: indicators of convenience and safety (legibility, presence of obstacles, or safety of crossings) were better rated by: ○ Participants not owning cars ○ Participants familiar with the shown segment ○ Participants walking more ofen • Suggested associations between levels of the hierarchy of walking needs: indicators of low level needs (convenience and safety) were associated with indicators of high level needs (comfort and attractiveness, including streetscape quality, vibrancy, feeling of relaxation but also famiiliarity)	• Limited sample non-representative of the overall population (civil engineering students aged 20-22, 48 males out of 50, a priori non-disabled) • Familiarity coded as a part of the construct “comfort and attractiveness”, while it could be considered as an individual characteristic

CHAPTER 3

3A: Methodology: search strategy

Overview

The search was based on (1) systematic database screening using defined search terms; (2) database screening for reviews citing the papers on the development of the model.
The search strategy was designed considering the strategies used by recent related systematic reviews, sensitivity tested and checked with a subject liaison librarian. The search terms focus on three topics:

1. Built environment: Local streets environments and elements of its quality
2. User: Users' perceptions
3. Mode of travel: Access by own means, or walking

Databases

Given the interdisciplinary nature of this research topic, databases relative to several fields were screened: health (CINAHL Complete, MedLine, PsycInfo, Sage Journals Public Health and SPORTDiscus); urban design (Art & Architecture Complete); transportation (Transportation Research Board); ergonomics and human factors (Ergonomics Abstracts); and social sciences (Humanities International Index, SocINDEX, and Sage Journals Social Sciences and Sociology). The Journal of Transport and Health is an important and recent publication, not indexed for now in the pre-cited databases, and is therefore added to the sources. The detailed search strategy is presented below.

Types of study included

Systematic reviews, non-systematic reviews, and thematic syntheses.

Condition or domain being studied

This umbrella review is part of a broader research aiming at informing the social model of walkability described above, and providing insights for street environment retrofits for Auckland, New Zealand. Therefore, it focuses on urban/suburban environments and examine evidence from places that can a priori be comparable to Auckland's context. This comparability has been framed in terms of human development index and car ownership, with thresholds defined below. The dimension of car ownership has been included as a proxy for the focus on traffic in street design.

Participants/population

Participants are adults (defined as 18+). The focus on adults is informed by the scope of the broader research, informing the social model of walkability explicitly for adults.

Intervention(s), exposure(s)

This analysis does not consider a specific intervention. This is a cross-sectional analysis where the street environment participants face is considered the exposure. As per need of comparability presented above, the "street environment" relates to (1) urban or suburban environments; (2) in countries a high or very high Human Development Index (HDI) and levels of car ownership of 200 or more vehicles per 1,000 population. The conditions on the geographical context are imposed so to exclude situations that could be considered as too different from New Zealand (having a very high HDI and an also high level of car ownership, at 770/1000 residents).
Based on an initial scoping, we don't expect a significant body of longitudinal evidence.

Comparator(s)/control

As per above, the evidence is expected to be mainly cross-sectional, relating street environment characteristics c1…x to perceptions p1…y. Therefore, for each identified ci - pj pair, the review will note the reviews' findings on the correlation, indicating the population group at the detail noted by the survey.
E.g. The objective characteristic "Absence of dropped curbs" could be linked with the perception "difficulty of access", and the correlation might be significant and negative for wheelchair users while non-significant for able-bodied adults.

Main outcome(s)

The perceived satisfaction of the street environment in the context of meeting walking needs.
These perceptions are framed using the social model of walkability described above, referring to a hierarchy ranging from the most basic needs (feasibility of the trip on foot) to the most sophisticated ones (pleasure), covering aspects such as perceived barriers, (un)safety or (un)pleasantness.

Additional outcome(s)

If the reviews report a further relation to levels of walking, this is noted.

Detailed search strategy

Concepts and terms
Key concepts for the search

1. Built environment: Local streets environments and elements of its quality
2. User: Users' perceptions
3. Mode of travel: Access by own means, or walking

Key words relative to each concept

Concept	Search
Streets environment	"urban form" OR "urban design" OR streetscape* OR street* OR "built environment*" OR neighborhood OR neighbourhood OR "physical environment*" OR "travel environment*" OR "road environment*" OR "traffic volume" OR "traffic speed*"
Perception	Perception* OR perceived OR subjective OR "self-report*" OR "self report*" OR experience* OR feeling* OR "sense of" OR phenomenological OR phenomenology OR pleasant* OR unpleasant OR easy OR ease OR difficult* OR supportive OR enjoy* OR stress OR stressful OR threatening OR barrier* OR obstacle* OR encourag* OR discourag* OR motivating OR attractive OR unattractive OR worry OR fear
Walking or access	walk* OR access* OR severance OR pedestrian* OR "foot traffic" OR "physical activity" OR "active travel" OR "active mode*"

The concepts were tested alone and then combined, checking quickly the relevance of the results obtained; the search terms were amended and adjusted.
Not all databases allow to filter efficiently for reviews. When this is an issue, the search is completed by including "AND review*" in the search, to be looked up within the title or the abstract.
An additional search is done with the term "thematic synthesis" in the title, abstract or key words, instead of the filtering by review status or using the search term "review*".

Overall search
(Streets environment) AND (Perception) AND (walking or access) [AND review* OR "thematic synthesis"]
Test with Scopus: 180 reviews published in peer-reviewed journals/ in E-F-S-D.

Period of publication

PROSPERO registration: 10 years, up to 23.3.2019.
Update: between April 2009 and November 2020. The rate of publication on walkability increased strongly after 2009 (74% of the entries re "walkability", in Scopus, date from 2009 or after). Starting from 2009 allowed therefore to capture most of the evidence while reducing the risk of primary results being repeated.

Databases

- EBSCO - Art & Architecture Complete, Australia/New Zealand Reference Centre, CINAHL Complete, eBook Collection (EBSCOhost), Ergonomics Abstracts, Humanities International Index, MEDLINE, SocINDEX with Full Text, SPORTDiscus with Full Text, OpenDissertations
- Scopus
- Transportation Research Board
- Sage Journals Public Health, Social Sciences, and Sociology
- Journal of Transport and Health

Inclusion criteria

Dimension	Inclusion criteria
Streets environments and their qualities, or Built Environment (BE)	Review examines specific objective aspects of the quality of the built environment (BE) as dependent variable influencing people's perceptions (P)
Perception of / satisfaction with the walking environment (P)	Review reports on specific elements of satisfaction regarding the walking environment as the outcome variable
Walking / wheeling (w)	Review reports the elements above in relation to specifically to walking or wheelchair as transport modes (and not for instance "active modes", that can induce confusion mixing possibly different needs for modes such as walking or cycling)
Population	Adults (18+), or reviews examining adults and children, or urban and rural living, but reporting clearly for adults.
Review design and primary studies examined	Systematic peer-reviewed literature reviews and review-type of documents from selected stakeholders (considered separately); Both quantitative and qualitative considered; Both individual or community level considered
Language	English, French, Spanish or German
Geographical area	Exposure: urban/ suburban streets environment. Review presents data for contexts that can be comparable with New Zealand. The criteria set for this are: Human Development Index: Countries with high or very high HDI (NZ: very high) Car ownership: countries with over 200 cars / 1,000 population (NZ 770)

3B: Data extraction

Data relative to the literature review										Data relative to the associations between objective WE characteristics and perceived walkability			
Code	Year	First author	Title	Aim	Population, ages	Population, impairments	Setting (urban/ rural)	N primary studies	Quality score [1-7]	Code	Associations - direct quotes	Reference	Geographic area
LR2-1	2018	Bruggencate, T.T.	Social needs of older people: A systematic literature review	"give more insight into the social needs of older people"	65+	Community-dwelling, but not more detail	Not defined	na	6	2	Pubs, churches and other third places provide social connectedness. Rather than age related facilities inter-generational access is preferred.	Buz et al, 2014	Spain
LR2-2	2017	Bullough, John D	Real-World Demonstrations of Novel Pedestrian Crosswalk Lighting	implicit: examine effects of better lighting at pedestrian crossings	not specified	not specified	suburban	na	1	10	Paskovic found that bollard luminaires in pedestrian areas reinforced “an inviting public realm” (19)	Paskovic, 19	Canada (Vancouver)
										11	The color of illumination can also play a role in impacting pedestrian perceptions of personal security. Several studies of “white light” for outdoor use have been made in which the white illumination from such light sources as mercury vapor lamps, metal halide (MH) lamps, fluorescent lamps, and LEDs was compared with the yellowish illumination from high-pressure sodium (HPS) lamps. HPS lamps are the most commonly used light source for outdoor lighting in the United States (20). Daley reported that individuals judged outdoor college campus lighting using MH lamps as producing brighter illumination that reinforced safety more than lighting using HPS lamps (21). Belcher et al. compared the responses of residents to MH and HPS street lighting, finding preferences for MH over HPS (22). Rea et al. performed a series of field experiments under MH and HPS lighting; under MH, streets were judged as brighter and safer than under HPS (23). Knight also reported that neighborhoods illuminated by MH lamps were judged as brighter, safer, and more comfortable than those lighted by HPS (24).	Daley (21), Belcher et al (22), Rea et al (23), Knight (24)	Daley (21) - US Belcher et al (22) - not clear Rea et al (23) - not clear Knight (24) - not clear
										12	Knight also reported that neighborhoods illuminated by MH lamps were judged as brighter, safer, and more comfortable than those lighted by HPS (24).	Knight (24)	Not clear
LR2-3	2017	Carr, K.	Universal design: A step toward successful aging	conceptualise role of BE and UD in older adults' participation	"Older" adults, without precise definition	not specified	Not defined	NA	1	13	Although accessible and adaptable design features provide accommodations that could be helpful for older adults, these features are often fixed in place and noticeable [59] and may promote a sense of segregation among end-users [16] and of stigmatization as being “seniors” or “disabled” [60].	16. Story MF, 1998; 60. Audirac I. 2008	Not clear; a priori Western societies, because UD
LR2-4	2017	Fotios, S	Road lighting and pedestrian reassurance after dark: A review.	identify evidence on correlations between road lighting and reassurance	not specified	not specified	Urban or rural	NA	1	14	Loewen et al. 21 who compared photographs of scenes in daylight [...] and at night [...]. [Participants systematically noted as "safer" well lit situations; for the situation of no open space and no refuge, the rating of safety was approximately 5 times higher with light] Hanyu 22 also sought ratings of items including safety whilst observing photographs of real locations, [...]and found a relationship between ratings of safe and lighting that was considered to be bright and uniform. Bishop and Rohrmann 25 compared evaluations of an outdoor environment in a real outdoor space and a video simulation [...] of the same environment, under both night-time and daytime conditions. The simulated environment did not yield the same results as the real environment: Evaluations made from the simulation tended to overrate the negative effects (e.g. disliking and threat) and under-rate the positive effects (pleasure, naturalness and overall liking). Information recall was found to be more accurate in the real environment Nair et al. 28 carried out before and after surveys following improvements to street lighting in a residential area in Glasgow, resulting in a 6% reduction in the number of people worried about assault and harassment. However, the reported changes in opinions are not statistically analysed and the changes are small (e.g. 6% means two of the 33 respondents changed opinion). Koga et al. 30 sought on-road ratings of the visual environment, concluding that feelings of security increased in light and busy streets: factor analysis derived five common factors from the evaluated items (liveliness, order, openness, intimateness and unity) and lighting was essential to every factor.	Loewen et al. 21 Hanyu 22 Painter 26, 27 Nair et al 28 Koga et al 30	Loewen et al. 21 - not clear Hanyu 22 - not clear Painter 26, 27 - not clear Nair et al 28 - UK Koga et al 30 - Japan

Data relative to the literature review										Data relative to the associations between objective WE characteristics and perceived walkability			
Code	Year	First author	Title	Aim	Population, ages	Population, impairments	Setting (urban/ rural)	N primary studies	Quality score [1-7]	Code	Associations - direct quotes	Reference	Geographic area
										17	Koga et al. 30 sought on-road ratings of the visual environment, concluding that feelings of security increased in light and busy streets: factor analysis derived five common factors from the evaluated items (liveliness, order, openness, intimateness and unity) and lighting was essential to every factor.	Koga et al 30	Japan
LR2-5	2012	Hand, Carri	Neighborhood Influences on Participation Among Older Adults With Chronic Health Conditions: A Scoping Review.	Identify neighbourhood characteristics related to participation, in older adults	Older adults - at least half the sample was age 55 years or more	Chronic health conditions	Not explicitely specified, "neighbourhood"	15	6.5	18.1	Low neighborhood economic status is associated with [...] difficulty in ADL and community mobility participation (Beard et al., 2009), and difficulty in ADL participation for men (Freedman, Grafova, Schoeni, & Rogowski, 2008). Area economic advantage also decreases the likelihood of difficulty in IADL participation in men when controlling for demographic variables but not when controlling for other neighborhood characteristics (Freedman et al., 2008).	(Beard et al., 2009; Freedman, Grafova, Schoeni, & Rogowski, 2008 - men only)	Not clear
										18.2	Low land-use diversity is associated with lower independence in IADL participation in people with lower extremity functional difficulties (Clarke & George, 2005).	(Clarke & George, 2005).	Not clear
										18.3	Street connectivity,[...] is linked to less difficulty in IADL participation in men (Freedman et al., 2008). Street characteristics, including low density of intersections, are also related to difficulty in community mobility (Beard et al., 2009).	(Beard et al., 2009; Freedman, Grafova, Schoeni, & Rogowski, 2008 - men only)	Not clear
										18.4	Low housing density, another indicator of lower walkability, is linked to lower independence in ADL participation among older adults with lower extremity functional limitations (Clarke & George, 2005).	(Clarke & George, 2005).	Not clear
LR2-6	2016	Hartig, T.	Living in cities, naturally	[Implicit: how natural features can contribute to psychological benefits]	not specified	no restriction/ focus	urban	na	1	19	Complementing what people have long said they seek through outdoor recreation and substantiating theoretical claims, laboratory and field experiments have repeatedly shown that spending time in natural environments or viewing scenes of nature can quickly help people to lift their mood, improve their ability to direct attention, and reduce physiological arousal to a greater degree than do urban streets and other comparison conditions (2, 8). Notes that (1) "nature" can mean different things and different people can experience contact with nature in very diverse settings, from urban environments to wilderness, and (2) important potentials for urban areas include parks but also views on water and land, and connected pathways for walking and biking.	T. Hartig, R. Mitchell, S. de Vries, H. Frumkin, Annu. Rev. Public Health 35, 207–228 (2014) T. Hartig et al., in Forests, Trees and Human Health, K. Nilsson et al., Eds. (Springer, Dordrecht, 2011), pp. 127–168	Not clear
LR2-7	2017	Hasan, R.	Utilization of footbridges: Influential factors and improvement proposals	Identify factors influencing the use of footbridges	not specified	no restriction/ focus	not clear, a priori rather urban	19	2	20	The second most important cause for not using the footbridge is the distance from its location, where pedestrians will find this distance as a waste of time to walk towards it, especially if they found themselves farther than 100 meters away from this footbridge [25].	Mutto, et al. [25]	Uganda
										21	By their limited physical ability due to their age, elderly people who try to cross the street will avoid the footbridge as it is a cause of extra effort when ascending the stairs, where sometimes the slope of the stairs carriage is more than 40 degrees [31]. [In conclusion:] The participation of elders showed that they did not use the footbridge in large numbers, mainly because of the efforts spent on ascending the stairs, especially if they were carrying bags.	Chengalur, Rodgers, and Bernard, 2004 [31]	Not clear
										22	On the other hand, the footbridge was considered as a safe facility to be used and this was the most cited factor for the high rate of usage. The stated factor which was expressed by most people of the studied population [12, 14, 25] refers to their sufficient realization of footbridges' benefits, which confirms that in some level of education, introducing the new generation of public to the safety concepts and to the purpose of these existed structures as a life savior when crossing the street, is an essential task for safer walking.	Hidalgo-Solórzano, et al. [12], Soltani and Mozayeni [14] - esp. older adults, carrying bags, Mutto, et al. [25]	Hidalgo-Solórzano, et al. [12] - Mexico city Soltani and Mozayeni [14] - Iran Mutto, et al. [25] - Uganda
LR2-8	2015	Hunter, Ruth F.	The impact of interventions to promote physical activity in urban green space: A systematic review and recommendations for future research.	assess effectiveness of measures to promote PA in urban green spaces	not specified	no restriction/ focus	urban	12	5.5	24	Intervention: Greening of vacant urban land (n ¼ 4436) (>725,000 m 2) from 1999 to 2008 involving removing trash and debris, grading the land, planting grass and trees, installing low wooden fences around perimeter; maintenance activities performed multiple times/ year Outcome: residents reporting less stress and more exercise ($p < 0.01$)	Branas et al 2011	USA

Data relative to the literature review										Data relative to the associations between objective WE characteristics and perceived walkability			
Code	Year	First author	Title	Aim	Population, ages	Population, impairments	Setting (urban/ rural)	N primary studies	Quality score [1-7]	Code	Associations - direct quotes	Reference	Geographic area
LR2-9	2009	Jacobsen PL	Who owns the roads? How motorised traffic discourages walking and bicycling.	examine effects of traffic on walking and cycling	not specified	no restriction/ focus	Not specified	na	0.5	25	Neighbours are less likely to know and trust each other in neighbourhoods with high traffic volume.	Appleyard D. Livable street, 1981.	USA
											Residents felt their delay in crossing streets increased as traffic volume increased.	Appleyard D. Livable street, 1981.	USA
LR2-10	2014	Karndacharuk, A.	A Review of the Evolution of Shared (Street) Space Concepts in Urban Environments	inform the evolution of the shared space concept from a NZ perspective	not specified	no restriction/ focus	urban	na	0.5	27	As also given in Table 1 in the Calmed Street category, there are a number of well-known techniques that give an emphasis on residential and people interaction to enhance the place function by diminishing the (vehicular) movement efficiency. These include 'Liveable Street' (Appleyard, 1980; Appleyard et al., 1981; ODT, 2002), 'Living Street' (Bain, Gray, & Rodgers, 2012;L A C ,2011), 'Civilised Street' (CABE, 2008; LCC, 2010) and 'Complete Street' (Kingsbury, Lowry, & Dixon, 2011; Laplante & McCann, 2008; North Carolina Department of Transportation, 2012), and 'Road Diet' (Huang, Stewart, & Zegeer, 2002; Rosales, 2006). Nevertheless, these approaches do not specifically aim at removing the segregation indicator between vehicles and pedestrians. The diagram also recognises supplementary functions towards the surrounding area and land-use activities outside the road reserve, such as economic, social, cultural, historic and environmental amenity, that contribute to the formation of 'sense of place' within the public space.	Appleyard, 1980; Appleyard et al., 1981; ODT, 2002, Bain, Gray, & Rodgers, 2012;L A C ,2011, CABE, 2008; LCC, 2010, Kingsbury, Lowry, & Dixon, 2011; Laplante & McCann, 2008; North Carolina Department of Transportation, 2012, Huang, Stewart, & Zegeer, 2002; Rosales, 2006	A 1980 - USA A 1981 - USA ODT 2012 - USA L A C ,2011 - USA CABE, 2008 - UK LCC, 2010, - USA Kings. 2011 - Not clear Lapl. 2008 - Not clear NCDT 2012 - USA Huang 2002 - Not clear Rosales, 2006 - Not clear
										28	Similar design features included a level, paved surface and minimum signage and marking. (2) Majority of intersection space (approximately 72%) allocated for vehicle movement and turning with little provision for staying activities. (3) Speed limit of 20 mph (32 km/h); Based on perception surveys, the majority of pedestrians worried about sharing space with vehicles (72%) and preferred conventional design (64%)	DfT (2010a) and Moody and Melia (2011)	UK
										29	Similar design features included a level, paved surface, minimum use of signage and marking, street furniture for pedestrian occupancy, trading activity, and entry and exit signage. (2) Safe zone was provided, but in some areas conflicting with seating and trading areas. (3) Speed limit of 20 mph (32 km/h); Based on perception surveys, both general public (99%) and businesses (93%) supported shared street upgrade	BHCC (2011a, 2011b), DfT (2010a) and Flow (2012)	UK
										30	Similar design features included a level surface, minimum road signage and marking and street furniture for pedestrians such as trees, lighting and fountains. (2) Roundabout intersection with road surface marking. (3) Provision of formal (zebra) pedestrian crossings and informal crossings using speed tables. (4) Pedestrians segregated from vehicles via different surface materials; Based on perception surveys, the perception of road safety declined (from 30% to 45%, rating 'moderate' or 'bad') while perception of personal safety improved (from 71% to 81%, rating 'reasonable' or 'good')	Hamilton-Baillie (2008b), NHL (2007) and Shared Space (2005, 2008a)	Netherlands
										31	Similar design features included a level surface, minimum road signage and marking and street furniture for pedestrians such as trees, lighting and fountains. (2) Roundabout intersection with road surface marking. (3) Provision of formal (zebra) pedestrian crossings and informal crossings using speed tables. (4) Pedestrians segregated from vehicles via different surface materials; Based on perception surveys, the perception of road safety declined (from 30% to 45%, rating 'moderate' or 'bad') while perception of personal safety improved (from 71% to 81%, rating 'reasonable' or 'good')	Hamilton-Baillie (2008b), NHL (2007) and Shared Space (2005, 2008a)	Netherlands
LR2-11	2017	Orstad, Stephanie L.	A Systematic Review of Agreement Between Perceived and Objective Neighborhood Environment Measures and Associations With	(1) Examine evidence on agreement between O and P neighbourhood measures and influence of possible	All ages; 28% of studies included children too	no restriction/ focus	Urban or rural	85	5	32	Destinations/Land use mix; % agreement : 13.0-95.0 ; significant in 18 pairs, ns in 1	2,3,4,7,16,18,25,42,47 ,49, 54,58,78	all studies: Northern America (49) Australia NZ (18) Europe (12) Asia (6)
											Residential density: 2 studies examining a total of 2 associations; level of agreement 60.3-76.2%, fair/good inter-rater agreement (0.21-0.48)	Arvidsson, 2011; Gebel, 2009	
											Street connectivity; % agreement : 53.0-63.7, ICC=.02 (poor), not correlated	Arvidsson, 2011; Gebel, 2009; Koohsari, 2014; Carlson, 2014	

Data relative to the literature review										Data relative to the associations between objective WE characteristics and perceived walkability			
Code	Year	First author	Title	Aim	Population, ages	Population, impairments	Setting (urban/ rural)	N primary studies	Quality score [1-7]	Code	Associations - direct quotes	Reference	Geographic area
			Physical Activity Outcomes.	confounders. (2) Examine how O and P correlate with PA							[From detail data received from the first author, 7.6.19: Availability of footpaths or walking trails Ten studies examined 12 pairs of associations between objective measures and perceptions. No pair had a good Kappa value or level of agreement. Six of the seven pairs where levels of agreement were examined have values above 40%, with a wide variation (46% to 93%). For walking trails, odds ratio was 1.4, p<0.05. Overall, 40% of the pairs have a fair association.	McAlexander, 2012, Abildso, 2007; Ball, 2008; Boehmer, 2006; Kirtland, 2003; Michael, 2006; Reed, 2004; Bailey 2014, Lee, 2014, Prins, 2009	
											[From detail data received from the first author, 7.6.19: Availability of public transport stops Four studies examined 4 pairs of associations between objective measures and perceptions. Inter-rater agreement was 0.04 (very low), and linear correlation was poor (r=-.35, p<.001)	Boehmer, 2006; Dewulf, 2012; McCormack; Adams, 2009	
											[From detail data received from the first author, 7.6.19: "Heavy traffic" / busy street as a barrier Two studies examined 7 pairs of associations between objective measures and perceptions. Inter-rater agreement was good in one case (0.59, busy street barrier, Troped, 2001) and low/none in the others.	Troped, 2001, McGinn, 2007	
											[From detail data received from the first author, 7.6.19: "High speed traffic" One study examined 6 pairs of associations between objective measures and perceptions. Inter-rater agreement was low/none (less than 0.14).	McGinn, 2007	
											[From detail data received from the first author, 7.6.19: Availability of recreation/PA facilities/coast;inter-rater agreement was good in only one of the 44 tested pairs (coast, k=0.66, Ball, 2008), and at least 11 of the 18 pairs tested for levels of agreement were above 40%. Very large variability amongst results and methods of assessment (but also facilities considered). % agreement : 23.0-91.0 ; significant in 29 pairs, ns in 17; It was not possible to distinguish between indoors and outdoors recreation	2,4,5,7,16,32,34,35,40, 44,47,49,54,64,65,70,73, 78, 97	
											[From detail data received from the first author, 7.6.19: Availability of Parks/Green space: % agreement ranged between 18 and 97% in the nine pairs tested, with fair evidence of linear correlation (r=0.54) across 13 studies for parks, but a low and negative correlation for "green spaces" in one study (r=-0.19, p<0.05, Bringolf-Isler, 2010)	Boehmer, 2006; Jilcott, 2007; Lackey, 2009; Maddison, 2009; Macintyre, 2008; Mccormack, 2008; Michael, 2006; Prins, 2009; Tilt, 2007; Adams, 2009; Bailey, 2014; Dunton, 2014; Hu, 2013, Bringolf-Isler, 2010	
											[From detail data received from the first author, 7.6.19: Footpaths maintenance Two studies examined 2 pairs of associations between objective measures and perceptions. One pair had a good level of agreement on path condition (84%, McAlexander, 2012), the other had a low inter-rater agreement (kappa-0.1)	McAlexander, 2012, Kirtland, 2003	
											[From detail data received from the first author, 7.6.19: Trees along the streets One study examined 2 pairs of associations between objective measures and perceptions. Kappa statistic was poor (0.2), level of agreement 52%, and the constructs were not correlated linearly (r=0.06, ns)	Adams, 2009	
											[From detail data received from the first author, 7.6.19: Exhaust fumes One study examined 1 pair of associations between objective measures and perceptions. Kappa statistic and level of agreement were not provided, and the constructs were not correlated linearly (r=0.09, p<0.05)	Adams, 2009	

Data relative to the literature review										Data relative to the associations between objective WE characteristics and perceived walkability			
Code	Year	First author	Title	Aim	Population, ages	Population, impairments	Setting (urban/ rural)	N primary studies	Quality score [1-7]	Code	Associations - direct quotes	Reference	Geographic area
											[From detail data received from the first author, 7.6.19: Availability of shops Seven studies examined 29 pairs of associations between objective measures and perceptions. For 27 pairs, kappa statistics and/or levels of agreement are reported. Five show good evidence of association, and seven a fair evidence. Overall, 44% of pairs show good/fair kappa or agreement. For six pairs, coefficients of correlations were examined, and all are below 0.36, p<0.01]	Boehmer, 2006; Tilt 2007; Adams, 2009; Bailey, 2014; Macdonald, 2013, Dewulf, 2012, Michael, 2006	
											[From detail data received from the first author, 7.6.19: Street lighting in the neighbourhood Two studies examined two pairs of associations between objective measures and perceptions. Inter-rater coefficient was poor (k=0.19) and there was no evidence of linear correlation	Kirtland, 2003; Adams, 2009	
LR2-12	2016	Pfeiffer, Deirdre	Planning for Happy Neighborhoods.	identify how planners can contribute to residents' happiness, at the neighbourhood level	not specified	no restriction/ focus	urban or rural neigihbourhoods	na	1	46	For instance, residents living in neighborhoods with buildings that have more street frontage and windows facing the street may be more aware of what is happening in the neighborhood and able to contest threats to personal security (J. Wilson & Kelling, 1982). [...] Research has established a link between residents' perceived personal security and their level of happiness. The results are conclusive: People who live in places they perceive as threatening their personal security tend to be less happy (Cutrona, Russell, Brown, Clark, & Hessling, 2005; Dolan et al., 2008; Lelkes, 2006; Morris, 2011).	J. Wilson & Kelling, 1982	Not clear
										47	A rich body of research has since confirmed links between access to open, natural, and green environments and happiness (Akers et al., 2012; L. Campbell & Wiesen, 2010; Kaplan, 2001; Wells & Laquatra, 2010). Access to these spaces can occur at different scales, from a window overlooking a grassy lawn or forest to living near a regional park. Windows offer a brief respite from other activities with little effort (Kaplan, 2001). Parks, community gardens, botanical gardens, building exteriors, and rights-of-way are examples of restorative open spaces that may make people feel happier (L. Campbell & Wiesen, 201). Access to active, green environments may be especially important to seniors' happiness (Loukaitou-Sideris, Levy-Storms, Chen, & Brozen, 2016; Wells & Laquatra, 2010). Research shows that seniors who use or live near parks report better physical and mental health, including happiness; however, parks must offer appropriate facilities and programming to attract seniors (Loukaitou-Sideris et al., 2016).	Akers et al., 2012; L. Campbell & Wiesen, 2010; Kaplan, 2001; Wells & Laquatra, 2010; Loukaitou-Sideris, Levy-Storms, Chen, & Brozen, 2016; Wells & Laquatra, 2010; Loukaitou-Sideris et al., 2016	Akers et al., 2012 - Not clear L. Camp. 2010 - Not clear Kaplan, 2001 - Not clear Wells & Laq., 2010 - Not clear Louk. et al., 2016 - USA
										48	Morris (2011) finds that living near subways is associated with being happier. Brereton et al. find no relationship between living near public transit and happiness in their survey of 1,500 Irish people […]	Morris 2011, Brereton et al 2008	not clear Ireland
										49	Brereton et al. find no relationship between living near public transit and happiness in their survey of 1,500 Irish people, yet those who live closer to major roads are less happy.	Brereton et al 2008	Ireland
										54	A study of 720 African-American mothers living in small to mid-sized U.S. cities fi nds that those who live in more disadvantaged neighborhoods with greater social disorder, as measured by dilapidation, delinquency, and substance abuse, are unhappier, particularly after undergoing a negative life event (Cutrona et al., 2005).	Cutrona et al., 2005	USA
LR2-13	2018	Vos, M.C.	Cleanliness unravelled: a review and integration of literature	present an overview of stimulus - organism - response variables related to cleanliness (objective aspects - perceptions - behaviours)	not specified	no restriction/ focus	streets and indoors	46	4	53	Lagrange et al. (1992) found that people exposed to signs of disorder (e.g. graffiti, unreturned shopping carts and visible violation of rules) had less positive perceptions of risk and more fear of crime.	Lagrange ,R .L . , Ferraro ,K .F . and Supancic ,M ., 1992	USA

3C: Methodological Quality Assessment results

Dimensions of assessment, from MQC		Code used in the table, next page
1	Is there a well-defined question?	1_Question
	Are the participants defined?	1.1_participants?
	Are the interventions/exposures defined?	1.2_intervention?
	Are the examined outcomes defined?	1.3_outcomes?
	Are the study designs defined?	1.4_designs?
2	Is there a defined search strategy?	2_Strategy
	Is at least one database named?	2.1_Database_named?
	Is the type of search noted (reference, hand searching, citation follow-up or expert contact)?	2.2_Type_search?
3	Are inclusion / exclusion criteria stated?	3_IncExcCrit
	Rules re participants	3.1_Participants
	Rules re intervention	3.2_Interventions
	Rules re outcomes	3.3_Outcomes
	Rules re design	3.4_Designs
4	States numbers of studies of each design included?	4_PrimStDesigns
5	Have the primary studies been quality assessed?	5_PrimStQual
6	Have the studies been appropriately synthesised?	6_Synth
7	More than one author involved at each stage?	7_XCheck

Additional, from Gebel et al:		Code used
A1	If older pedestrians (65+) were included, were the associations specified for them?	A_Segm_Age
A2	If if people with impairments were included, were the associations specified for them?	A_Segm_Imp

Key study information									Methodological Quality Checklist (MQC)*: seven dimensions								Additional criteria from Gebel et al**		
#	Year	First author	Design	Outcome: Perceptions	Outcome ≠ Perceptions	Population, ages	Population, impairments	Setting	Is there a well defined question?	Is there a defined search strategy?	Are inclusion / exclusion criteria stated?	States numbers of studies of each design included?	Have the primary studies been quality assessed?	Have the studies been appropriately synthesised?	More than one author involved at each stage?	**Total**	If older pedestrians (65+) were included, were the associations specified for them?	If if people with impairments were included, were the associations specified for them?	Grand total
LR2-1	2018	Bruggencate, T.T.	Systematic literature review	Fulfilment of social needs	0	65+	Community-dwelling, but not more detail	Not defined	1	1	1	1	1	0.5	0.5	**6**	1	0	**7**
LR2-2	2017	Bullough, John D	Review	0	Effects of brighter lighting at pedestrian crossings	not specified	not specified	suburban	0.5	0	0	0	0	0.5	0	**1**	0	0	**1**
LR2-3	2013	Carr, K.	Review	0	Participation	"Older" adults, without precise definition	not specified	Not defined	0.5	0	0	0	0	0.5	0	**1**	1	0	**2**
LR2-4	2015	Fotios, S	Review	Reassurance	0	not specified	not specified	Urban or rural	0.5	0	0	0	0	0.5	0	**1**	0	0	**1**
LR2-5	2012	Hand, Carri	Scoping review	0	Participation	Older adults - at least half the sample was age 55 years or more	People with chronic health conditions, without further detail regarding associated impairments	Not explicitely specified, "neighbourhood"	1	1	1	1	0	0.5	0.5	**5**	1	0.5	**6.5**
LR2-6	2016	Hartig, T.	Perspective paper	0	Psychological benefits	not specified	no restriction/ focus	urban	0.5	0	0	0	0	0.5	0	**1**	0	0	**1**
LR2-7	2017	Hasan, R.	Review	0	Use of footbridges	not specified	no restriction/ focus	not clear, a priori rather urban	0	1	0.5	0	0	0.5	0	**2**	0.5	0.5	**3**
LR2-8	2015	Hunter, Ruth F.	Systematic literature review	0	PA	not specified	no restriction/ focus	urban	0.5	1	0.5	1	1	1	0.5	**5.5**	0	0	**5.5**
LR2-9	2009	Jacobsen PL	Review	0	0	not specified	no restriction/ focus	Not specified	0	0	0	0	0	0.5	0	**0.5**	0.5	0	**1**
LR2-10	2014	Karndacharuk, A.	Review	0	0	not specified	no restriction/ focus	urban	0	0	0	0	0	0.5	0	**0.5**	0	0	**0.5**
LR2-11	2017	Orstad, Stephanie L.	Systematic literature review	BE attributes as perceived	0	All ages; 28% of studies included children too	no restriction/ focus	Urban or rural	0.5	1	1	1	0	1	0.5	**5**	0.5	0.5	**6**
LR2-12	2016	Pfeiffer, Deirdre	Review	Happiness	0	not specified	no restriction/ focus	urban or rural neigihbourhoods	0.5	0	0	0	0	0.5	0	**1**	0.5	0	**1.5**
LR2-13	2018	Vos, M.C.	Systematic literature review	Cleanliness	0	not specified	no restriction/ focus	streets and indoors	0.5	1	0.5	1	0	1	0	**4**	0	0	**4**
LR2-14	2020	Gomez, Luis F	Systematic literature review	Self-rated health and health-related quality of life	0	not specified	no restriction/ focus	urban - Latin-American cities >1m residents	0.5	1	0.5	1	0.5	1	0.5	**5**	0	0	**5**
LR2-16	2019	Kruize, Hanneke	Review	0	Environmental sustainabilty, health, and health equity.	not specified	no restriction/ focus	not specified	0.5	0.5	0	0	0	0.5	0	**1.5**	1	0	**2.5**
LR2-17	2019	Beemer, Cody J	Review	0	Mental health	not specified	no restriction/ focus	"developed countries", without specification on the metric and threshold used	0	0	0	0	0	1	0	**1**	0	0	**1**
LR2-18	2019	Atoyebi, O.A	Review	Mobility difficulties	0	"older adults", ages not specified	users of mobility assistive devices, without further detail	not specified	0.5	0	0	0	0	1	0	**1.5**	1	1	**3.5**
LR2-19	2020	Blitz, Andreas	Systematic literature review	0	Walking and cycling behaviour	not specified	no restriction/ focus	not specified	0	1	0	0	0	0.5	0	**1.5**	0	0	**1.5**
LR2-20	2019	Hunter, R F	Systematic literature review	0	Environment, health, wellbeing, social aspects and equity	not specified	no restriction/ focus	urban	0	1	0.5	1	1	0.5	1	**5**	1	0	**6**
LR2-21	2019	Wilkie, Stephanie	Scoping review	0	Health and behaviours	not specified	no restriction/ focus	urban, from post-industrialised countries	0	1	1	1	0	0.5	0.5	**4**	0	0	**4**
LR2-22	2019	Badland, H	Review	0	Health inequities	no restriction	no restriction/ focus	urban, in "developed countries"	0	0	0.5	0	0	0	0	**0.5**	0	0	**0.5**
									7.5	**10.5**	**7**	**8**	**3.5**	**13**	**4**		**8**	**2.5**	

* Bambra, C., Gibson, M., Sowden, A. J., Wright, K., Whitehead, M., & Petticrew, M. (2009). Working for health? Evidence from systematic reviews on the effects on health and health inequalities of organisational changes to the psychosocial work environment. Preventive Medicine, 48(5), 454–461. https://doi.org/10.1016/j.ypmed.2008.12.018

** Gebel, K., Ding, D., Foster, C., Bauman, A. E., & Sallis, J. F. (2015). Improving Current Practice in Reviews of the Built Environment and Physical Activity. Sports Medicine, 45(3), 297–302. https://doi.org/10.1007/s40279-014-0273-8

Color coding

Key study informations (blue)	MQC >=4
Key study informations (grey)	MQC<=2
Assessment: MQC and additional criteria	
0	Criteria not fulfilled
0.5	Criteria partially fulfilled
1	Criteria fulfilled

CHAPTER 4

4A: Questions, Auckland Transport Active Modes Survey 2018

Excerpt from the 2018 survey questionnaire – TRA, Auckland Transport [3].

Code	Question	Possible answers	Asked to
S7_1	Do you have any disability or impairment that affects your ability to walk?	y/n (coded 2/1)	all
A6_1	On average, how often do you [walk for 10 minutes or more at a time], for any reason?	1 Never / Virtually never 2 Less than monthly 3 Once or twice a month 4 Once a week....................... 5 2-4 Days per week 6 5 Days per week or more	! only non-disabled participants (S7_1=1)
Q2	Thinking about the past week, how many times did you use each mode of transport when travelling for these occasions? *(list of 11 possible purposes such as work or shopping, + "some other occasion")*	Number of trips for each occasion and each mode	All those who did declare traveling for the different occasions
Q10	From the list below, what are the key reasons you choose to walk? Please select all that apply Possible motivatorQ10_ There's no other way to get where I need to go .... 15 Keeps me fit / helps me get fitter .... 1 It's fun.. 2 Saves money... 3 Saves time .... 4 More consistent travel time .... 5 Avoids parking hassles... 6 Availability of paths / walking routes .... 7 Helps reduce traffic congestion... 9 Helps address environmental concerns... 10 Provides me with some 'me time' .... 11 Allows me to enjoy the weather...................................... 12 Better routes are available than previously .... 13 Other (please specify)... 97	y/n for each possible motivator (coded 1/0)	IF A6_a =2-6 (WALKERS), excluding people with disabilities becausee not asked question A6_a
Q11	Sometimes people tell us there are things that stop them from walking as much as they otherwise would. When it comes to walking in Auckland, which of these statements, if any, apply to you? Please select all that apply Possible barrier..Q11_ It's not enjoyable because of the hills .... 1 It's not enjoyable because of the weather .... 14 I don't feel safe walking in the day .... 20 I don't feel safe walking in the dark .... 21 I live too far away for it to be practical .... 4 Walking is not a quick way for me to get where I need to go .... 5 The pavements/footpaths in my area are not in a good condition ... 9 I can't be bothered/too much effort .... 15 I always have too much stuff to carry .... 16 I have to think about transporting other people .... 17 Walking adds too much to my journey time .... 22 Walking routes are boring, not very attractive .... 23 I don't know how long it would take to walk .... 24 Some other reason (please specify) 97	y/n for each possible barrier (coded 1/0)	! only able-bodied, = S7_1=1
B8	Which of the following statements best describes you when it comes to walking, and the amount of walking you do?	Please select one only I only walk if I have to 1 I would like to walk less ...... 2 I am happy with the amount of walking I do .... 3 I would like to walk more 4	IF A6_a =2-6 (WALKERS), excluding people with disabilities becausee not asked question A6_a

Code	Question	Possible answers	Asked to
B14	In general, how safe do you feel / would you feel walking during the daytime- _1 In relation to traffic and vehicles? _2 In relation to crime? _3 In relation to hazards that can cause you harm or to trip and fall?	Ranking, from 0 - "Not at all safe" to 10 - "Extremely safe", + Don't Know (coded 99)	! only able-bodied, = S7_1=1
B15	In general, how safe do you feel / would you feel walking during the night time- _1 In relation to traffic and vehicles? _2 In relation to crime? _3 In relation to hazards that can cause you harm or to trip and fall?	Ranking, from 0 - "Not at all safe" to 10 - "Extremely safe", + Don't Know (coded 99)	! only able-bodied, = S7_1=1
Q15	And thinking about these trips you made in the last week. Would it be reasonable to walk for any of these?	Please select one only for each type of trip It isn't reasonable I could, but I don't Do it occasionally Already do this often	People who did make trips for these occasions but by other mode.
Q18	Overall, how do you view the current state of walking in Auckland? Please give us your opinion, even if you don't walk much yourself. ...	Ranking, from 0 - "Very poor" to 10 - "Very good", + Don't Know (coded 99)	All

4B: R code

```
################################################################
################################################################
###
### Predicting walking as a dichotomous outcome
### GBM
### 5.0b
### Walking: tertile 1 vs 3, reduced set of variables
### TEST OF DEPTHS
### September 2019
###
################################################################
################################################################



# Setup ------------------------------------------------------------------

setwd("C:/Users/tbozovic/OneDrive - AUT University/a1_STUDY_1_quant/Part-2-AT/ML")

library(tidyverse)
library(dplyr)
library(ggplot2)
library(gghighlight)
library(gbm)
library(MASS)
library(Metrics)
library(ROCR)
library(e1071)
library(ipred)
library(reshape2)
library(pdp)

# Import data
AT_activemodes_16_18_extended_v3_12Dec18..sel.abled.traveled <-
read.csv("C:/Users/tbozovic/OneDrive - AUT University/a1_STUDY_1_quant/Part-2-
AT/0_data-AT-16-18/AT_activemodes_16_18_extended_v3_12Dec18--sel-abled-traveled.csv",
encoding="UTF-8")
a <- AT_activemodes_16_18_extended_v3_12Dec18..sel.abled.traveled
# 3652 observations of 1874 variables

# Subset dataset ---------------------------------------------------------

# Limit to 30 trips walked,
# Eliminate those who walk "virtually never" (A6_1 ==1), not asked many of the
questions of interest

a2 <- a %>%
  filter(Q2_7_S < 31) %>%
  filter(A6_1 >1)
# OK, 3456 observations instead of 3652

# Calculate tertiles, dichotomise walking in t1, t3 -----------------------

t1 <- quantile(a2$Q2_7_S, probs=0.3333)
# first tertile = 0
table(a2$Q2_7_S==t1)
# 1343 respondents walked 0 trips, = 39% of the sample

t3 <- quantile(a2$Q2_7_S, probs=0.6666)
# third tertile = 5
table(a2$Q2_7_S>=t3)
# 1,091 waked stictly more than 5, 1223 walked 5 and more, 35%


a3 <- a2 %>% mutate(walk_13 = case_when(Q2_7_S == t1 ~ "walk_t1",
                                        Q2_7_S >= t3 ~ "walk_t3"))
# OK, t1 = 1343, t3 = 1223

a3 <- a3 %>%
  filter(walk_13 != "NA")
# OK, a3 2566 observations instead of 3456; = t1 + t3


### Recode walk_13 for GBM: tertile 1 == 0, tertile 3 == 1
```

```
a4 <- a3 %>% mutate (walk_t = case_when(walk_13 == "walk_t1" ~ 0,
                                   walk_13 == "walk_t3" ~ 1))
# OK, 0 = 1343, 1 = 1223


# Select numeric or categorical variables, excluding:
#    those directly related (A1, freq walking; B3, trips walked previous week)
#    B8 attitude to walking - low influence in first run (5.0_opt), examined
separately later
#    variables that are mainly NA
#    trip purposes (included until now)
# Save as "vt13"


######### Select variables of interest + outcome = walking >= 7 trips/w

vt13 <- a4 %>%

  dplyr::select(

    walk_t,               # Dichotomised outcome, above
    S1, dS2,              # Demographics: gender and age group, not S4/S5, area
    Q1_6,                 # Went to PT, previous week; not other Q1_: trip purposes
    Q18_1,                # Overall perception, state of walking in Auckland
    starts_with("Q11_"),  # Barriers
    starts_with("Q10_"),  # Motivations; ! Q10_97_other = free text!
    B14_1)                # Perception of safety vs traffic, day time; B14_2 and _3
empty
# 36 variables

# Remove AQ10_97 and Q11_97_other = free text
vt13["Q10_97_other"] <- NULL
vt13["Q11_97_other"] <- NULL
# OK, 2566 obs, 34 variables


# Split the data - 80% training, 20% test ---------------------------------


n <- nrow(vt13)                        # 2566 records
n_train <- round(n * 0.8)              # 80% of records, 2053

set.seed(123)                          # set seed, for reproductibility of random
sample
train_indices <- sample(1:n, n_train) # 2053 indices selected randomly for training

vt13_train <- vt13[train_indices, ]       # 80% of data for training - OK, 2053 obs,
34 var
vt13_test  <- vt13[-train_indices, ]      # 20% of data for testing  - OK, 513 obs, 34
var


# Train and test GBM models, walk_t13 ------------------------------------------------
-

# Define hyper parameters to be tested
depths     <- seq(1, 5, 1)

# List and vector for storing models and AUC
m17_list   <- list()                       # Empty list to store models all variables
ntree_opt  <- c()                          # Empty vector to store optimal n trees
preds_list <- list()
AUCs       <- c()                          # Empty vector to store AUCs
influences <- list()
```

```
for (i in 1:5) {                    # Loop, 1 model for each depth

  maxdepth <- depths[i]

  # Test avec 1000 trees
  mod_test   <- gbm(formula = walk_t ~ .,
                      distribution = "bernoulli",
                      data = vt13_train,
                      n.trees = 1000,
                      cv.folds = 20,
                      interaction.depth = maxdepth)

  # Identify early stopping
  ntree_opt_i <- gbm.perf(object = mod_test,
                           method = "cv",
                           oobag.curve = FALSE)

  ntree_opt[[i]] <- ntree_opt_i

  # Model i with optimal n trees
  mod_i       <- gbm(formula = walk_t ~ .,
                   distribution = "bernoulli",
                   data = vt13_train,
                   n.trees = ntree_opt_i,
                   cv.folds = 20,
                   interaction.depth = maxdepth)

  # Generate predictions
  pred_i        <-  predict(object = mod_i,
                           newdata = vt13_test,
                           n.trees = ntree_opt_i,
                           type="response")

  preds_list[[i]] <- pred_i

  # Calculate and store AUC
  AUCs[i]       <- auc(actual = vt13_test$walk_t, predicted = pred_i)

  # Store the relative influences, non-ordered
  influences[[i]]<- summary(mod_i, plotit = FALSE, order = FALSE,
                          method = relative.influence, normalize = TRUE)
}


models           <- data.frame(seq(1,5,1), ntree_opt, AUCs)
colnames(models) <- c("Interaction_depth", "Optimal_n_trees", "AUC")
write.csv(models, file="Models_17_test_depths_1_5_overview_AUC_trees.csv")
write.csv(influences, file = "Models_17_test_depths_1_5_influences.csv")


plot_AUC    <- ggplot(models, aes(x=Interaction_depth, y=AUCs))+
  geom_bar(stat="identity") + ylim(0,1) +
  geom_text(aes(label = sprintf("%0.2f", round(AUCs, digits = 2))), size = 4, hjust =
0.5, vjust = -1)
plot_ntrees <- ggplot(models, aes(x=Interaction_depth,
y=Optimal_n_trees))+geom_bar(stat="identity")+
  geom_text(aes(label = Optimal_n_trees), size = 4, hjust = 0.5, vjust = 3)

results <- ggarrange(plot_AUC, plot_ntrees,
          ncol = 1, nrow = 2)

annotate_figure(results,
                fig.lab = "AUC values and optimal number of trees, for tested
interaction depths", fig.lab.face = "bold",
                top = text_grob(" ", face = "bold", size = 14),
)
```

```
###### Plot ROC curves

# List of actual values (same for all)
m <- length(preds_list)
actuals_list <- rep(list(vt13_test$walk_t), m)

# Plot the ROC curves
pred <- prediction(preds_list, actuals_list)
rocs <- performance(pred, "tpr", "fpr")          # True Positive Rate vs False
Positive Rate
plot(rocs, col = as.list(1:m), main = "Test Set ROC Curves; GBM predicting walking
levels, tertile 1 or 3")
legend(x = "bottomright",
       legend = c("GBM, CV 20, depth = 1",
                  "GBM, CV 20, depth = 2",
                  "GBM, CV 20, depth = 3",
                  "GBM, CV 20, depth = 4",
                  "GBM, CV 20, depth = 5"
       ), fill = 1:m)


bestmodel <- 2    # set level of interaction of the (marginally) better model


# Examine influences -----------------------------------------

theme_inf <- theme(axis.ticks = element_blank(),
                   axis.text = element_text(size=8))


summary <- influences[[bestmodel]]
summary <- filter(summary, rel.inf !=0)

imp_m17_2 <- ggplot(summary[1:20,], aes(x=reorder(var, -rel.inf),
y=rel.inf))+geom_bar(stat="identity") +
  ggtitle("Model 17, walking (tertiles 1 or 3) vs barriers, motivations, perceptions,
age and gender",
          subtitle="Depth =2. Non null variables regarding relative influence. AT data
2016-18, N=2566; 25.9.19") +
  ylab("Relative influence") +
  xlab("Variables") + theme_inf


imp_m17_h <- ggplot(summary, aes(x=rel.inf))+geom_histogram(bins = 40) +
  ggtitle("Model 17, walking (tertiles 1 or 3) vs barriers, motivations, perceptions,
age and gender",
          subtitle="Distribution of relative influences of the variables tested;
Dashed lines: Q25, Q75, Q90") +
  ylab("Number of variables (total possible = 33)") +
  xlab("Relative influence")  +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.25)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.75)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.90)), color="black",
linetype="dashed", size=1) +
  scale_x_continuous(breaks = seq(0,22,2))

quantile(summary_m17_2$rel.inf, probs=0.75)
# 75% of the variables have an influence < 3.7 %


# Split data: PT users and non-users ----------------------------------------

vt13_PT    <- filter(vt13, Q1_6==1) # only those who went to PT stops
vt13_nonPT <- filter(vt13, Q1_6==0)

### Training and test data, for both
vt13_PT_train    <- filter(vt13_train, Q1_6==1) # only those who went to PT stops
vt13_PT_test     <- filter(vt13_test, Q1_6==1)

vt13_nonPT_train <- filter(vt13_train, Q1_6==0) # only those who didn't go to PT stops
vt13_nonPT_test  <- filter(vt13_test, Q1_6==0)
```

```
# Hide Q1_6
vt13_PT_train["Q1_6"]     <- NULL
vt13_PT_test["Q1_6"]      <- NULL
vt13_nonPT_train["Q1_6"]  <- NULL
vt13_nonPT_test["Q1_6"]   <- NULL
# OK, 33 variables


# NON-USERS PT: Train and test GBM models, walk_t13 ---------------------------------

# List and vector for storing models and AUC
ntree_opt_nonPT  <- c()                           # Empty vector to store optimal n
trees
preds_list_nonPT <- list()
AUCs_nonPT       <- c()                           # Empty vector to store AUCs
influences_nonPT <- list()


for (i in 1:5) {                   # Loop, 1 model for each depth

  maxdepth <- depths[i]

  # Test avec 1000 trees
  mod_test   <- gbm(formula = walk_t ~ .,
                    distribution = "bernoulli",
                    data = vt13_nonPT_train,
                    n.trees = 200,
                    cv.folds = 20,
                    interaction.depth = maxdepth)

  # Identify early stopping
  ntree_opt_i <- gbm.perf(object = mod_test,
                          method = "cv",
                          oobag.curve = FALSE)

  ntree_opt_nonPT[[i]] <- ntree_opt_i

  # Model i with optimal n trees
  mod_i       <- gbm(formula = walk_t ~ .,
                     distribution = "bernoulli",
                     data = vt13_nonPT_train,
                     n.trees = ntree_opt_i,
                     cv.folds = 20,
                     interaction.depth = maxdepth)

  # Generate predictions
  pred_i         <-  predict(object = mod_i,
                             newdata = vt13_nonPT_test,
                             n.trees = ntree_opt_i,
                             type="response")

  preds_list_nonPT[[i]] <- pred_i

  # Calculate and store AUC
  AUCs_nonPT[i]        <- auc(actual = vt13_nonPT_test$walk_t, predicted = pred_i)

  # Store the relative influences, non-ordered
  influences_nonPT[[i]]<- summary(mod_i, plotit = FALSE, order = FALSE,
                            method = relative.influence, normalize = TRUE)
}



models_nonPT           <- data.frame(seq(1,5,1), ntree_opt_nonPT, AUCs_nonPT)
colnames(models_nonPT) <- c("Interaction_depth", "Optimal_n_trees", "AUC")
write.csv(models_nonPT, file="Models_17_nonPT_test_depths_1_5_overview_AUC_trees.csv")
write.csv(influences_nonPT, file = "Models_17_nonPT_test_depths_1_5_influences.csv")


plot_AUC_nonPT    <- ggplot(models_nonPT, aes(x=Interaction_depth, y=AUC))+
  geom_bar(stat="identity") + ylim(0,1) +
  geom_text(aes(label = sprintf("%0.2f", round(AUCs_nonPT, digits = 2))), size = 4,
hjust = 0.5, vjust = -1)
plot_ntrees_nonPT <- ggplot(models_nonPT, aes(x=Interaction_depth,
y=Optimal_n_trees))+geom_bar(stat="identity")+
  geom_text(aes(label = Optimal_n_trees), size = 4, hjust = 0.5, vjust = 3)
```

```
results_nonPT <- ggarrange(plot_AUC_nonPT, plot_ntrees_nonPT,
                     ncol = 1, nrow = 2)

annotate_figure(results_nonPT,
                fig.lab = "Non-users of PT; AUC values and optimal number of trees,
for tested interaction depths", fig.lab.face = "bold",
                top = text_grob(" ", face = "bold", size = 14),)


###### Plot ROC curves

# List of actual values (same for all)
m <- length(preds_list_nonPT)
actuals_list_nonPT <- rep(list(vt13_nonPT_test$walk_t), m)

# Plot the ROC curves
pred_nonPT <- prediction(preds_list_nonPT, actuals_list_nonPT)
rocs_nonPT <- performance(pred_nonPT, "tpr", "fpr")          # True Positive Rate vs
False Positive Rate
plot(rocs_nonPT, col = as.list(1:m), main = "ROC Curves; predicting walking as tertile
1 or 3, NON-users PT")
legend(x = "bottomright",
       legend = c("GBM, CV 20, depth = 1",
                  "GBM, CV 20, depth = 2",
                  "GBM, CV 20, depth = 3",
                  "GBM, CV 20, depth = 4",
                  "GBM, CV 20, depth = 5"), fill = 1:m)

bestmodel_nonPT <- models_nonPT[which.max(AUCs_nonPT),]$Interaction_depth    # set
level of interaction of the (marginally) better model


# Examine influences -----------------------------------------

summary_nonPT <- influences_nonPT[[bestmodel_nonPT]]
summary_nonPT <- filter(summary_nonPT, rel.inf !=0)

imp_m17_2_nonPT <- ggplot(summary_nonPT[1:20,], aes(x=reorder(var, -rel.inf),
y=rel.inf))+geom_bar(stat="identity") +
  ggtitle("Model 17, walking (tertiles 1 or 3), non-PT users: relative influences",
          subtitle="Depth =2. Non null variables regarding relative influence. AT data
2016-18, N=2566; 25.9.19") +
  ylab("Relative influence") +
  xlab("Variables") + theme_inf


imp_m17_h_nonPT <- ggplot(summary_nonPT, aes(x=rel.inf))+geom_histogram(bins = 40) +
  ggtitle("Model 17, walking (tertiles 1 or 3), non-PT users: relative influences",
          subtitle="Distribution of relative influences of the variables tested;
Dashed lines: Q25, Q75, Q90") +
  ylab("Number of variables (total possible = 32)") +
  xlab("Relative influence")  +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.25)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.75)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.90)), color="black",
linetype="dashed", size=1) +
  scale_x_continuous(breaks = seq(0,22,2))

quantile(summary_nonPT$rel.inf, probs=0.75)
# 75% of the variables have an influence < 6.9 %
```

```
# PT USERS ONLY: Train and test GBM models, walk_t13 --------------------------------


# List and vector for storing models and AUC
ntree_opt_PT  <- c()                        # Empty vector to store optimal n trees
preds_list_PT <- list()
AUCs_PT       <- c()                        # Empty vector to store AUCs
influences_PT <- list()


for (i in 1:5) {                   # Loop, 1 model for each depth

  maxdepth <- depths[i]

  # Test avec 1000 trees
  mod_test   <- gbm(formula = walk_t ~ .,
                    distribution = "bernoulli",
                    data = vt13_PT_train,
                    n.trees = 200,
                    cv.folds = 20,
                    interaction.depth = maxdepth)

  # Identify early stopping
  ntree_opt_i <- gbm.perf(object = mod_test,
                          method = "cv",
                          oobag.curve = FALSE)

  ntree_opt_PT[[i]] <- ntree_opt_i

  # Model i with optimal n trees
  mod_i       <- gbm(formula = walk_t ~ .,
                     distribution = "bernoulli",
                     data = vt13_PT_train,
                     n.trees = ntree_opt_i,
                     cv.folds = 20,
                     interaction.depth = maxdepth)

  # Generate predictions
  pred_i         <-  predict(object = mod_i,
                             newdata = vt13_PT_test,
                             n.trees = ntree_opt_i,
                             type="response")

  preds_list_PT[[i]] <- pred_i

  # Calculate and store AUC
  AUCs_PT[i]        <- auc(actual = vt13_PT_test$walk_t, predicted = pred_i)

  # Store the relative influences, non-ordered
  influences_PT[[i]]<- summary(mod_i, plotit = FALSE, order = FALSE,
                                  method = relative.influence, normalize = TRUE)
}


models_PT          <- data.frame(seq(1,5,1), ntree_opt_PT, AUCs_PT)
colnames(models_PT) <- c("Interaction_depth", "Optimal_n_trees", "AUC")
write.csv(models_PT, file="Models_17_PT_test_depths_1_5_overview_AUC_trees.csv")
write.csv(influences_PT, file = "Models_17_PT_test_depths_1_5_influences.csv")


plot_AUC_PT    <- ggplot(models_PT, aes(x=Interaction_depth, y=AUC))+
  geom_bar(stat="identity") + ylim(0,1) +
  geom_text(aes(label = sprintf("%0.2f", round(AUCs_PT, digits = 2))), size = 4, hjust
= 0.5, vjust = -1)
plot_ntrees_PT <- ggplot(models_PT, aes(x=Interaction_depth,
y=Optimal_n_trees))+geom_bar(stat="identity")+
  geom_text(aes(label = Optimal_n_trees), size = 4, hjust = 0.5, vjust = 3)

results_PT <- ggarrange(plot_AUC_PT, plot_ntrees_PT,
                          ncol = 1, nrow = 2)

annotate_figure(results_PT,
                fig.lab = "PT users only; AUC values and optimal number of trees, for
tested interaction depths", fig.lab.face = "bold",
                top = text_grob(" ", face = "bold", size = 14),)
###### Plot ROC curves
```

```
# List of actual values (same for all)
m <- length(preds_list_PT)
actuals_list_PT <- rep(list(vt13_PT_test$walk_t), m)

# Plot the ROC curves
pred_PT <- prediction(preds_list_PT, actuals_list_PT)
rocs_PT <- performance(pred_PT, "tpr", "fpr")          # True Positive Rate vs False
Positive Rate
plot(rocs_PT, col = as.list(1:m), main = "ROC Curves; predicting walking as tertile 1
or 3, PT users")
legend(x = "bottomright",
       legend = c("GBM, CV 20, depth = 1",
                  "GBM, CV 20, depth = 2",
                  "GBM, CV 20, depth = 3",
                  "GBM, CV 20, depth = 4",
                  "GBM, CV 20, depth = 5"
       ), fill = 1:m)


bestmodel_PT <- models_PT[which.max(AUCs_PT),]$Interaction_depth    # set level of
interaction of the (marginally) better model
# 1


# Examine influences ----------------------------------------

summary_PT <- influences_PT[[bestmodel_PT]]
summary_PT <- filter(summary_PT, rel.inf !=0)

imp_17_PT <- ggplot(summary_PT, aes(x=reorder(var, -rel.inf),
y=rel.inf))+geom_bar(stat="identity") +
  ggtitle("Model 17, walking (tertiles 1 or 3), PT users: relative influences",
          subtitle="Depth =1. Non null variables regarding relative influence. AT data
2016-18, N=822; 25.9.19") +
  ylab("Relative influence") +
  xlab("Variables") + theme_inf


imp_m17_h_PT <- ggplot(summary_PT, aes(x=rel.inf))+geom_histogram(bins = 40) +
  ggtitle("Model 17, walking (tertiles 1 or 3), PT users: relative influences",
          subtitle="Distribution of relative influences of the variables tested;
Dashed lines: Q25, Q75, Q90") +
  ylab("Number of variables (total possible = 32)") +
  xlab("Relative influence")  +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.25)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.75)), color="black",
linetype="dashed", size=1) +
  geom_vline(aes(xintercept=quantile(rel.inf, probs=0.90)), color="black",
linetype="dashed", size=1) +
  scale_x_continuous(breaks = seq(0,22,2))

quantile(summary_PT$rel.inf, probs=0.75)
# 75% of the variables have an influence < 7.9 %


### Extract interesting associations
walk_age <- table(vt13_PT$dS2, vt13_PT$walk_t)
write.csv(walk_age, file="Walk_tertiles_vs_age___PT_users.csv")

walk_money <- table(vt13_PT$Q10_3, vt13_PT$walk_t)
write.csv(walk_money, file="Walk_tertiles_vs_motivation_money___PT_users.csv")

walk_safety <- table(vt13_PT$B14_1, vt13_PT$walk_t)
write.csv(walk_safety, file="Walk_tertiles_vs_P_safety___PT_users.csv")


# Comparison: PT, non-PT -------------------------------------------------

# One df with the influences from the best non PT and PT models
influences_df <- data.frame(influences_nonPT[[bestmodel_nonPT]],
                            influences_PT[[bestmodel_PT]])

colnames(influences_df) <- c("Var", "Rel_inf_nonPT", "Var.1", "Rel_inf_PT")
```

```
write.csv(influences_df, file = "Influences_models_17_nonPT_vs_PT.csv")

# Present non PT as negative values, for representation
# Add variables _above2, to present onlu influences >2%
influences_df <- influences_df %>% mutate(
  Rel_inf_nonPT_neg = Rel_inf_nonPT*(-1),
  Rel_inf_nonPT_neg_above2 = ifelse(Rel_inf_nonPT_neg<(-2), Rel_inf_nonPT_neg, ""),
  Rel_inf_PT_above2 = ifelse(Rel_inf_PT>2, Rel_inf_PT, ""))


# Comparison PT - non PT; select only necessary variables
influences_graph <- influences_df %>%
  dplyr::select(
    Var,
    Rel_inf_nonPT_neg,
    Rel_inf_PT)

# One vertical bar chart with compared influences PT / non PT

influences_graph_melt        <- melt(influences_graph, id.vars= c("Var"))

theme_comp <- theme(axis.ticks.y = element_blank(),
                    axis.text.y = element_text(size=8),
                    axis.text.x = element_text(size=10))

inf_comp <- ggplot(influences_graph_melt, aes(x=Var, y=value,
fill=variable))+geom_bar(stat="identity")+
  ggtitle("Walking (tertiles 1 or 3, model 17): relative influences vs use of PT",
          subtitle="Best fitting model for each category. AT data 2016-18, N=2566;
25.9.19") +
  ylab("Relative influence of features; [%]*(-1) for non users of PT, for
representation") +
  xlab("Variables") + theme_comp +
  scale_fill_manual(values = c("#24281A", "#CEAB07"), labels = c("Non-users of PT",
"PT users"))

  inf_comp +
    coord_flip() +
    theme(legend.title = element_blank(),
          legend.position=c(0, 1),
          legend.justification = c(0, 1))


### Comparison including only variables with influences >2%

# Filtered version, with only |influences| > 2 percent

influences_graph_filter <- influences_graph %>%
    filter(Rel_inf_nonPT_neg <(-2) | Rel_inf_PT >2)

# One vertical bar chart with compared influences PT / non PT

influences_graph_filter_melt <- melt(influences_graph_filter, id.vars= c("Var"))

inf_comp_filter <- ggplot(influences_graph_filter_melt, aes(x=Var, y=value,
fill=variable))+geom_bar(stat="identity")+
  ggtitle("Walking (tertiles 1 or 3, model 17): relative influences vs use of PT; only
>2%",
          subtitle="Best fitting model for each category. AT data 2016-18, N=2566;
25.9.19") +
  ylab("Relative influence of features; [%]*(-1) for non users of PT, for
representation") +
  xlab("Variables") + theme_comp +
  scale_fill_manual(values = c("#24281A", "#CEAB07"), labels = c("Non-users of PT",
"PT users"))

inf_comp_filter +
  coord_flip() +                              # Rotate 90 degrees
  theme(legend.title = element_blank(),       # No legend label
        legend.position=c(0, 1),              # Legend upper rght
        legend.justification = c(0, 1)) +

# Add labels
  geom_text(label=format(influences_graph_filter_melt$value, digits = 0),
            size = 3, hjust = 1.5, vjust = 0.5)
```

```
# Highlight influences >2%
inf_comp_filter +
  coord_flip() +                              # Rotate 90 degrees
  gghighlight(value <(-2) | value >2, label_key = value) +
  theme(legend.title = element_blank(),       # No legend label
        legend.position=c(0, 1),              # Legend upper rght
        legend.justification = c(0, 1))


# Test vertical bars

influences_graph_positive <- influences_df %>%
  dplyr::select(
    Var,
    Rel_inf_nonPT,
    Rel_inf_PT)

influences_graph_positive_melt <- melt(influences_graph_positive, id.vars= c("Var"))

theme_comp_v <- theme(axis.ticks = element_blank(),
                    axis.text.y = element_text(size=10),
                    axis.text.x = element_text(size=8, angle =90, hjust=0))

inf_comp_vert <- ggplot(influences_graph_positive_melt, aes(x=Var, y=value,
fill=factor(variable), width = .6) ) +geom_bar(stat="identity", position =
position_dodge2())+
  ggtitle("Walking (tertiles 1 or 3, model 17): relative influences vs use of PT",
          subtitle="Best fitting model for each category. AT data 2016-18, N=2566;
25.9.19") +
  ylab("Relative influence of features; [%]") +
  xlab("Variables") + theme_comp_v +
  scale_fill_manual(values = c("#24281A", "#CEAB07"), labels = c("Non-users of PT",
"PT users"))

inf_comp_vert +
  theme(legend.title = element_blank(),       # No legend label
        legend.position=c(1, 1),              # Legend upper rght
        legend.justification = c(0, 1))
```

4C: Testing for pairwise associations

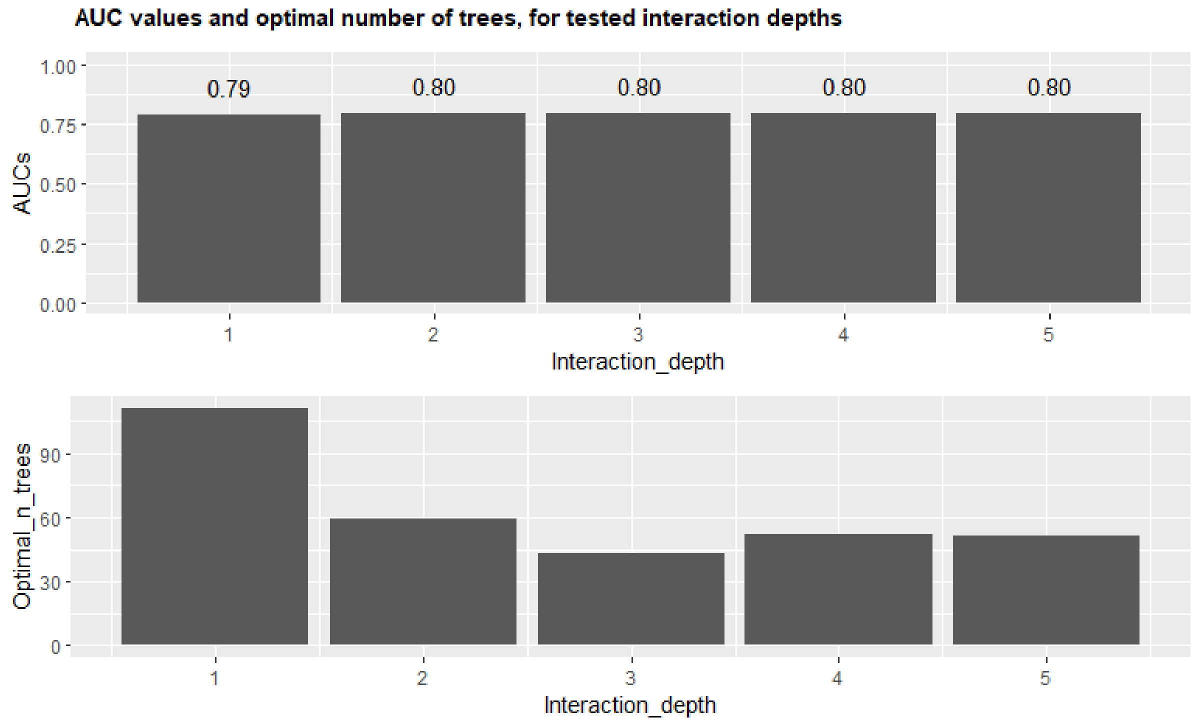
41 variables
479 significant associations (p<0.05), out of 820 possible associations

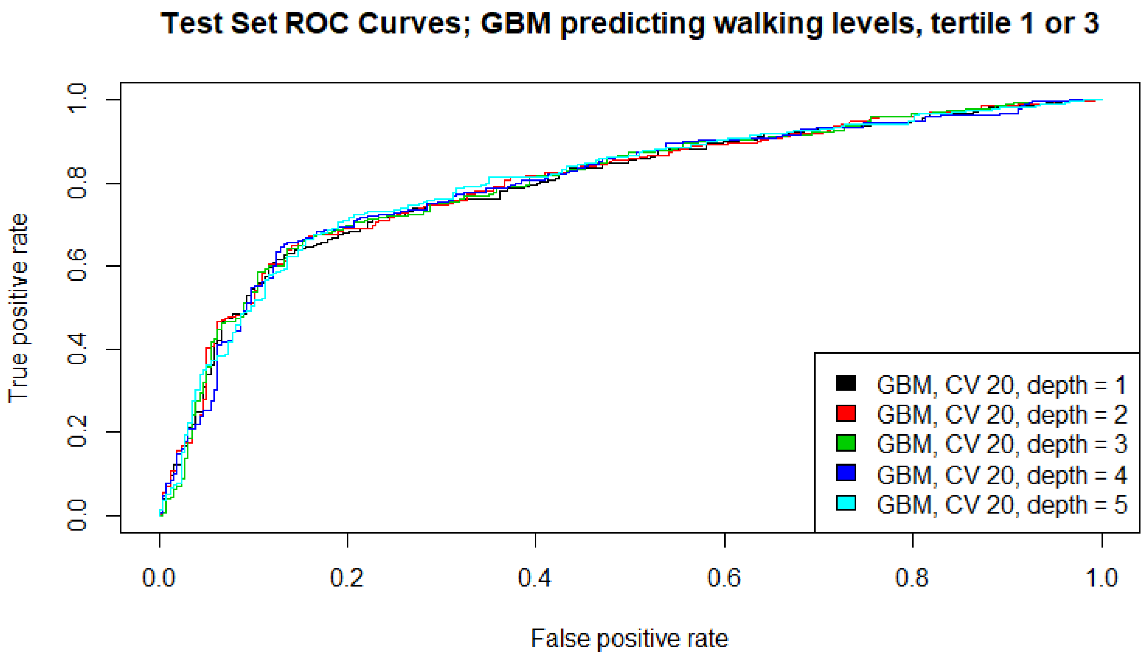
Variable examined - code	Variable examined - explanation	Number of variables with associations significant at p<0.05
walk_13	Levels of walking: tertile 1 or 3	33
Poor_perception_walking	Q18 overall perception of walking "low" or "high"*	22
Dissatisfied_w_walking	Declares avoiding walking or wanting to walk less, true/false	23
Q10_1	Fitness	26
Q10_2	Fun	19
Q10_3	Save money	27
Q10_4	Save time	22
Q10_5	Consistent travel time	24
Q10_6	Less parking hassle	24
Q10_7	Available w paths	23
Q10_9	Reduce congestion	26
Q10_10	Environment	25
Q10_11	Me time	26
Q10_12	Enjoy weather	25
Q10_13	Better routes	22
Q10_97	Other	15
Q11_1	Hills	26
Q11_4	Live too far	24
Q11_5	Not quick	21
Q11_9	Footpaths	21
Q11_14	Weather	26
Q11_15	Too much effort	20
Q11_16	Too much stuff to carry	28
Q11_17	Need transport others	22
Q11_20	Safety, day	27
Q11_21	Safety, night	33
Q11_22	Adds too much time	22
Q11_23	Boring routes	28
Q11_24	Doesn't know how long it would take	24
Q11_97	Other	24
Poor_s_day_traffic	Perceived safety re traffic, by day time "low" or "high"*	20
Poor_s_day_crime	Perceived safety re crime, by day time "low" or "high"*	18
Poor_s_day_tripping	Perceived safety re tripping/falling, by day time "low" or "high"*	12
Poor_s_night_traffic	Perceived safety re traffic, by night time "low" or "high"*	26
Poor_s_night_crime	Perceived safety re crime, by night time "low" or "high"*	27
Poor_s_night_tripping	Perceived safety re tripping/falling, by night time "low" or "high"*	16
Age_65plus	Age 65 and over, true/false	26
Q10_15	Declares walking because no other choice	26
Use_of_car	Did use the car in the previous week (driver or passenger)	22
NotEmployed	Not employed	20
LowIncome	Income <60% of median	17

* low: <4/10; high: >6/10

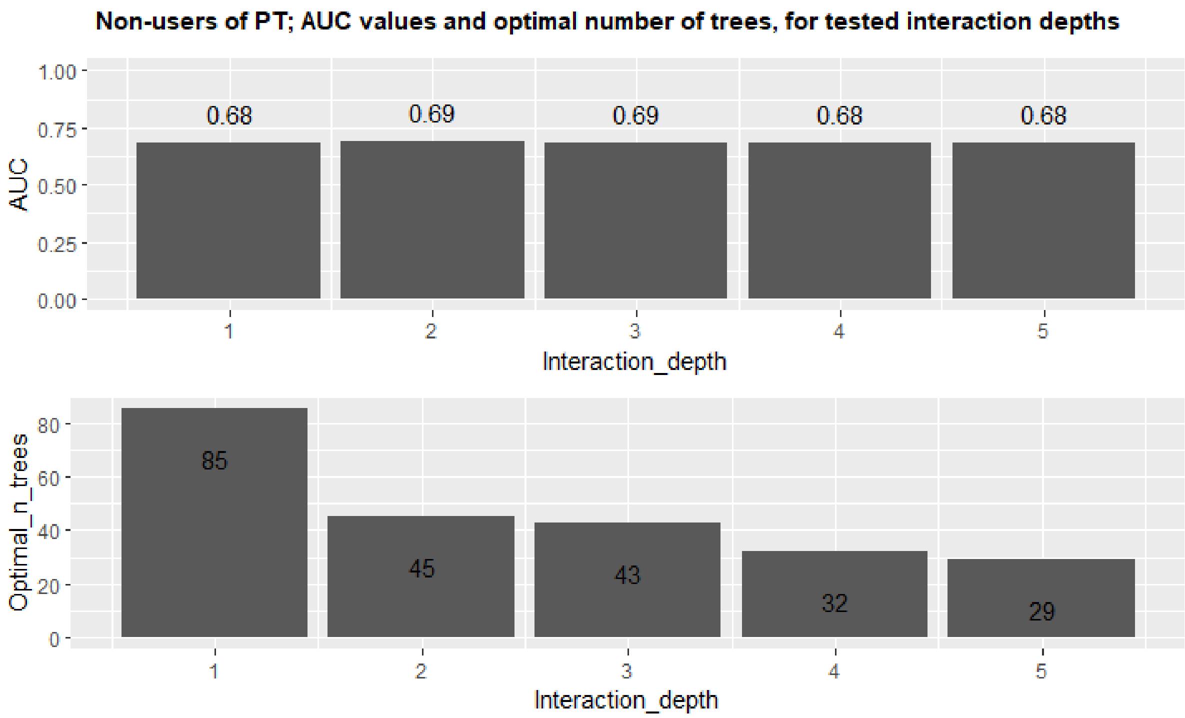
4D: Accuracy testing of machine learning models

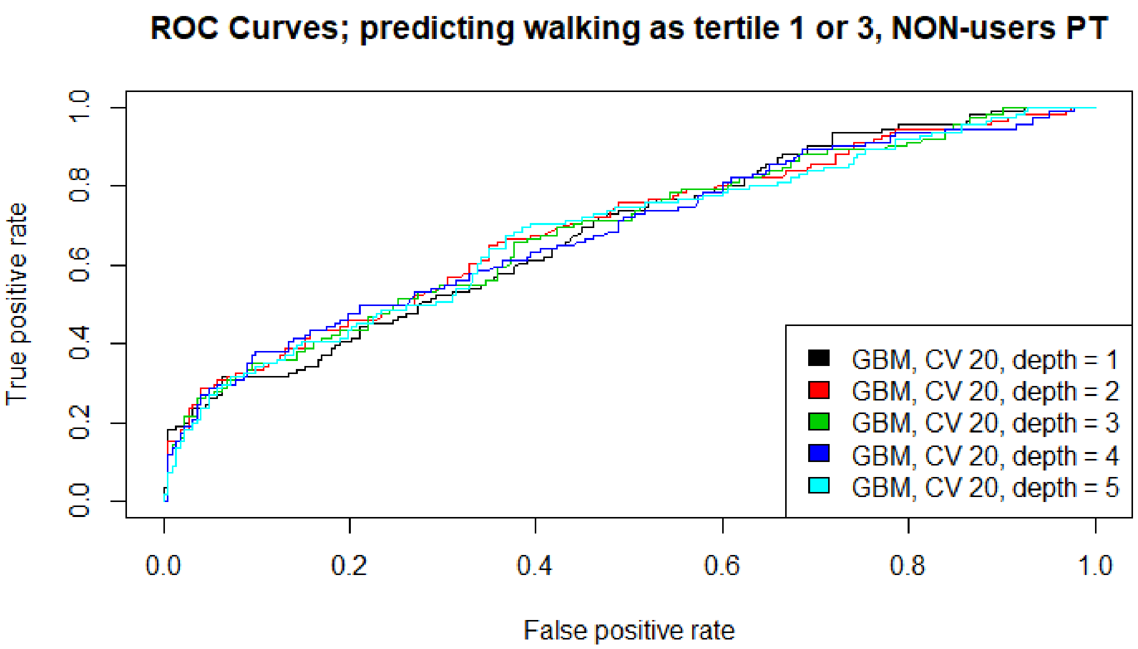
Whole population



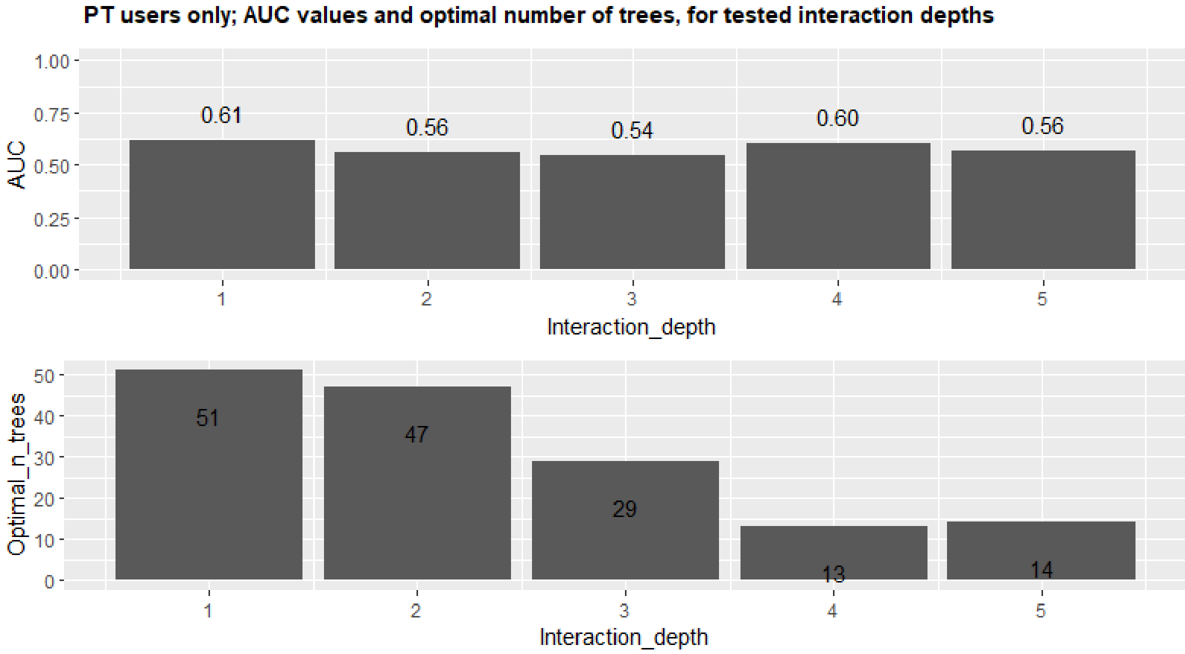


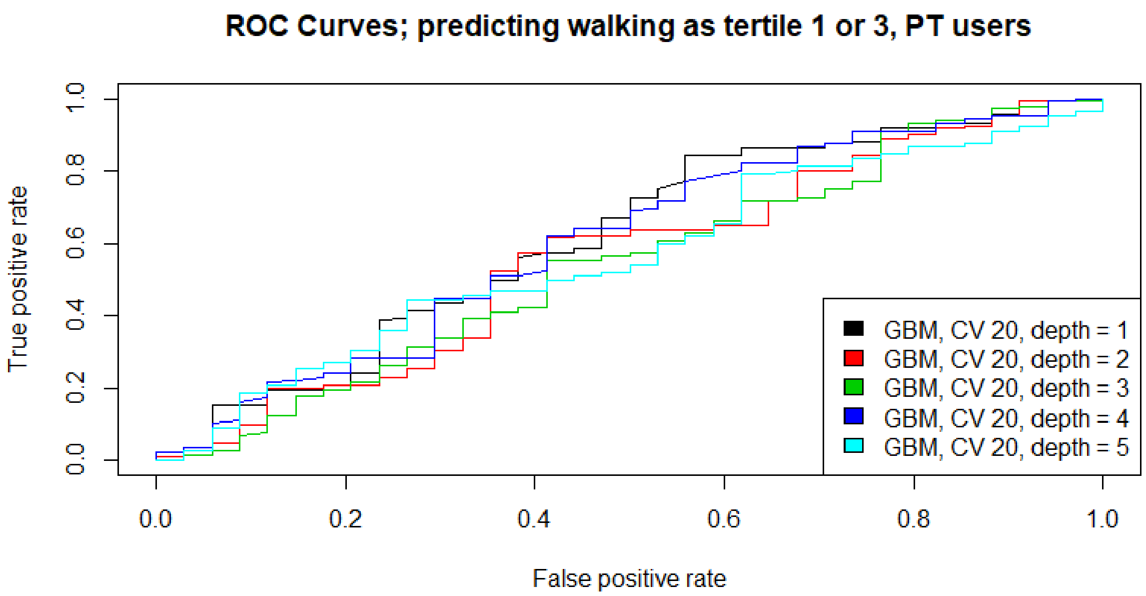
Non-users of public transport





Public transport users





4E: Detailed results

Whole population and control for use of public transport

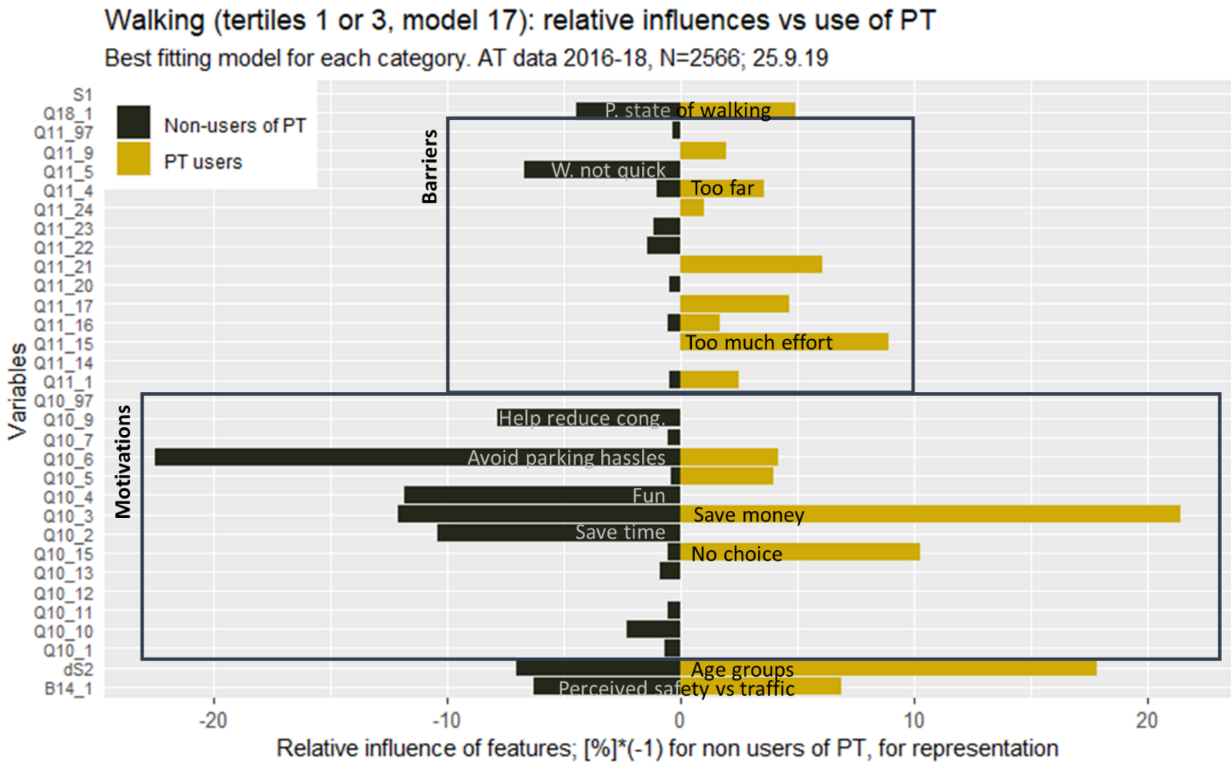


Figure 1: Relative influence of features, controlling for the use of public transport

Comparing users and non-users of Public Transport (PT)

Influences (percentage, relative to usefulness in training the models)

Variable code and explanation		all respondents	only non users of PT	only PT users	PT / nonPT	log(PT / nonPT)
		N = 2,566	N = 1,744	N = 822		
S1	Gender	0.0	0.0	0.0		
dS2	Age group	6.3	7.0	17.8	2.5	0.4
Q1_6	Travelled to/from PT, previous week	42.8	0.0	0.0		
Q18_1	Overall satisfaction, 0-10	5.2	4.4	5.0	1.1	0.0
Q11_1	Hills	0.0	0.4	2.5	5.8	0.8
Q11_14	Weather	0.0	0.0	0.0		
Q11_20	Safety, day	0.0	0.5	0.0	0.0	
Q11_21	Safety, night	0.6	0.0	6.1		
Q11_4	Live too far, not practical	1.1	1.0	3.6	3.6	0.6
Q11_5	Walking not quick	1.8	6.7	0.0	0.0	
Q11_9	Footpaths condition	0.0	0.0	2.0		
Q11_15	Too much effort	0.4	0.0	8.9		
Q11_16	Too much stuff to carry	0.0	0.5	1.7	3.1	0.5
Q11_17	Need transport others	0.2	0.0	4.6		
Q11_22	Adds too much time	1.6	1.4	0.0	0.0	
Q11_23	Boring routes	0.1	1.1	0.0	0.0	
Q11_24	Doesn't know how long it takes	0.0	0.0	1.0		
Q11_97	Other reason	0.3	0.4	0.0	0.0	
Q10_15	No choice	3.0	0.5	10.3	19.6	1.3
Q10_1	Fitness	0.4	0.7	0.0	0.0	
Q10_2	Fun	2.3	10.4	0.0	0.0	
Q10_3	Saves money	12.3	12.0	21.4	1.8	0.2
Q10_4	Saves time	2.4	11.8	0.0	0.0	
Q10_5	More consistent travel time	1.2	0.4	4.0	10.1	1.0
Q10_6	Avoids parking hassles	11.6	22.4	4.2	0.2	-0.7
Q10_7	Availability of paths / walking routes	0.0	0.5	0.0	0.0	
Q10_9	Helps reduce traffic congestion	2.4	7.8	0.0	0.0	
Q10_10	Environment	0.9	2.3	0.0	0.0	
Q10_11	"Me time"	0.4	0.6	0.0	0.0	
Q10_12	Enjoy the weather	0.0	0.0	0.0		
Q10_13	Better routes available	0.5	0.8	0.0	0.0	
Q10_97	Other reason	0.0	0.0	0.0		
B14_1	Safety traffic	2.0	6.2	6.9	1.1	0.0
	Sum	100.0	100.0	100.0		
	Count	33	33	33		

Comparing respondents with or without choice

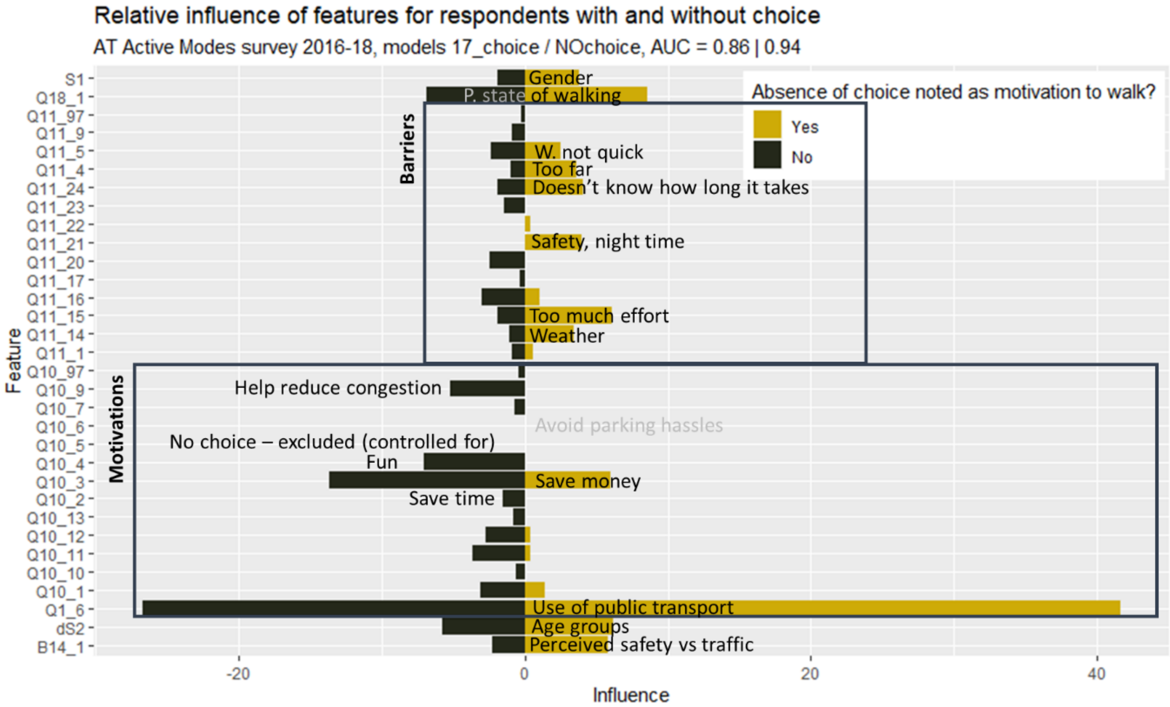


Figure 2: Relative influence of features for predicting walking behaviour controlling for the availability of choice

Influences (percentage, relative to usefulness in training the models)

Variable code and explanation		only WITH choice N = 2,229	only WITHOUT choice N = 337	choice / NO choice	log (choice/ NOchoice)
S1	Gender	1.9	3.8	2.0	0.3
dS2	Age group	5.7	6.2	1.1	0.0
Q1_6	Travelled to/from PT, previous week	26.6	41.6	1.6	0.2
Q18_1	Overall satisfaction, 0-10	6.8	8.6	1.3	0.1
Q11_1	Hills	0.9	0.6	0.7	-0.1
Q11_14	Weather	1.1	3.4	3.2	0.5
Q11_20	Safety, day	2.4	0.0	0.0	
Q11_21	Safety, night	0.0	4.0		
Q11_4	Live too far, not practical	0.9	3.6	3.8	0.6
Q11_5	Walking not quick	2.4	2.5	1.1	0.0
Q11_9	Footpaths condition	0.9	0.0	0.0	
Q11_15	Too much effort	1.9	6.1	3.2	0.5
Q11_16	Too much stuff to carry	3.0	1.1	0.4	-0.5
Q11_17	Need transport others	0.3	0.0	0.0	
Q11_22	Adds too much time	0.0	0.4		
Q11_23	Boring routes	1.4	0.0	0.0	
Q11_24	Doesn't know how long it takes	1.9	4.1	2.2	0.3
Q11_97	Other reason	0.2	0.0	0.0	
Q10_15	No choice	0.0	0.0		
Q10_1	Fitness	3.1	1.4	0.5	-0.3
Q10_2	Fun	1.5	0.0	0.0	
Q10_3	Saves money	13.6	6.0	0.4	-0.4
Q10_4	Saves time	7.0	0.0	0.0	
Q10_5	More consistent travel time	0.0	0.0		
Q10_6	Avoids parking hassles	0.0	0.0		
Q10_7	Availability of paths / walking routes	0.7	0.0	0.0	
Q10_9	Helps reduce traffic congestion	5.2	0.0	0.0	
Q10_10	Environment	0.6	0.0	0.0	
Q10_11	"Me time"	3.7	0.4	0.1	-1.0
Q10_12	Enjoy the weather	2.7	0.4	0.2	-0.8
Q10_13	Better routes available	0.7	0.0	0.0	
Q10_97	Other reason	0.4	0.0	0.0	
B14_1	Safety traffic	2.3	5.8	2.5	0.4
	Sum	100.0	100.0		
	Count	33	33		

CHAPTER 5

5A: Methods

Aims and principles

The investigation starts from the assumptions that diverse individuals might react differently to a same input (e.g. environmental feature), that their decisions can be messy and biased, and also that a same individual might behave differently in various contexts [4–6]. Further, the data are obtained from interviews inevitably biased by their structured nature, asking for instance about the "difficulties" encountered or about the levels of safety regarding traffic.
The design considered (1) the importance of individual characteristics and constraints as moderators of the relationship between UE and walking behaviour; (2) lived experiences as valuable sources of information ("I go here and I see this"); (3) the need to be specific, so to be able to provide a feedback for the practice, and therefore obtain inputs on the nature of the experienced barriers to walking/wheelchair access. The team was interested in better understanding the roles of different types and levels of impairments and considered critical to capture aspects of self-selection, general motivations and barriers, and availability of options.
The adopted methods have been chosen because they allow to better understand the decision patterns of a broad range of users, capturing the "points of friction" so to provide inputs towards an environment supportive of walking. Triangulation of data is used to explore and develop emerging themes. Each method is described below. The investigation has similarities with market research aiming to identify what customers think of a certain product (here: walking environment), and how this product should be improved (here: what barriers need to be removed)[7].

Interviews

Selection and recruitment
Recruitment was planned to be done through the Ministry of Transport, who were to contact a subsample of the Household Travel Survey participants living in areas with a pre-determined Walkscore® level (70 to 90) and having agreed to being contacted by the Ministry of Transport for further research. A total of 194 participants were identified and contacted on 9.12.19 by the Ministry of Transport's contractor, on behalf of the research team. Two participants accepted to be contacted but none of them provided a response within a month after having been contacted by the research team.
The recruitment was continued by selecting four neighbourhoods having average Walkscore® levels corresponding to the defined band but contrasted in terms of through traffic[8] (used as a proxy for traffic-oriented design) and public transport service. The neighbourhoods are:

		Through traffic through neighbourhood activity centre	
		Low (<12,000 vehicles/d, average, 5 work days)	High (>23,000 vehicles/d, average, 5 work days)
Quality of the PT service	High – TransitScore >70	Mount Eden	Kinglsand
	Low – TransitScore <50	Papakura	Mt Roskill

Recruitment was done through information sessions organised and advertised locally and on social media. The posters had the following tagline: "How easy is it to walk* to your destinations or your bus stop?", specifying that "walking" includes wheelchair access.
Given that the first 30 participants were almost all non-disabled, the constraint on neighbourhoods was relaxed. Disabled people's organisations were contacted and interested participants were included if they lived in Auckland, and not necessarily in one of the four pre-defined neighbourhoods.

Methodological decisions taken

The interview process and outputs are influenced by some key decisions taken:

- **Convenience sampling: participants were recruited through public information sessions, posters, emails and social media**. The sample cannot be therefore seen as representative of "Aucklanders" but should be seen as people who do have some interest in walking and sharing their lived experiences.
- **The sampling ensured that half of the participants have self-declared impairments.** The questions on the impairments relate to (1) the first four questions of the Washington Group Short Set[9], identifying four potential difficulties (seeing, hearing, walking and concentrating/remembering) and four possible levels of difficulty (no difficulty, some difficulty, a lot of difficulty, cannot do at all); and (2) the NZ Household Travel Survey[10], having specified the question about walking ("Do you have difficulty walking 500m unaided?"), and added two additional questions, about the difficulty of using public transport and driving. This method views disability as a much more complex construct than the dichotomy "disabled"/ "non-disabled", each participant having a unique profile on this 6x4 matrix. Recruitment ensured that half of the participants have at least some difficulty regarding seeing, hearing, walking and concentrating/remembering.
- **Interviews were quantitative and structured,** a decision taken to cover in a systematic way the dimensions of interest; the interviews contained number of closed questions asking typically participants to rate certain elements from 0 to 10, chosen because (1) it allows comparability of answers across topics and participants; it allows comparability between gathered answers Auckland Transport's Active Modes survey and (3) it prompts open questions ("what") in a systematic way - every time the participant rates an aspect 3/10 or below (threshold arbitrarily defined for poor quality).
- **Interviews were recorded and answers were captured on the fly** (ratings and specific insights – i.e. not enough time available to cross at the crossing [x], when asked what makes a walked trip feel unpleasant). Recordings were used to extract specific exact quotes, but the interviews have not been fully transcribed. This was a key design decision, as it allows to tackle the desired breadth. The downside is the fact that the researcher "filtered" to some extent all the answers on the fly, noting for instance the main characteristic (e.g. "not enough time to cross, at the place x") and ignoring the subtlety of the exact words chosen and the latent inputs (pauses, sighs, laughter, body language, etc.). The usual trips participants wanted to share were drawn on a paper map, by the interviewee or the researcher. This method was chosen so to facilitate participants' inputs and avoid possible technological barriers (the alternative would have been using a tablet or a touch screen). The truthfulness of the information was assessed with a sub-group of participants (those who had agreed to continue being part of the project as Citizen Scientists, an aspect that will be presented in a future publication) – the group was presented with the findings identifying the "what" was considered difficult/unpleasant or unsafe, and invited to question and challenge the findings.
- **The qualitative dimension ("what" matters) has been assessed for trustworthiness** verifying the four dimensions posited by Guba and Lincoln[11]:
    - **Credibility** relates to the confidence in the "truth" of the findings. It was assessed through (1) the review of the findings by a sub-group of participants, invited to question and challenge the results; and (2) the survey of the locations identified as major barriers (photos and description of the causes indicated by the participants);
    - **Transferability** ensures that results could be applied in other contexts. Transferability is a key consideration here, as the aim of the research is to provide practical insights for transport planning and urban design practices in Auckland. Three mechanisms were

used: (1) identification of main themes relative to general motivations / discentives to walking and to specific aspects that respondents find difficult or unpleasant; (2) survey on the ground of specific environmental aspects identified as difficult or unpleasant, aiming at better describing their nature; (3) outlining systemic aspects that might be important in areas other than Auckland (e.g. specific aspects of road design noted as problematic).

- **Dependability** demonstrates that the findings could be repeated. The structured format of the interview and the clear rules set for further investigation (see above) make it easy to repeat the investigation in other contexts or at other times. This work would be most useful, to test to what extent the results can be extrapolated (see systemic issues identified above).
- **Confirmability** verifies that the findings are shaped by respondents and not the biases and motivations of the researcher. In the present study, a source of bias can come from the framing of the interviews (e.g. asking what specific environmental characteristics are "difficult" or "unpleasant"; using other words could have possibly yielded other results) and the fact that inputs are mostly noted on the fly and not integrally and formally transcribed. The bias is controlled for by the review of the results done by a sub-group of participants.

5A2: Information sheet for interview participants

Participant Information Sheet for interview participants

Date Information Sheet Produced: 31.1.2020

Project Title: Quality of the walking environment and difficulties to access local destinations.

An Invitation

Tena koe,

My name is Tamara Bozovic, I am a PhD candidate at Auckland University of Technology (AUT). Together with the research team (Professor Erica Hinkson and Dr Moushumi Chaudhury), I would like to invite you to take part in a research project. This research focuses on Aucklanders who experience difficulties accessing to their local destinations, and on their neighbourhood street environment. We would like to find out what the difficulties are, and how they influence the choice to walk to the local destinations or access them by wheelchair. If you do experience difficulties of walking/wheeling to your local destinations or bus stops, I would like to invite you to participate to a face-to-face interview where we will speak of the local trips you usually make of the trips you would like to make more often, and of your general perceptions of your walking environment. Below, I would like to provide you with some more information about the research. You are welcome to ask any questions you may have.

What is the purpose of this research?

This research aims to contribute to the efforts of improving the urban environment. It is important because the streets' environments can cause difficulties that discourage walking. Aucklanders' levels of walking are rather low, and strategies such as the Auckland Plan aim to encourage accessing local destinations on foot or by wheelchair, for all. Understanding the difficulties can help the local authorities improve the streets environments by addressing those aspects that matter most.

This research will provide insights into what these difficulties are and how they influence people's choices for moving around. The results will be shared with all the participants, presented to the local authorities responsible for the redesign of existing components of urban environments, and submitted for publication to scientific journals and conferences.

How was I identified and why am I being invited to participate in this research?

You received this sheet after having responded to the team's invitation. Announcement about this project was done via posters, local info sessions, newsletters and social media. After having invited all adult Aucklanders living in four designated neighbourhoods (Mt Eden, Mt Roskill, Kingsland and Papakura), the invitation was extended beyond those neighbourhoods in order to recruit participants who experience difficulties seeing, hearing, walking unaccompanied 500m or remembering/concentrating. The neighbourhoods had been selected because they present a similar availability of everyday destinations but different qualities of walking environments and public transport service.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

If you wish to participate, please contact me by email or telephone. To participate, you will be asked to sign a Consent Form. You will find this document at the end of this letter. You can either send me a scanned signed copy with your email, or you can sign this document when we meet for the interview.

What will happen in this research?

In this research, I will amongst others realise a series of face to face interviews. You are invited to participate to this phase. In these interviews, we will discuss the local destinations reached, the mode of transport used, the perceived level of ease of access, and the aspects that can be difficult for accessing places on foot or by wheelchair (what they are, where they are). For each participant, I will also capture elements that can be important for understanding the choices around walking. These include the time of residence in the neighbourhood, reason for choosing to live there, occupation, age group, mobility impairments type and level, usually available transport options or help, and perception of community. I will note the information on a paper form, and we will annotate together a paper map showing the destinations, routes, and possible difficulties encountered. The interviews will also be audio taped, so that I can check the information noted. They will last about 45 minutes and will be arranged at a time and place that suits you, for instance in a local public space (library…) or at your home.

What are the discomforts and risks?

It is not anticipated that participants will encounter any risk from participating in this research.

What are the benefits?

To date, the understanding on how the streets environment possibly hinders or prevents trips on foot or by wheelchair is very poor. Internationally, the quantity of data is weak, and presents many biases. This research will contribute to local authorities' effort to improve existing urban environments. Having a good evidence is important in order to target the biggest difficulties for residents and visitors (e.g. people with disabilities, parents with prams, older people). Beyond Auckland, the findings could be useful for other New Zealand or Australian urban areas, given that the issues are likely to be linked to system design practices, being similar. Ultimately, addressing main barriers to access improves everyone's ability to participate, and helps create a more supportive environment for an ageing population. We also hope that the results will be useful to the local practitioners working on the streets' design.

For me, this research will contribute to the obtention of a PhD and allow me to submit findings to academic journals and conferences. Beyond this, I feel privileged to be able to leverage users' insights to help improve the transport planning and urban design practices.

We value your time and will offer a koha ($30 supermarket voucher) in sign of appreciation.

How will my privacy be protected?

All information that you give us will be treated as private and confidential. Only me and the researchers involved in the study will have access to the records. Research records will be kept in a locked file and sorted by number codes, not by names. In any sort of report we publish, information will be presented in a way that doesn't allow to identify you or any other participant in any way. Data will be stored on AUT premises for 6 years and will be permanently destroyed after this period.

What are the costs of participating in this research?

There are no costs except for your personal time, for participating to the interview. The interviews are expected to last about 45 minutes.

What opportunity do I have to consider this invitation?

If you are happy to participate in this research, please let me know your decision by the 28 February 2020.

Will I receive feedback on the results of this research?

Yes, you will receive a summary of the findings unless you indicate in the Consent Form that you do not wish to receive them.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor Erica Hinckson: Erica.hinckson@aut.ac.nz, +64 9 921 9999 ext 7224.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , +64 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Tamara Bozovic, AUT City Campus, Auckland, E-mail: rfq8954@aut.ac.nz, Ph: 021 212 35 03

Project Supervisor Contact Details:

Professor Erica Hinckson: Erica.hinckson@aut.ac.nz, +64 9 921 9999 ext 7224.

5A3: Consent form for interview participants

Consent Form for interview participants

Project title: ***Quality of the walking environment and difficulties to access local destinations***

Project Supervisor: ***Professor Erica Hinckson***

Researcher: ***Tamara Bozovic***

○ I have read and understood the information provided about this research project in the Information Sheet dated 31.1.2020.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

………………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 12 December 2018, AUTEC Reference number 18/431.

Note: The Participant should retain a copy of this form.

5B: Interview questions

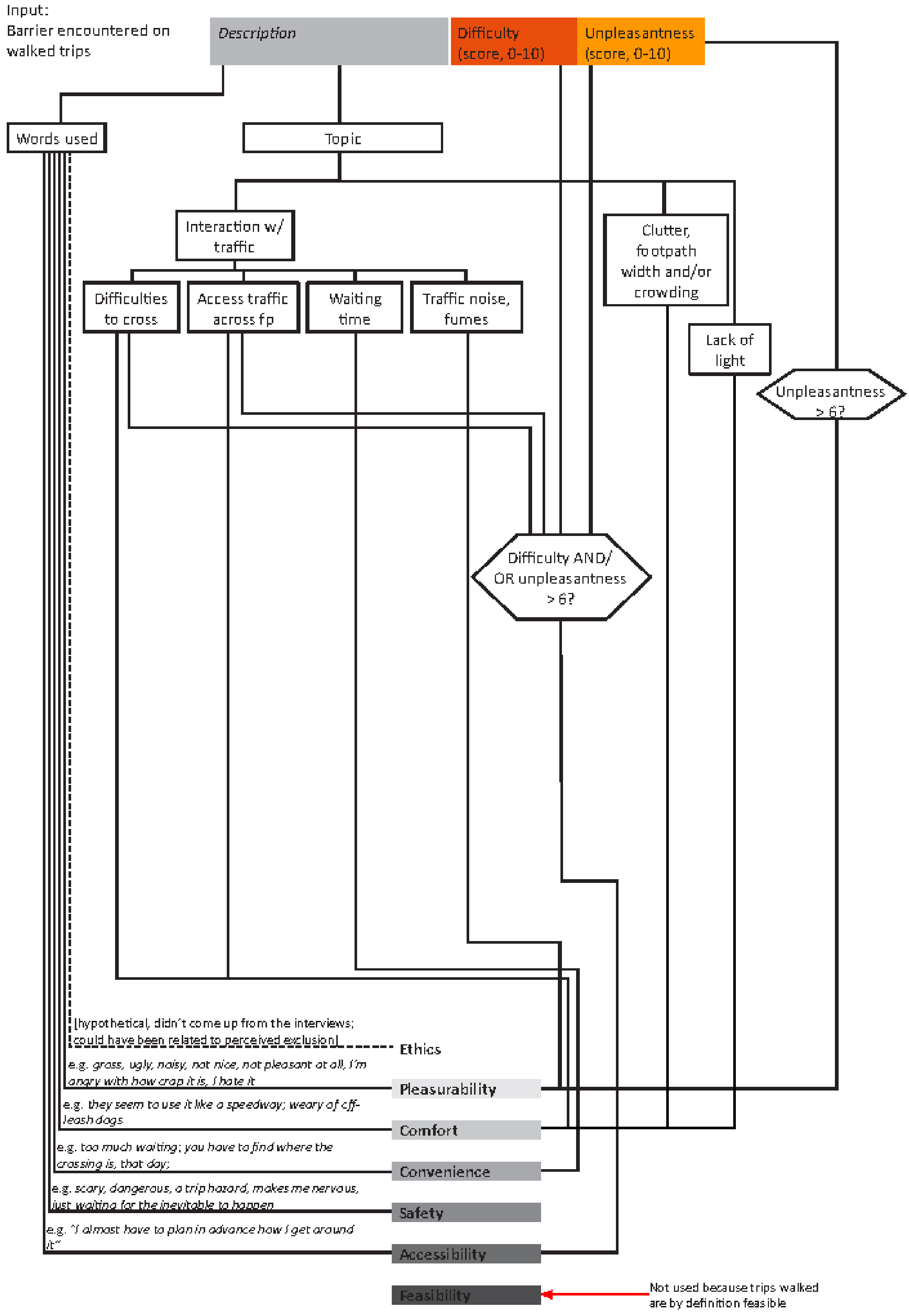
All questions have the option don't know / no answer

Question	Answers*
Could you tell me your age?	
What gender do you identify with?	F/M/I
What is your level of income?	Open, coded against pre-defined levels: <10,000 10-20,000 20-40,000 40-60,000 60-80,000 80-100,000 100-120,000 120-150,000 150-200,000 >200,000
What is your highest education level?	Open, coded against pre-defined levels: Primary Secondary High school Bachelors Honors Masters PhD Technical school Apprenticeship Postgrad
What is your current occupation?	Open, coded against pre-defined levels: woking full time working part time studying studying and working retired unemployed looking for a job not working for the moment part time + child care
Do you live with other people?	Single Single w kids With partner Partner + kid(s) Married no kids Married w kids Separated, w kids Divorced Widow
Do you have a drivers' licence?	y/n
Is a car usually available for you to use?	y/n/sometimes
For how long have you lived in in [neighbourhood]?	Numeric
What was the main reason for coming to live in [neighbourhood]?	Lack of other choice
	Compared options and this one was better
	Love the neighbourhood, wanted to live here
Where do you meet your community?	Open, no prompted answers
How many of the facilities (such as shops, schools, post shops, libraries and medical services) that you want to go to, can you easily get to?	1. All of them
	2. Most of them
	3. Some of them
	4. Only a few of them
	5. None of them
How many times per week do you walk for 10 minutes or more?	
How many kilometres did you drive, last year, approximately?	
Did you use public transport, last year?	

Question	Answers*
How many trips by public transport did you take last month, approximately?	
Do you have difficulties seeing, even when wearing glasses?	a. No - no difficulty
	b. Yes – some difficulty
	c. Yes – a lot of difficulty
	d. Cannot do at all
Do you have difficulty hearing, even if using a hearing aid?	same as above
Do you have difficulty walking 500m unaided?	
Do you have difficulty remembering or concentrating?	
Do you have difficulty using public transport?	
Do you have difficulty driving?	
When it comes to walking, in general, in Auckland, would you say that:	... you only walk if you have to
	... you would like to walk less
	... you are happy with the amount of walking you do
	... you would like to walk more (one choice)
What are the key reasons you choose to walk?	open
When it comes to walking in Auckland, what could stop you from walking as much as you otherwise would?	open
>>> **how safe** do you feel / would you feel walking during the daytime, regarding	
a. traffic	All answers: 0 to 10, idem AT
b. tripping/falling	
c. crime	
>>> **how safe** do you feel / would you feel walking during the night time, regarding	
a. traffic	All answers: 0 to 10, idem AT
b. tripping/falling	
c. crime	
How easy do you find walking in your neighbourhood by day time?	0 to 10, idem AT
How easy do you find walking in your neighbourhood by night time?	
How pleasant do you find walking in your neighbourhood by day time?	
How pleasant do you find walking in your neighbourhood by night time?	
Has anything improved your access, in your neighbourhood?	yes/no
What improvement(s) did you notice?	open
Let's talk about your usual trips and places you go. We will talk about the trips one by one. One trip can have one or more destinations. Let's talk about the first trip that comes to mind... (for the next ones: Is there another trip you can think of?)	
What is this trip for?	Open
How do you make that trip?	select one mode, idem HTS
How do you choose to make that trip by [mode]?	Open; -> categories based on AT Q11
How often do you make that trip?	frequency range, same as above
How easy is that trip?	0 to 10, idem AT
How pleasant is that trip?	0 to 10, idem AT
Can we map the places you visit on this trip? What would be the first one?	Code, noted by interviewer, in order
(what is this destination, if not already answered)	Selected HTS destinations, as above
How important is it for you to go there?	0 to 10, idem AT
Do you make this trip with someone?	
Why do you choose to go with someone?	1. Need help
	2. Company / social
	3. Because in charge of that person (child, ...)
	4. Other
	*
Do you make this trip by day time or night?	1. Day time
	2. Night time
	3. Either or

Question	Answers*
	*
How safe from traffic do you feel?	0 to 10, idem AT
How safe do you feel regarding tripping/falling?	0 to 10, idem AT
How do you chose the route? [prompted if not already mentioned by the interviewee, otherwise just noted]	
Is there anything that might make this trip difficult, upleasant or both?	
Barrier - nature	Own words; note on the map if specific features identified.
Barrier - level of difficulty	0 to 10
Barrier - level of unpleasantness	0 to 10
[Id for all elements the interviewee raises: note on the map if aspect of the built environment, and note difficulty)	
What do you enjoy about this route this route?	Open; note on the map if specific features noted, and note for each what they are (e.g. park, views, etc.). Features listed.
Do you have the possibility to go to [destination] using a different mode of transport?	y/n
*** [if yes] - how would you describe that alternative	
Is the distance to this destination something you could do on foot/by wheelchair?	
>>> [if yes] how easy would it be to walk?	0 to 10, idem AT
>>> [if yes] how pleasant would it be to walk there?	
>>> [if yes] how safe from traffic would you feel?	
>>> [if yes] how safe would you feel regarding tripping and falling?	
Are there any other destinations you would like to go to but struggle to get to?	Selected HTS destinations, as above
if yes - where would you like to go?	
(what is this destination, if not already answered)	
How important is it for you to go there?	0 to 10, idem AT
Can you tell me why you don't go there?	
Is the distance to this destination something you could do on foot/by wheelchair?	
>>> [if yes] how easy would it be to walk?	0 to 10, idem AT
>>> [if yes] how pleasant would it be to walk there?	0 to 10, idem AT
>>> [if yes] how safe from traffic would you feel?	0 to 10, idem AT
>>> [if yes] how safe would you feel regarding tripping and falling?	
Is there something else you would like to add?	**Open**

5C: Coding protocol



5C2: WE categories, for coding

The list of considered features of the WE was first developed after the general literature review (chapter 2). It included those features that had been associated with walking or that were assumed to be associated but for which evidence was not sufficient yet. The table below presents the examined factors, each having specific categories attached to it. While the factors aim at distinct characteristics, the categories can have overlapping definitions. This is due to the lack of consensus on the WE categorisation and the ensuing variety of constructs examined in different studies. For instance, some will examine street connectivity while others will look more specifically at pedestrian connectivity. Here, the choice was made to have categories that relate to the aspects commonly studied, so to ensure a more specific description of the associations between WE features and perceptions.

Dimension		Category	Reasons for inclusion of the category	Subcategory	
Destinations	**a**	Distance to desired end destinations	Overall access to destinations has associated with walking [12–15]. Walkability indices typically calculate a score based on combined availability of different types of destinations (e.g. [16, 17]), however the levels of agreement between those measures and the users' perceptions can range from poor to almost excellent [18]. Different types of destinations can have different levels of importance for users (e.g. [19]); however, they were grouped for the interviews due to (1) the relatively low number of mentions; (2) the fact that interviewees were not talking about any type of destination but only those desired (e.g. often not talking about "the shops" in general but about that specific shop they want to get to); and (3) trips combining purposes and destinations.		
	b	Residential density	The residential density has been associated with walking levels although review authors report inconsistencies in findings [12–15, 20, 21].		
	c	Distance to public transport stops	Access to public transport has been correlated with levels of walking although with some inconsistencies in findings [12, 13, 15, 22].		
Walking network	**a1**	Street connectivity / block size	Proposed as a high level determinant of walkability indices [17] and associated with walking levels although with inconsistencies [12–15, 20, 21].		
	a2	Pedestrian connectivity	Pedestrian connectivity is more consistently correlated with walking than street connectivity [15, 20, 22, 23]. Vale et al note the importance of differentiating between pedestrian connectivity and street connectivity, as street connectivity doesn't necessarily represent well the connectivity as experienced by pedestrians [23]. Detours (for instance related to using a pedestrian overbridge) can be seen as an extra effort [24] and were included in the general notion of connectivity.		
	b	Stairs	Stairs can be challenging or dissuasive for elderly people [24, 25]., but are variably and infrequently assessed [25].		
	c	Topography	Vale et al not the importance of slope in the accessibility assessment, and its insufficient and inconsistent consideration in walkability indices [23].		
Walking environment quality	**a**	Footpaths	Footpaths are a core aspect of pedestrian infrastructure. Footpaths width has been historically associated with levels of service and still appears in some indicators [26]. The available width, its reductions through objects or clutter, and the quality of the surface can be particularly important for some populations, e.g. wheelchair users [14, 27]. Different types of possible barriers have been examined separately.	1	design (width, directness); including fixed obstacles and the clear width they leave
				2	materials, execution
				3	absence
				4	temporary obstruction/ clutter
				5	maintenance

		Obstructions can be particularly important for some populations, e.g. people with mobility impairments [3, 21].		
b	Traffic	Higher traffic speeds have been related to difficulties of crossing the streets [28, 29] and with perceptions of safety [30]. Traffic volume has been associated with human perceptions since the 1960s [31–33]. Noise has been associated with well-being (e.g. recent review by Maurer Braun and colleagues [34]) and with walking, but evidence is limited and results are mixed [14, 22, 35]. Noise can be particularly important for people with limited vision, as an indicator of vehicles' travel paths [36]. Air pollution is assumed to have similar consequences as noise, possibly with even less available evidence [22]. Safety from traffic has been in turn diversely correlated with levels of walking, which can be due to the diversity of measurement methods [12, 13, 15, 22] – traffic speed is included here as one possible objective dimension that could contribute to perceptions of safety.	1 2 3 4	volumes and speeds noise and pollution traffic across the footpaths sharing space with bicycle riders
c	Crossing facilities	Crossing facilities can act as facilitators or barriers, if the provision is adequate or lacunar [14, 22, 28]. Perceiving crossings as difficult can correlate with dramatically reduced walking trips [37, 38]. Interrupted pedestrian infrastructure can have serious consequences, especially for people with reduced mobility [14, 22, 27]. Both provision and detail of execution (possible barriers) can be important and have therefore been examined separately.	1 2 3 4 5	non-signalised: layout, geometry signalised, waiting time signalised, layout, geometry signalised, drivers' behaviour availability of appropriate xing facilities
d	Conjunction: crossing facilities AND traffic conditions	Crossing facilities can act as facilitators or barriers, if the provision is adequate or lacunar [14, 22, 28]. Perceiving crossings as difficult can correlate with dramatically reduced walking trips [37, 38].		
e	Activation: presence of other people, "eyes on the street"	The presence of other people has been associated with walking levels – e.g. recent review by Salvo and colleagues [22]. Jane Jacobs' seminal work presented this characteristic as crucial for the quality of the broader street environment since the 1960s [31] and had been further developed and illustrated namely by Jan Gehl across the world [32]. These two authors consider the transparent facades as an integral part of this element of natural surveillance, coined "eyes on the street" [31]. The presence of people seen as threatening can be associated with levels of walking, although with inconsistencies [13, 22]. It could be confounded by individual characteristics and is included here given the need to gather better evidence.	1 2 3 4 5 6	Presence of other people walking Presence of other people sojourning/playing Transparent facades, café/shop windows Presence of police Presence of people seen as threatening Empty street/road

			Presence of police seems to be associated with walking but in inconsistent ways, as outlined in the recent review by Salvo and colleagues [22]. It could be confounded by individual characteristics. It is included here given the need to gather better evidence of what it means for whom.		
	f	Street furniture	The possibility to sit can be important for older populations [13] or people with disabilities [30].	1	presence (benches, …)
				2	layout
	g	Use of the space by other people, (in)civilities	Littering, vandalism and decay have been negatively associated with walking [13, 22].		
	h	Landscape	Greenery, landscaping and sceneries defined as "pleasing" have been positively but inconsistently associated with walking, as reported in recent reviews [12, 13, 15, 22]. Street aesthetics have been associated with walking levels [39, 40].	1	architectural quality
				2	views
				3	greenery
	i	Holistic design quality	Jane Jacobs and Jan Gehl have been amongst authors to illustrate the importance of street proportions and human scale from an ethnographic perspective [31, 32].		
	j	Lighting (presence, quality)	Lighting was positively but inconsistently associated with walking. [13, 15, 22]		
	k	Shelter (presence, quality)	Importance of shelter has been ethnographically demonstrated by Jan Gehl [32] and outlined as important for bus users' perception of quality of service [30]. The evidence is however limited.		
	l	Availability of toilets/water	Availability of water and toilets can be assumed to play a role especially for older populations, but evidence is limited and inconsistent. [13]		
	m	Separate design features for PwDs	Older and disabled people can feel stigmatised by separate design features [41]. These features can be perceived as pointing their old age or disability, when they are noticeable and fixed in place [41].		
Broader transport system - ease, convenience and cost of alternatives	**a**	Public transport	Walking is typically the first/last mile associated to public transport, and the quality of PT connections can motivate to use PT and walk to/from [42, 43]. The ease of use includes the ease of access, covering aspects such as steps or stairs [30].	1	availability and efficiency of public transport services
				2	accessibility of public transport bus stops (design)
				3	cost
				4	comfort and lighting of PT stops
	b	Driving	Convenience of driving and parking have been found to deter from walking [44–46]. AT survey confirmed those aspects and added the dimension of cost [42].	1	ease, overall
				2	availability of parking
				3	cost of parking
				4	travel times
				5	environmental pollution
	c	Other modes	Levels of walking were related to the ease, efficiency and cost of alternatives available [42]. Public transport and driving are the	1	efficiency of rideshare
				2	cost of rideshare
				3	bicycle - travel time

	most obvious ones, included above. Here, we also include rideshare/taxi, and bicycle riding.	4	bicycle - good infrastructure available
		5	bicycle - ease of parking

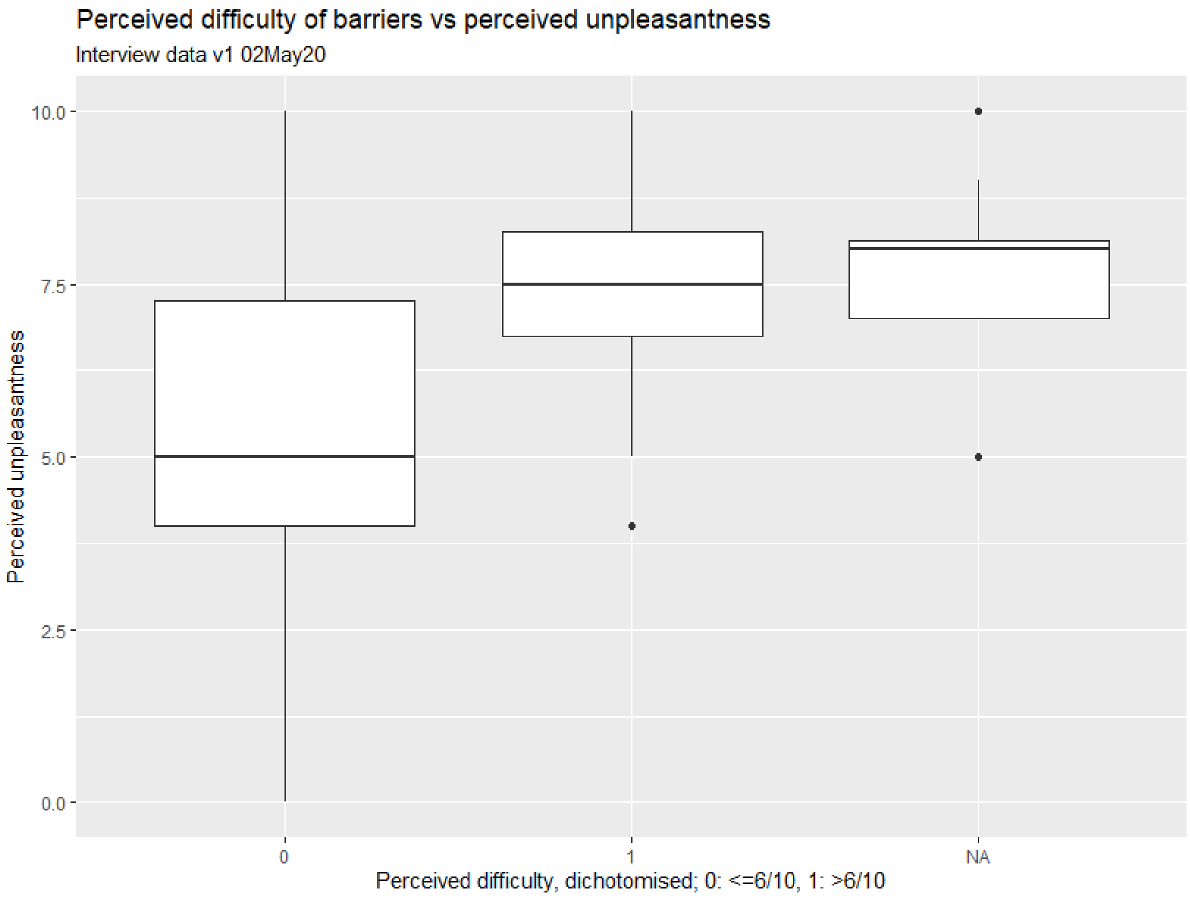
5D: Results – frequencies of mentions of topics against different questions

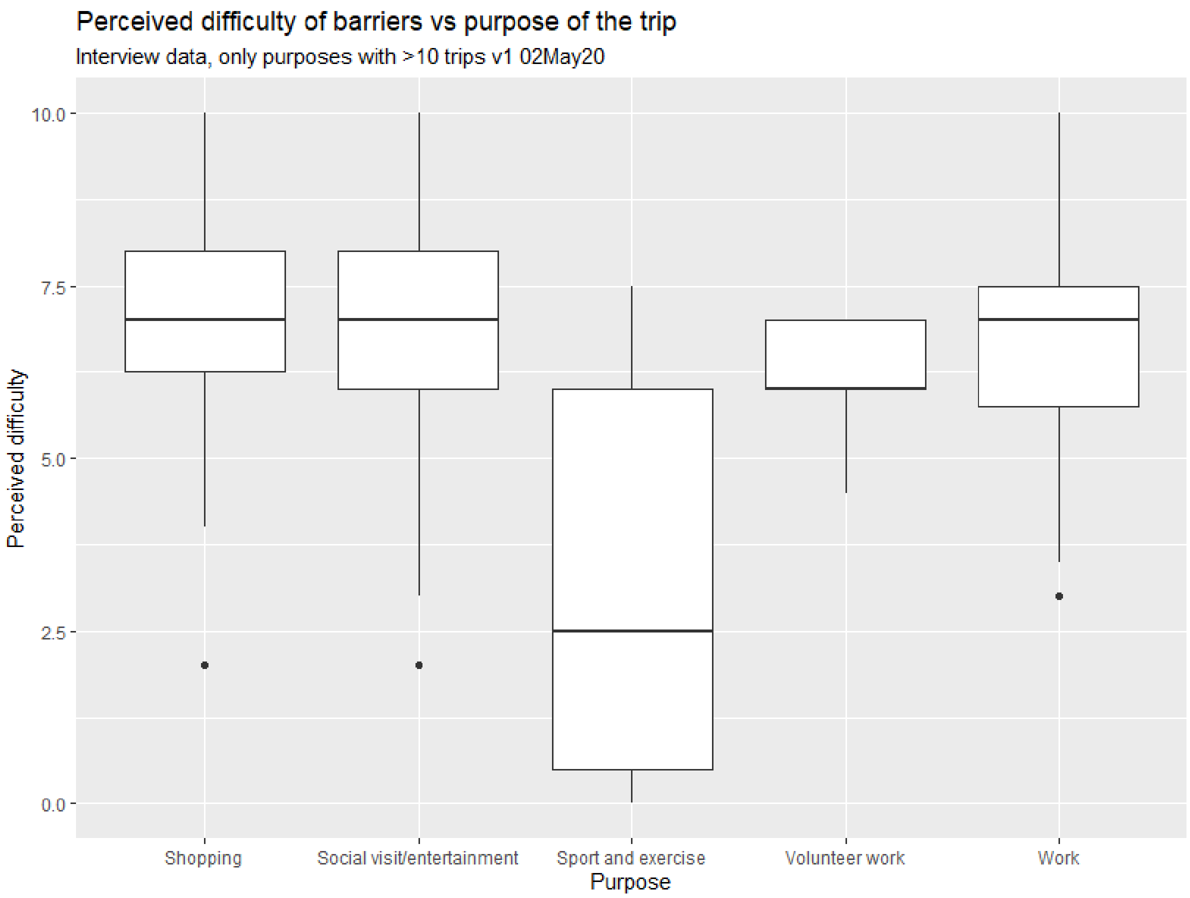
Dimension	Category	Subcategory	Motivations, overall	Deterrents, overall	Barriers to walking specific trips	TOTAL, person-level	Choice of walking	Choice of NOT walking	Appealing features noted, for trips walked	Noted as difficult (>6/10)	Unpleasant (>6/10)	TOTAL, trip-level
Destinations	Distance desired end destinations		7	13	11	31	12	2	6	0	0	20
	Distance to public transport stops		2	0	0	2	0	0	0	0	0	0
Walking network	Street connectivity / block size		0	3	1	4	0	1	2	1	0	4
	Stairs		0	0	0	0	0	0	0	0	0	0
	Topography		1	4	2	7	1	2	6	2	0	11
Street environment - quality	Footpaths	design (width, directness)	0	0	4	4	0	0	30	3	3	36
		materials, execution	0	0	0	0	0	0	0	1	3	4
		absence	0	0	0	0	0	0	0	0	1	1
		temporary obstruction/ clutter	0	0	0	0	0	0	0	0	5	5
		maintenance	0	2	0	2	0	1	3	1	0	5
	Traffic	volumes and speeds	0	5	1	6	0	0	10	13	16	39
		noise and pollution	0	2	0	2	0	1	2	2	3	8
		Traffic across the footpaths	0	0	0	0	0	0	0	2	4	6
		Sharing space with bicycle riders	0	0	0	0	0	1	0	0	0	1
	Crossing facilities	non-signalised: layout, geometry	0	0	7	7	0	0	0	14	12	26
		signalised, waiting time	0	0	0	0	0	0	0	4	1	5
		signalised, layout, geometry	0	0	0	0	0	0	0	2	0	2
		signalised, drivers' behaviour	0	0	0	0	0	0	0	0	0	0
		availability of appropriate crossing facilities	0	0	0	0	0	0	0	1	0	1
	Conjunction: crossing facilities AND traffic conditions		0	4	3	7	0	0	12	0	4	16
	Activation: presence of other people, "eyes on the street"		3	2	4	9	3	2	11	2	3	21
	Street furniture	presence (benches, …)	0	1	0	1	0	0	0	0	0	0
		layout	0	0	1	1	0	0	0	2	0	2
	Use of the space by other people, (in)civilities		0	0	1	1	0	0	0	0	0	0
	Landscape	architectural quality	0	3	2	5	0	0	4	2	1	7
		views	1	0	0	1	0	0	16	0	0	16
		greenery	5	3	0	8	1	0	49	0	0	50
	Holistic design quality		2	4	4	10	0	0	13	2	4	19
	Lighting (presence, quality)		0	1	1	2	0	1	0	4	2	3
	Shelter (presence, quality)		0	2	0	2	0	0	0	0	2	6
	Availability of toilets/water		0	1	0	1	0	0	1	1	0	2
Broader transport system	Public transport	availability and efficiency of public transport services	10	0	2	12	15	3	0	0	0	18
		accessibility of public transport bus stops (design)	3	0	1	4	0	0	0	0	0	0
		cost	0	0	0	0	2	0	0	0	0	2
		comfort and lighting of PT stops	0	0	0	0	0	0	0	0	0	0
	Driving	ease, overall	2	1	1	4	0	8	0	0	0	8
		availability of parking	3	0	0	3	9	1	0	0	0	10
		cost of parking	0	0	0	0	3	0	0	0	0	3
		travel times	1	0	0	1	0	2	0	0	0	2
		environmental pollution	1	0	0	1	0	0	0	0	0	0
	Other modes	efficiency of rideshare	0	0	0	0	0	0	0	0	0	0
		cost of rideshare	0	0	0	0	0	0	0	0	0	0
		bicycle - travel time	0	0	0	0	0	2	0	0	0	2
		bicycle - good infrastructure available	0	0	0	0	1	0	0	0	0	1
		bicycle - ease of parking	0	0	0	0	0	1	0	0	0	1
Total			**41**	**51**	**46**	**138**	**47**	**28**	**165**	**59**	**64**	**363**
% Street qual			27%	59%	61%	**50%**	9%	21%	92%	95%	100%	**77%**
Does street quality appear more often? Chi2 p			<.01	>.05	>.05	>.05	<.01	<.01	<.01	<.01	<.01	>.05

5E: Results – levels of difficulty and unpleasantness scores against individual and trip-related attribute variables

Table 1: Variables associated with difficulty and/or unpleasantness of the barriers reported. The splits displayed are those for which dichotomised difficulty and / or dichotomised unpleasantness (>=6/10 or not, for both measures) were significantly different for different values of the variable (Chi2 measure, p<0.05)

		Difficulty		Unpleasantness	
Variable		m	sd	m	sd
Impairment noted	No	5.9	2.4	6.6	1.9
	Yes	6.8	2.1	7.1	2.3
Purpose	Work, shopping, social, appointments, errands	6.5	2.1	6.9	2.0
	Sport and exercise	3.3	3.3	6.5	3.5
Barrier having a street design attribute	No	5.7	3.0	6.8	2.8
	Yes	6.6	1.8	6.8	1.7
Having an alternative to walking the trip	No	6.5	2.3	[not significant at p<.05]	
	Yes	6.3	2.3		
Traffic along route noted as barrier	No	6.0	2.3	[not significant at p<.05]	
	Yes	7.7	1.4		


Perceived difficulty of barriers vs perceived unpleasantness
Interview data v1 02May20
Perceived unpleasantness
10.0
7.5
5.0
2.5
0.0
0
1
NA
Perceived difficulty, dichotomised; 0: <=6/10, 1: >6/10


Perceived difficulty of barriers vs purpose of the trip
Interview data, only purposes with >10 trips v1 02May20
Perceived difficulty
10.0
7.5
5.0
2.5
0.0
Shopping
Social visit/entertainment
Sport and exercise
Volunteer work
Work
Purpose

5F: Results – frequencies of barriers noted

All barriers, disabled / not disabled

Count of t_code	Non-disabled	Disabled	Total
Crossing facilities- non-signalised: layout, geometry	27	16	**43**
Footpaths- design (width, directness, obstructions; permanent or temp)	9	13	**22**
Footpaths- materials, execution, maintenance	4	11	**15**
Traffic: volume and speed	5	7	**12**
Holistic design quality	9		**9**
Traffic across the footpaths	5	3	**8**
Crossing facilities- signalised, waiting time	6		**6**
Lighting (presence, quality)	6		**6**
Traffic: noise, fumes		4	**4**
Crossing facilities- signalised, layout, time available		2	**2**
Activation: presence of other people, “eyes on the street”	1		**1**
Availability of toilets/water		1	**1**
Crossing facilities- signalised, red light running		1	**1**
Shelter (presence, quality)		1	**1**
Use of the space by other people, (in)civilities		1	**1**
Work sites, water dripping from them	1		**1**
Signalised crossings, other issue	1		**1**
Total	**74**	**60**	**134**

Difficult AND unpleasant, disabled / not disabled

Count of t_code	Non-disabled	Disabled	Total
Crossing facilities- non-signalised: layout, geometry	8	6	**14**
Footpaths- materials, execution, maintenance	2	6	**8**
Footpaths- design (width, directness, obstructions; permanent or temp)		5	**5**
Crossing facilities- signalised, waiting time	3		**3**
Traffic across the footpaths	1	2	**3**
Holistic design quality	2		**2**
traffic: volume and speed		1	**1**
Use of the space by other people, (in)civilities		1	**1**
Total	**16**	**21**	**37**

CHAPTER 6

6A: Rationale for the metrics used

Critical feature	Topics (interviews)	Selected measures	Rationale related to selected measures	Secondary data used	Data collection
Crossing facilities, non-signalised: layout, geometry	Having to pay attention to different traffic movements, fast traffic speed forcing to decide quickly, traffic speed and density making it hard to find a gap, feeling overall exposed; also, for blind participants: overall noise making it extremely risky to attempt crossing	1. Number of traffic movements in conflict with the pedestrian crossing	The number of different traffic movements the pedestrian is exposed to is a proxy of the complexity of crossing, indicated as an element of difficulty.	n/a	Observation in situ
		2. Traffic volume across the pedestrian crossing	Traffic volume (number of cars) was indicated as an element of difficulty and is an important parameter for the design of the [47] pedestrian facility.	Peak hour traffic volume [48]	When traffic count data is not available, or older than 10 years: count in situ (workday outside of school holidays, 4.30-5.30 pm - peak identified from the TomTom 2019 data [49]). See appendix 6E page 86.**Error! Reference source not found.**
		3. Percentage of heavy vehicles in the traffic across the pedestrian crossing	Heavy vehicles are both a source of additional noise and are potentially intimidating when crossing.	Percentage of heavy vehicles in the average daily traffic [48]	n/a
		4. Traffic speed and turning radii	The speed of the traffic across the pedestrian crossing can contribute to the difficulty and sense of vulnerability. Direct left hook radii were examined as proxies for cornering traffic speeds (Turner et al, NZTA) and safety-related issues (left turning traffic comes almost from behind the pedestrian crossing in the same direction – illustration)	Speed limits [50], a series of measures for the cornering speeds and an estimate of the v85 speed going straight (see below, data collection)	For intersections: measure of the turning radii based on aerial photo (Auckland Council's geoportal [51] 1:250). Traffic speed was measured for a selection of intersections having different left hook radii. The methodology is detailed in **Error! Reference source not found.**.
		5. Type of crossing	The type of crossing is important for the prioritisation of retrofit (*what* to target) and is typically prescribed by the guidelines [47].	n/a	Observation in situ
		6. Distance to cross	The distance to cross is directly related to the time someone is exposed to the traffic.	Auckland Council's geoportal	Desktop data collection, Auckland Council's geoportal [51], and measuring tool (1:250)
		7. Number of lanes to cross	Allows to calculate the traffic density per lane	n/a	Observation in situ
		8. Presence of constraints to traffic movements and speeds	To inform the Healthy Street metrics and identify possible patterns (e.g. generalised absence of constraints)	n/a	Observation in situ
Footpaths design & obstructions (width, directness, obstructions)	Difficulty of having to dodge people and obstructions (e.g. scooters abandoned on the footpaths or containers) - irritating for non-disabled people, and problematic for blind / low vision people.	1. Footpath width: width of the walking route at its narrowest point, considering the obstructions present	The difficulties relate to the usable width, alone or in combination with the pedestrian flows using the footpath and/or the obstructions present	n/a	Measures in situ (walk along, noting the typical widths and the localised narrowing due to street furniture for instance). The obstructions can be different on different days. The observed obstructions are described.
		2. Length of the segment <2m and <1.5m		Auckland Council's geoportal	Desktop data collection, Auckland Council's geoportal [51], and measuring tool (1:250). The lengths are measured separately for both sides, and the critical side is taken into account (relating to the frequent difficulties to cross / possible inability to use the opposite side)
		4. Pedestrian traffic through the narrowest section, peak h	Pedestrian traffic allows to put in context the footpaths width. Most guidelines recommend widths in relation to the business of the street.	Automatic pedestrian counts for locations in the city centre [52]	For the locations where pedestrian counts were not available, manual counts were done on workdays outside of school holidays, at the estimated peak time (4.30-6 pm). See **Error! R eference source not found.**.
		5. Observation: what causes obstructions? Nature of built in or temporary elements that cause a narrowing of the footpath		n/a	Observation and measures in situ (walk along, noting the localised narrowing and the causes).
Traffic volumes and speeds	Discomfort caused by traffic volumes, speeds, and resulting noise and fumes. Unpleasant to walk along and causing difficulties / impossibilities to cross.	1. Traffic volume (number of vehicles passing along the indicated footpath)	Associated with discomfort of walking and difficulties to cross	See above (traffic data collection, non-signalised intersections)	See above (traffic data collection, non-signalised intersections)
		2. Traffic speeds	Associated with discomfort of walking and difficulties to cross		
		3. Proportion of heavy vehicles	Heavy vehicles are both a source of additional noise and potentially intimidating if attempting to cross		
Lighting (presence, quality)	Feeling unsafe by dark due to insufficient lighting. This can relate to stranger danger or worries about falling (e.g. cracked walking surfaces)	1. Intensity of lighting (lux)	Characterise the experienced lack of light	n/a	Measures in situ - See **Error! Reference source not found.**
		2. Type of lighting (functional, atmosphere? Blue or warm?)	Characterise the type of lighting (human scale or not)	n/a	Observation in situ
Holistic design quality	"Grey", uninteresting environments, with "not much going on" and/or car-oriented and unpleasant in part because of the traffic present	Measures noted for traffic (above) and:	Those aspects have been identified as major characteristics of street amenity (e.g. Gehl and Healthy Streets framework)	See above	See above
		1. Street width		Auckland Council's geoportal	Desktop data collection, Auckland Council's geoportal [51], and measuring tool (1:250).
		2. Carriageway width		Auckland Council's geoportal	Desktop data collection, Auckland Council's geoportal [51], and measuring tool (1:250).
		3. Typical number of lanes		n/a	Observation in situ
		4. Facades transparency - Percentage of transparent facades along the indicated segment		n/a	Visit in situ and rough mapping of transparent facades. Desktop calculation of length using Auckland Council's geoportal. The side of the street with lesser transparency is taken into account.
		5. Typical street proportions		n/a	Estimated visual width (from façade to façade) and heights, based on observation in situ
		6. Tree canopies – distances between canopies		Auckland Council's geoportal	Desktop data collection, Auckland Council's geoportal [51], and measuring tool (1:250). See supplementary file A.
		7. Availability of safe crossings: average distance between signalised crossings			
Activation	Participants reported environments that felt uncomfortable because of a lack of human presence. In three of the four cases, they specified that it was after dark.	1. Pedestrian traffic, after dark for the cases where it was specified, and at the network peak hour otherwise	Both metrics inform the low human presence reported by the participants. The Healthy Streets framework considers them together when assessing the natural surveillance (level of oversight of the street).	n/a	Measures in situ: manual 1/2h counts
		2. Facades transparency - Percentage of transparent facades along the indicated segment		n/a	Visit in situ and rough mapping of transparent facades. Desktop calculation of length using Auckland Council's geoportal. Both sides of the street are examined separately and the critical one is taken into account (considering the width of the indicated roads and the fact that a transparent façade on the opposite side offers limited overview).

6B: Methods

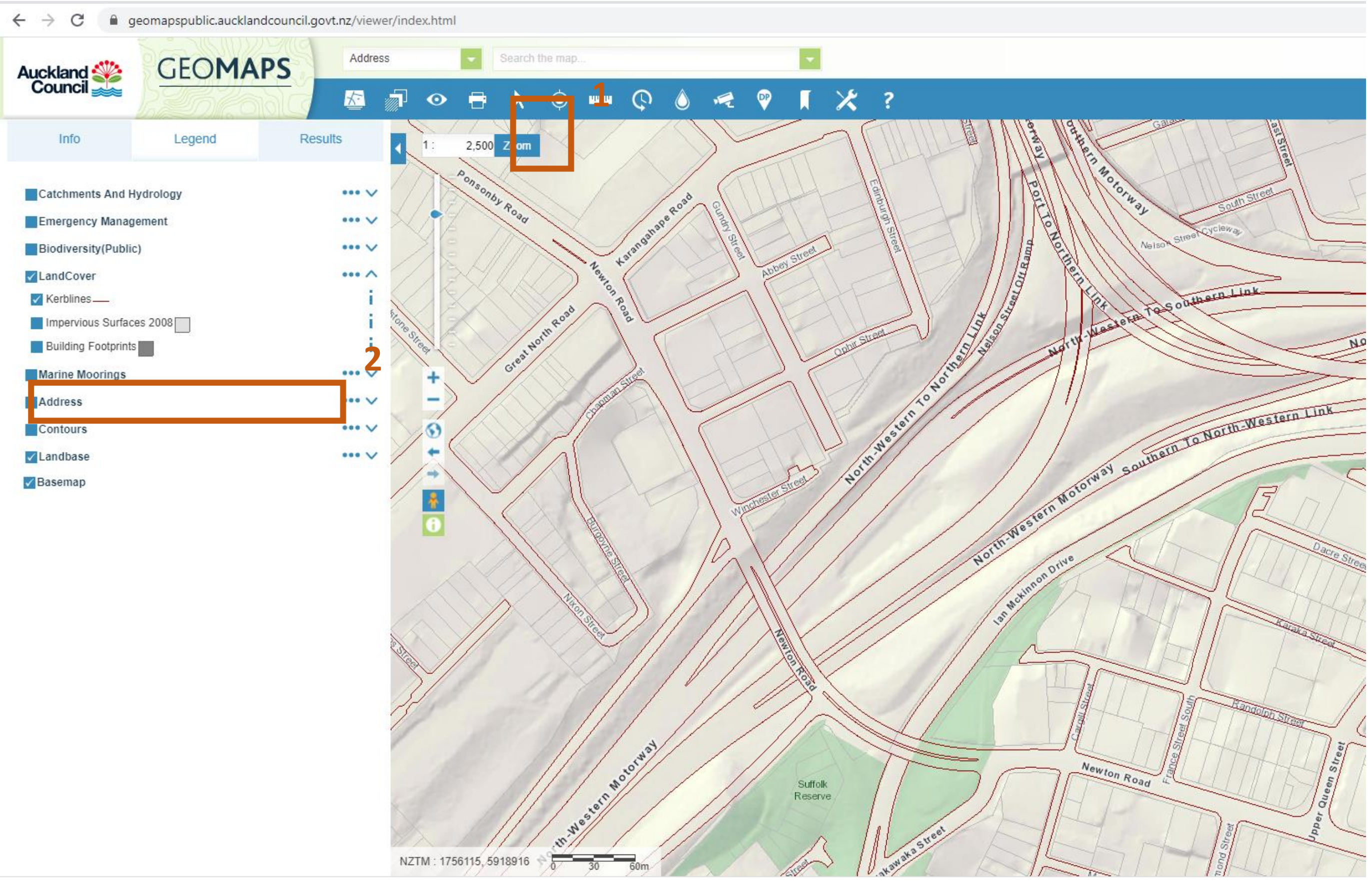
Non-signalised intersections

Radii estimate

Kerblines were accessed through Auckland Council's geographic information portal: https://geomapspublic.aucklandcouncil.govt.nz/viewer/index.html

They can be displayed by:

1. Choosing "Environment", within the six possible themes
2. Selecting "Kerblines", within the LandCover menu

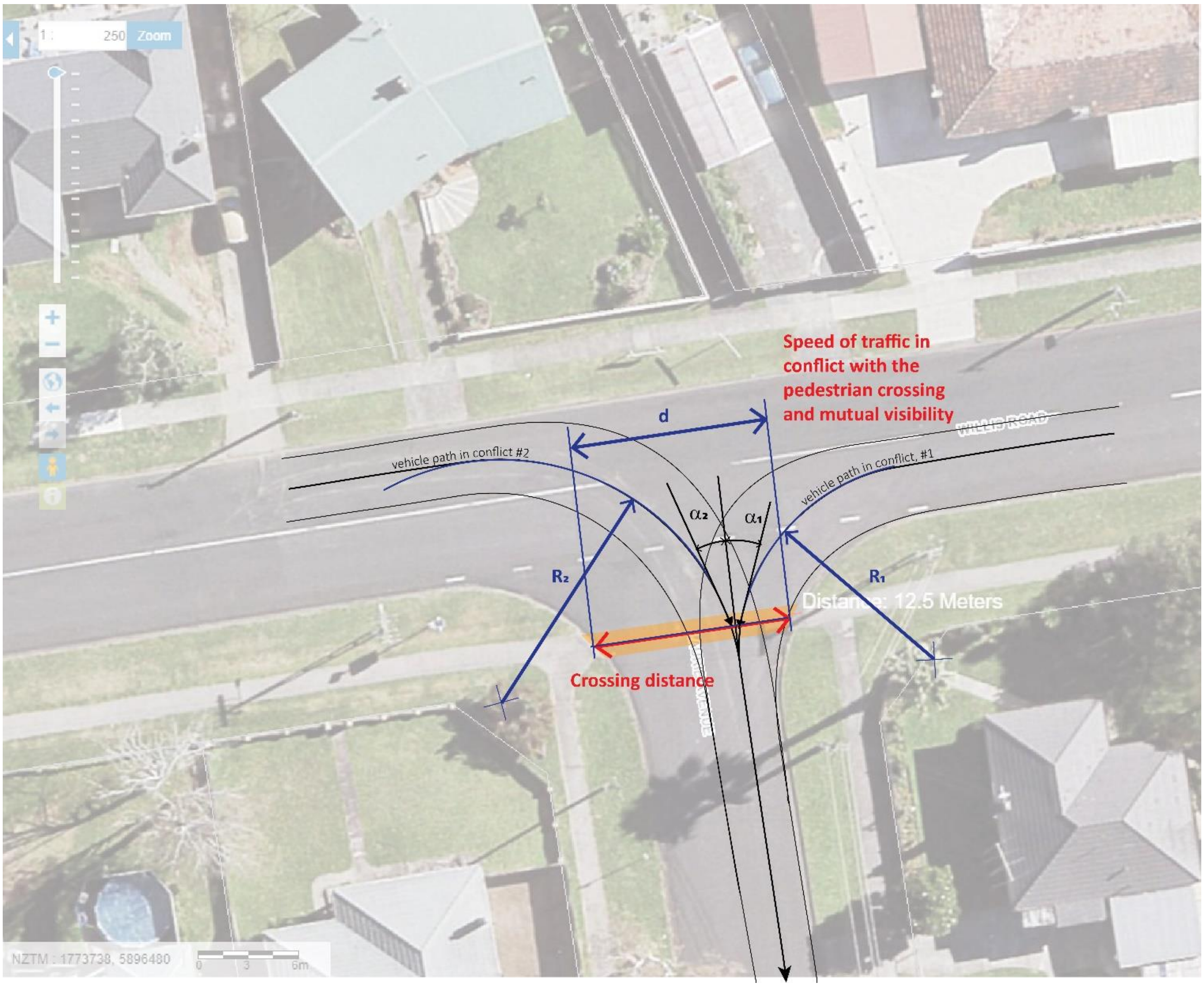


For each examined intersection, radii were estimated based on 1:250 kerblines map and aerial photo, as follows:

1. **Tracing the vehicle path** for the movement turning left onto the pedestrian crossing. The path consists in three lines:
   - Inner limit, following the left-hand side kerbs; this represents the limits of the left side of the area swept by the vehicle's chassis.
   - Outer limit, following the road centre lines; this represents the limits of the right side of the area swept by the vehicle's chassis.
   - Path axis (centre line), being situated in the middle of the inner and the outer limits. The path axis is further used to estimate the radius [53]. To be noted that in some cases, the carriageway space available allows the driver to choose different cornering approaches, more or less tight. In those cases, the path axis examined was a practical fast curve, approximated as being 1.5m away from the inner limit (=~ half of the vehicle's chassis (1m) and a movement buffer (0.5m).

2. **Tracing the axes of the two roads or streets intersecting.** As for the path axis, in the case of carriageways wider than 3.5m, the axis is traced 1.5m from the left-hand side limit.
3. **Tracing two tangents to the path axis**, located at
   - the point where the path starts deviating from the axis of the street or road on which the vehicle was initially driving (A)
   - the point where the path merges with the axis of the street or road towards which the vehicle moves (B)
4. **Identifying the centre of the turning radius**, at the intersection of the two tangents
5. **Tracing a circle with R=turning radius**, to verify the fit with the vehicle path, and measuring the radius

Adobe Illustrator was used for this process although different vectorial drawing tools could be similarly helpful.



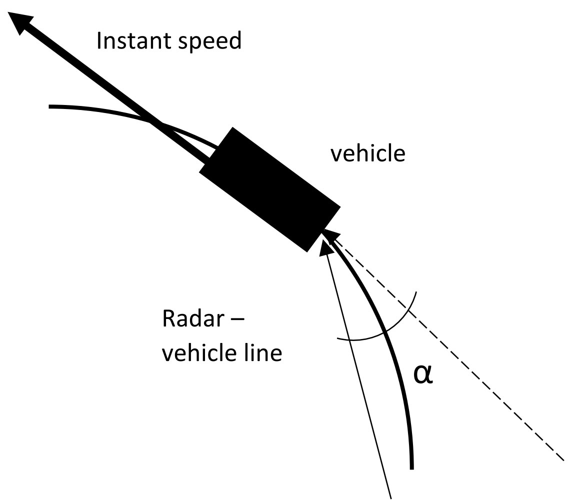
Speed measure

Cornering traffic speeds were measured in six locations having different geometries (kerb radii) using the Stalker ATS II speed gun [54] and measuring the speeds of 100 vehicles at each location. Only free vehicles were considered (i.e. not driving immediately behind other vehicles), excluding those that stopped before the curve (e.g. at the red light or to let pedestrians cross). Descriptions of the locations chosen and the rationale for these locations being chosen as case studies are presented below.

Table 2: Case study locations for the measures of cornering speeds

Left hook radius [m]	Location	Comments
8	Central Street - New North Road, Kingsland	Smallest of the problematic radii
12	Newton road onramp	This specific hook was noted by three participants and the radius corresponds also to seven other cases (Dominion road side streets). The chosen location has a casual pedestrian crossing and no "side friction" – it is located on an overbridge, without parking, buildings, trees or much footpath activity.
18	Slip lane Dominion-Balmoral	In theory, allows 30 km/h. The considered location has a zebra crossing.
22	Carlton Gore – George St	One of the largest indicated radii and associated with a cornering traffic movement perceived as particularly dangerous and complicate to negotiate
30	Piwakawa St – Ian McInnon Drive	Location chosen because of a particularly large radius coupled with a quasi-absence of side friction, making it conceptually comparable to the Newton Road onramp. The intersection is signalised.

The aim was to capture speed measures so that line connecting the speed gun and the vehicle would be aligned with the vehicles' direction. This ideal case scenario was not always possible, namely in presence of wide, multi-lane roads, where the line of sight was obstructed by important traffic flows.
The best location often presented a deviation (α on the image below) with the ideal line of sight (dashed line). The measures taken were therefore corrected: $V_{corrected} = V_{measured} / \cos(\alpha)$.



Speed was measured with a hand-held radar gun[6] at the level of the pedestrian crossing, tangentially to the travel path (vehicle traveling outbound, unless otherwise specified). Speed was analysed only for free vehicles (not impeded by a preceding vehicle, not having had to stop before taking the corner and without a presence of pedestrians that could have influenced the choice of speed). During the data collection, speed reading was noted, marking also the possible presence of pedestrians on the crossing or waiting to cross, with special marks for larger vehicles (van, truck, or car with trailer). In the analysis process, the measures where pedestrians were present were not considered. All vehicle types were however analysed together.
The speed could be influenced by (1) The presence of pedestrians wanting to cross; (2) The presence of pedestrians on the crossing; (3) The vehicle type (e.g. van or truck). Those aspects were captured as meta-data, labelling each measure as appropriate. Cars that stopped for pedestrians were not included (speed with "presence of pedestrians" = car slowed down/ dodged pedestrians but didn't stop).
Precautions were taken not to influence the vehicle speed (the surveyor was by default standing with her back to the traffic and pointing the radar towards the vehicle only when they had passed her.

Estimate of the V85 speed

All the crossings reported as problematic and all except one sections where traffic along the footpath was reported as being a barrier are on arterial roads with similar typologies: 50 km/h speed limit, two to four lanes, limited gradient, some side friction (non-signalised intersections, kerb parking, access to shops or destinations. V85 was estimated on one arterial in question (New North road through Kingsland neighbourhood centre). The examined location is typologically comparable to the other cases and provides a relatively conservative estimate of the speed as it is on the higher end of the range, regarding side friction (higher footpath activity and kerb parking).

[6] Applied Concepts, Inc. 2018. "ATS II The STALKER Acceleration Testing System."

Footpaths

Footpaths widths

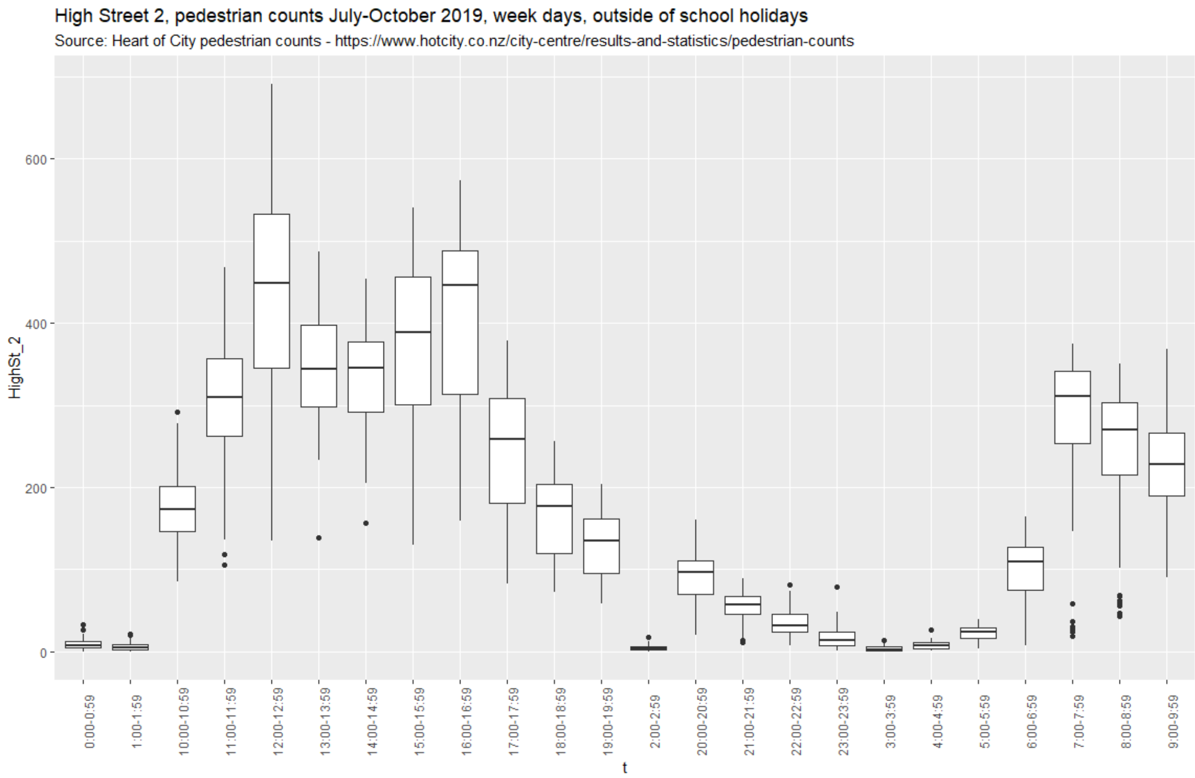
Footpaths widths are frequently inconsistent, built with varying standards along a same street and narrowed by built-in or temporary obstacles, or even by people standing. The narrowest section was identified and informed, for each street, as per Healthy Streets Guidelines [55]. This measure can however be misleading as it could relate to very diverse situations. It could be assumed that (1) a wide footpath having one localised narrowing of the width x; (2) a footpath having a continuous width x on its entire length; or (3) a footpath having a through route of the width x available but slaloming between obstacles on the left and the right side, could yield three different experiences. In addition, the presence of people and the traffic could influence the perceptions. Some interviewees spoke of the footpaths width and proximity to traffic as two notions that are associated, with the idea that the edge of a footpath close to a dense and/or fast-moving traffic is de facto not usable. The width of that non-usable area is not clearly defined. Additional metrics were added to help differentiate the contexts (percentage of the section length narrower than 1.5 and 2m) but have their own limitations (arbitrary limits). The variety of obstacles and their disposition (more or less obvious, allowing or not a straight path) are difficult to measure. While the guidelines and best practice speak of a direct through route, clear of any obstruction, on the ground this through route often cannot be visualised, especially when permanent or temporary obstructions are present on one or the other side, in alternation, and sometimes both simultaneously (see Figure 7). Temporary obstructions that participants noted on their usual routes are by definition variable and induce variable remaining through route widths (or in some cases, the disappearance of the through route). One or even several visits in situ cannot claim to have measured and identified the obstructions as experienced and remembered by the participants.

Pedestrian counts

Ad hoc counts were coordinated by the first author and realised by six research assistants (post graduate students from the same School). The counts aimed at gathering (1) pedestrian volumes, for those streets where footpath crowding or difficulties of dodging other people were noted; and (2) traffic volumes, for crossings where automatic count data was not available. For both counts, it was decided to realise manual counts during the peak hour. The decision was mainly driven by the desire to capture diversity of the pedestrians (e.g. walking, mobility device, children in prams, people on scooters) and the need to observe specific constraints (for instance, people waiting for the bus and therefore obstructing the footpath). An adapted version of Gehl Studios record sheets [56] was used. It was financially and logistically not possible to count pedestrian volumes for several days, from morning to evening. Peak hours were therefore targeted, estimated namely from available automatic counters. The realised measures are presented below. All measures were taken outside of school holidays and also outside of New Zealand's COVID-19 lockdown.

Issue reported by participants	Surveyed period	Time of the day	Survey days
Busy / crowded footpaths	90 minutes at each site – allowing to adjust locally the peak hour definition and consider the maximum 60-minutes traffic	from 4.00 pm till 5.30 pm	Tuesdays, Wednesdays and Thursdays outside of school holidays and NZ lockdown
Busy / crowded footpaths near schools, only at school start/finish	As before, and in addition: 30 minutes leading to the school start or immediately after the end of the school day.	8.00-8.30 (Kelvin School, Papakura, classes starting at 8.30 am) 15.00-15.30 Dominion Rd School (classes finishing at 3pm)	Week days outside of school holidays and NZ lockdown
Absence of other people	20 minutes	Sunset/dark, if mentioned by the participants (7-8pm); 4-5pm if not (previously identified peak hour)	Week days outside of school holidays and NZ lockdown

The second lockdown for Auckland city, that happened on 12th August 2020 happened halfway through the campaign of counts, that was resumed on 20 October 2020. However, the measure should be seen as an estimate, given the uncertainty of the peak hour but also the large variability of pedestrian flows on different days. The dispersion of pedestrian counts based on automatic counts made in High Street (Auckland Central) before the street was transformed is presented below.



Tree canopies

Distances between canopies are examined separately for both sides of the street and the critical gap is taken into account (considering the difficulty to cross the indicated roads due to generally large carriageway widths, heavy traffic, and scarcity of signalised intersections, meaning that it is not always feasible to change sides to benefit from the tree shade).

6C: Findings, non-signalised crossings

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - NZTA Pedestrian Design Guide [47]	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings vs Auckland's context
1. Number of traffic movements in conflict with the pedestrian crossing	No specific recommendation. Metric #12 specifies that people should not feel intimidated by vehicles.	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).	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.	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	**Metric #1 total two-way traffic, peak hour** Ideal (score 3): <500 vehicles/h (v/h) Score 2: 500-1,000 v/h Score 1: > 1,000 v/h, bike lane Score 0: > 1,000 v/h, no bike lane **Metric #10 Midblock crossings, suitability** Ideal (score 3): <200 v/h uncontrolled Score 2: 200-1,000 v/h uncontrolled Score 1: > 1,000 v/h uncontrolled	**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 doesn't 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 [60]	Traffic levels measures showed a high dispersion, from 50 to 1,720 vehicles per hour (median: 800, IQR 1,470). 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 [55]**.** 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 E).
3. percentage of heavy vehicles (HCV) in the traffic across the pedestrian crossing	**No metric regarding interaction of HCV with pedestrians** (metric #2 addresses interaction with bike riders; ideal: <2% HCV) Metric #5, noise from large vehicles Ideal (score 3): <5% HV, peak Score 2: 5-10 % HV, peak Score 1: > 10 % HV, peak	**No assessment thresholds**. The guideline examines notes HCV only from the perspective of their requirements regarding road layout geometry, encouraging even to consider slip lanes at intersections with high volumes of HCV (p. 6-24).	**No assessment thresholds**. The manual acknowledges the impacts of heavy traffic on noise and air pollution and 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).	Heavy vehicle traffic was available as a percentage of total traffic, and not peak hour traffic, for 20 of the 30 instances. Considering the total traffic and the thresholds from the Healthy Streets approach [55], two instances had <2% heavy traffic, twelve had less than 5% and eight >= 5%.	The measures were not exceptional for Auckland: heavy vehicles proportions are available in over 3800 recent measures across the city, 73% are under 5% and 27% above.
4. traffic speed and turning radii	**Metric #3, speed of motorised traffic** Ideal (score 3): v85 <32 km/h Score 2: v85 32-40 km/h Score 1: v85 40-48 km/h Score 0: v85 >48 km/h	**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 [60] but the manual and the engineering design code relative to pedestrian infrastructure don't provide an overview of radii to consider and their relationship to speed.	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: 54km/h; IQR 6 km/h)). V85 for the cornering speeds were estimated between 23 km/h (8m radius) and 42 km/h (30m radius). Detail: see supplementary file D.	All the cases were in areas limited to 50 km/h, which is the typical speed limit in Auckland's urban areas [50]. 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 3.5m, as this corresponds to typical road design standards for a 50 km/h environment (highways manual).
5. type of crossing / provision of crossing aids	**Metric #8: Ease of crossing side roads for people walking** Ideal (score 3): side roads closed to vehicles Score 2: features encouraging cautious driving Score 1: dropped kerbs only Score 0: no dropped kerbs **Metric #10 Midblock crossings, suitability** Ideal (score 3): uncontrolled, <200 v/h or zebra (or signalised, with pedestrian priority) Score 2: uncontrolled, 200-1,000 v/h Score 1: uncontrolled, >1,000 v/h (or signalised, d>15m, speed limit >50 km/h)	**No strict rules.** Aids enter the calculation of levels of service (i.e. 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)	**No strict rules.** Choice of crossing is presented as dependent on traffic 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 doesn't provide assessment thresholds.	Eighteen crossings were casual without any physical aid; two were 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.	An overview of the numbers of crossings by types has not been identified. However, it is known that Auckland has just under 200 signalised intersections [61]. 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	**Not clear – distances are indicated for signalised crossings (**Metric #10 Midblock crossings, suitability; Ideal (score 3): zebra (or signalised, with pedestrian priority); Score 2: signalised, <15 m to cross; Score 1: signalised, d>15 m, speed limit >50 km/h)	**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 (6.4m; Footpaths and Public Realm p. 31)	Distances to cross are generally important: All intersections also involve crossing a distance >10m (and even >20 m in three cases), except for one case (slip lane, width = 5.4 m). The minimum crossing distance would be 6m, but is wider in practice (traffic lanes wider than 3 m and carriageways widened by 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 3m and above, and roadside parking.
7. number of lanes to cross	**No specific recommendation**	**No strict rules.** The idea is that less lanes is safer. The guideline recommends examining if road space can be reallocated (Table 6.1).	**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 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)	The crossings (four exceptions) 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 streets side by side (two plus three lanes).	The vast majority of the crossings involved up to two lanes, typical of any residential street. The values are therefore not exceptional.
8. constraints to traffic movements and speeds	**Metric #7: Reducing the use of private vehicles** Ideal (score 3): access only, no through movement Score 2: some restrictions Score 1:no restrictions See also point 5 above	**No strict rules.** When considering improvements, the guideline recommends questioning traffic volumes and speeds and adapting them if possible (Table 6.1)	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.	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.

6D: Findings, non-signalised crossings, detail: traffic volume, turning radii, speeds

Traffic volumes, across the reported instances

	Average daily traffic [vhc/d]				Peak hour traffic [vhc/h]			
n	median	IQR	minimum	maximum	median	IQR	minimum	maximum
30	9,525	16,738	970	23,500	780	1,459	110	1,720

Average daily traffic [vehicles/d]	N cases	% cases
<1,000	1	3%
[1,000-2,000[	7	23%
2,000-5,000[	1	3%
5,000-10,000[	5	17%
[10,000-20,000[	7	23%
>=20,000	5	17%
NA	4	13%
Total	**30**	**100%**

Average peak h traffic [vehicles/h]	N cases	% cases
<500	10	33%
[500-1,000[	7	23%
[1,000-2,000[	13	43%
Total	**30**	**100%**

Traffic volumes and type of crossing

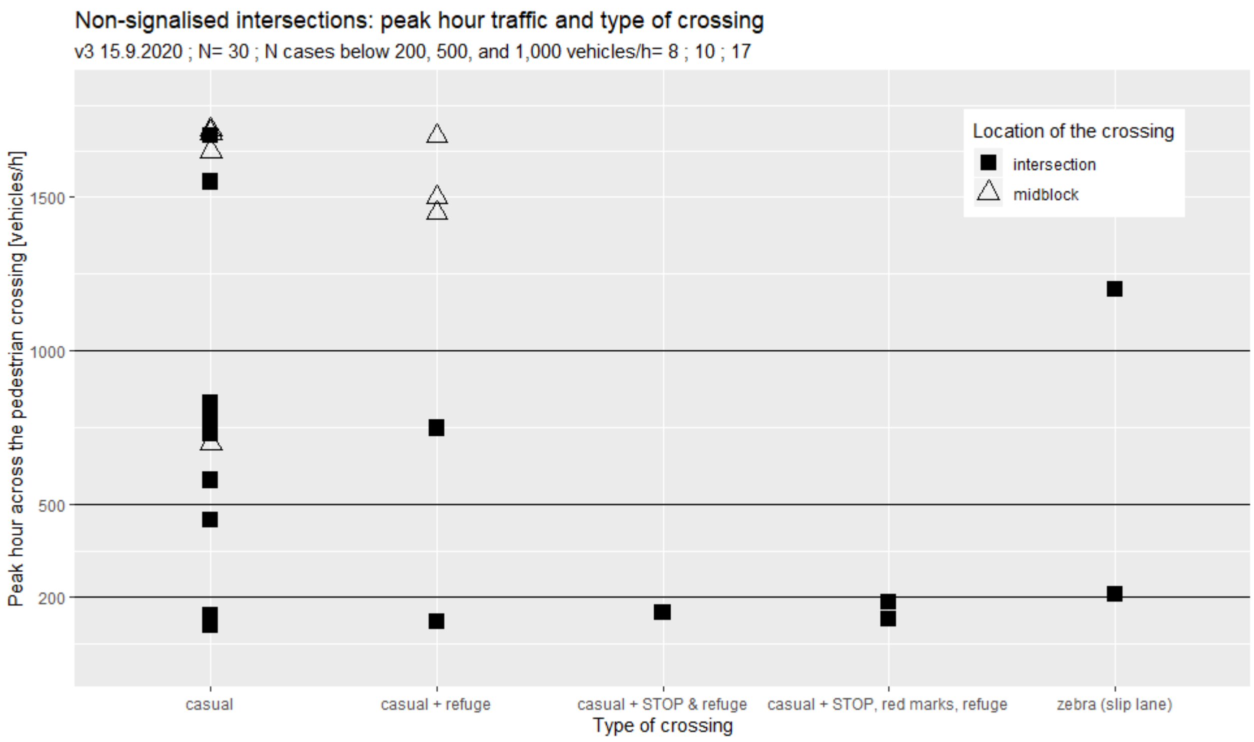


Figure 3: Type of crossing and peak hour traffic

Number of movements in conflict

Figure 4: Non-signalised crossings by peak hour traffic, crossing type and number of traffic movements in conflict with the indicated crossing

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. It was not possible to inform the association between turning radii and cornering speeds through local measures or results from published empirical studies. Therefore, measures were taken on the ground for a sample of locations presenting a range of radii corresponding to those indicated by the participants. A total of 966 measures were examined.

The measures of speed relative to each radius band are presented in Table 3 and supplementary file D. 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 ($p<.001$). The measures indicated that the speed selection could be higher than the theoretical design speed, as calculated according to the AUSTROADS technical design guidelines [53]. 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 and others lights, one had a raised platform, and the side friction varied), the speeds for each radius had approximately normal distributions centred around increasing median values.

Table 3: 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**

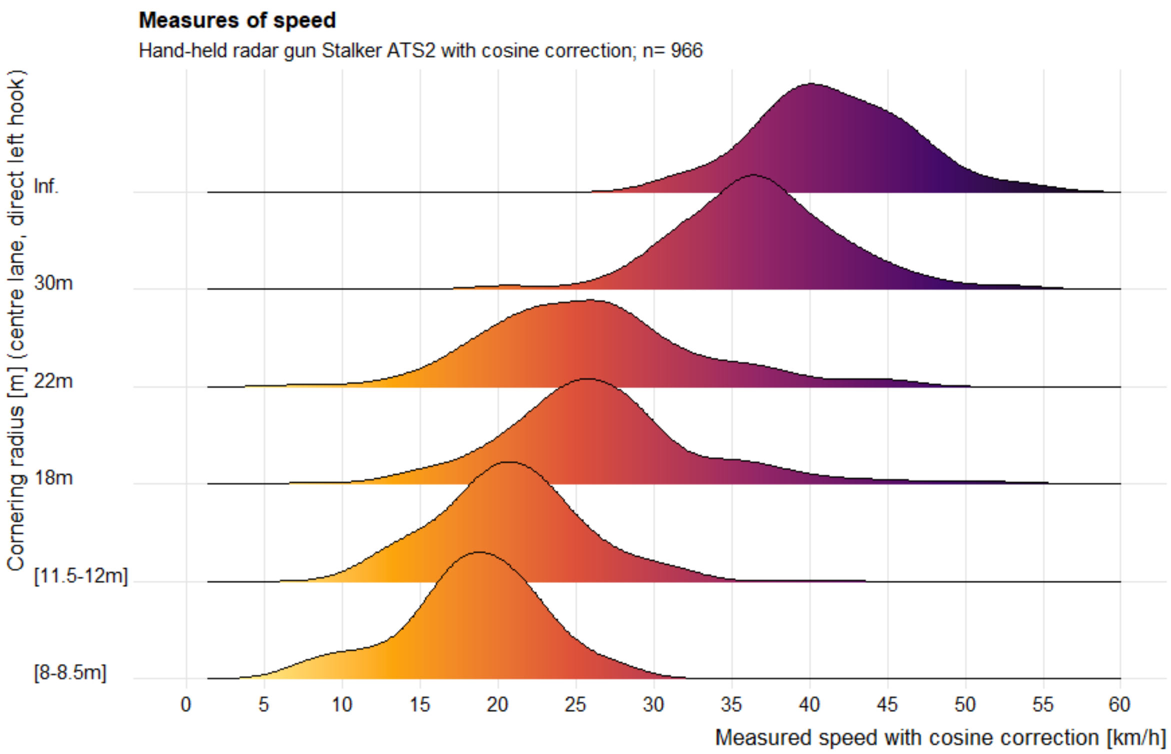
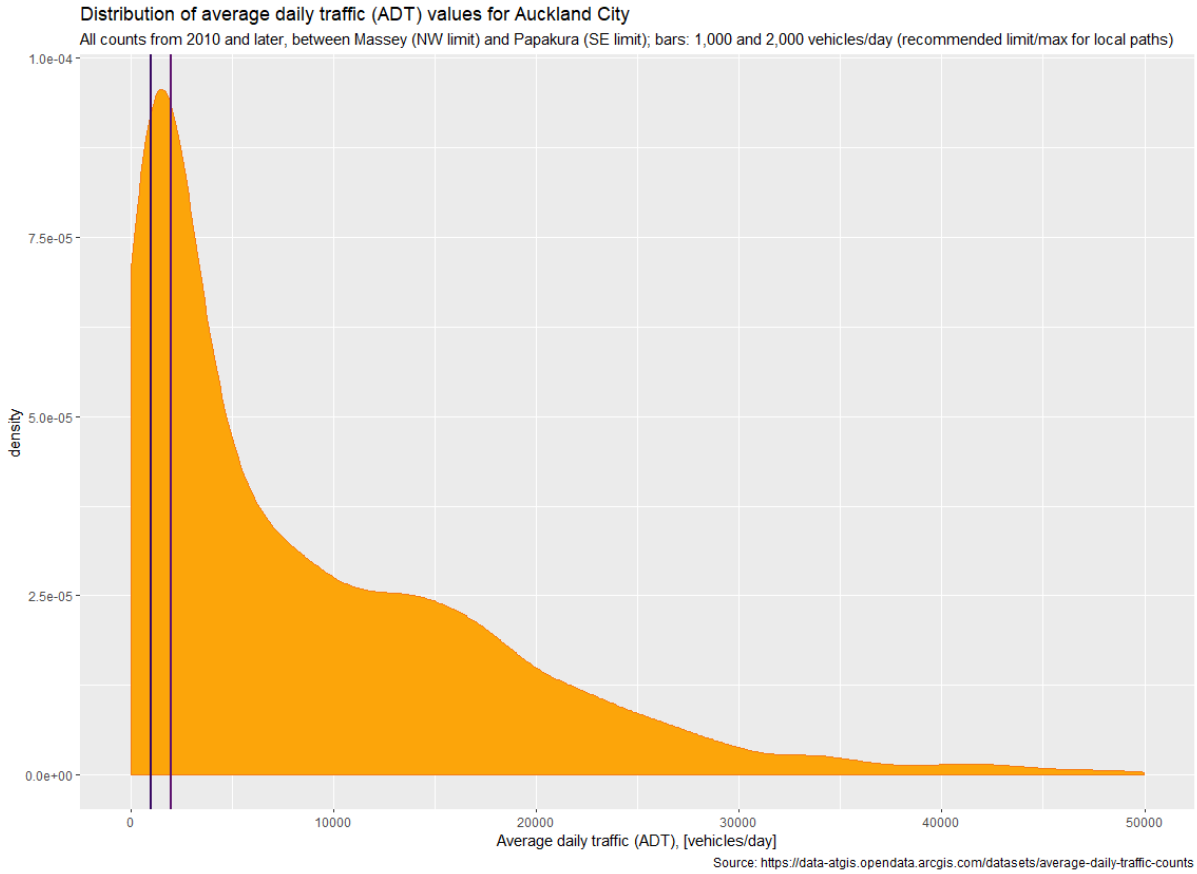


Figure 5: Distributions of speeds for different cornering radii (direct left hook)

6E: Analysis of Auckland's traffic volumes

Overview



ADT traffic [vehicles/d]	n	%
<1,000	637	16%
[1,000-2,000[	534	14%
[2,000-5,000[	691	18%
[5,000-10,000[	615	16%
[10,000-20,000[	858	22%
>=20,000	525	13%

Peak traffic [vehicles/h]	n	%
<200	675	22%
[200-500[	636	20%
[500-1000[	603	19%
[1,000-2,000[	920	30%
>2,000	269	9%

R code

```
##############################################################
###
### Auckland traffic overview
###
##############################################################

# Setup -----------------------------------------------------------------

setwd("C:/Users/user/OneDrive - AUT University/a2-
STUDY_2_qual/4_BE_survey/2_external_data")

library(dplyr)
library(ggplot2)
library(wesanderson)
library(viridis)
library(stringr)
library(ggridges)
library(gridExtra)
library(scales)

.version  <- "v3"
.date     <- "15.9.2020"

# Import data -----------------------------------------------------------

AT_Traffic_counts_download_20.08.20 <- read.csv("C:/Users/user/OneDrive - AUT
University/a2-
STUDY_2_qual/4_BE_survey/2_external_data/AT_Traffic_counts_download_20.08.20.csv")
a <- AT_Traffic_counts_download_20.08.20
# 10,880 obs

colnames(a)[1]<-"X"


# Select Auckland city -----------------------------------------------------

# Isthmus: approx: Massey / Westgate (N-W) to Papakura / Red Hill (S-E)
NW_limit_lat_lon   <- c(-36.831195, 174.605873)   # Coordinates from Google Maps
NW_limit_converted <- c(1743204.724, 5922649.384) # Converted to NZTM using
https://www.geodesy.linz.govt.nz/concord/index.cgi

SE_limit_lat_lon   <- c(-37.071222, 174.970368)   # Coordinates from Google Maps
SE_limit_converted <- c(1775161.361, 5895409.881) # Converted to NZTM using
https://www.geodesy.linz.govt.nz/concord/index.cgi

NZTMX_interval     <- c(NW_limit_converted[1], SE_limit_converted[1])
NZTMY_interval     <- c(SE_limit_converted[2], NW_limit_converted[2])

# Select observations within the rectangle NW-SE limits
a_city <- a %>%
  filter(NZTMX >NW_limit_converted[1]) %>%
  filter(NZTMX <SE_limit_converted[1]) %>%
  filter(NZTMY <NW_limit_converted[2]) %>%
  filter(NZTMY >SE_limit_converted[2])

# Filter ----------------------------------------------------------------

# Specify year, filter older than 10 years, and define motorway status
a_city_mw <- a_city %>%
  mutate(count_yyyy = str_sub(count_date, 1, 4)) %>%  # Extract the first 4 characters
of count_date, === year
  filter(as.numeric(count_yyyy)>2009) %>%
  mutate(motorway = case_when(str_detect(road_name, "MOTORWAY") |
str_detect(road_name, "HIGHWAY") ~ 1 ) )
# 3918 obs
```

```
# Categories, for adt, HCV and peak -------------------------------------------

a_city_mw$adt_category         <- cut(a_city_mw$adt,
                                      breaks=c(0,1000, 2000, 5000, 10000, 20000, Inf),
                                      include.lowest=T, right=F,
                                      labels=c("<1,000","[1,000-2,000[", "[2,000-
5,000[", "[5,000-10,000[","[10,000-20,000[", ">=20,000"))


a_city_mw$peaktraffic_category <- cut(a_city_mw$peaktraffic,
                                      breaks=c(0,200, 500,1000, 2000, Inf),
                                      include.lowest=T, right=F,
                                      labels=c("<200","[200-500[","[500-1000[",
"[1,000-2,000[", ">2,000"))

a_city_mw$pcheavy_category     <- cut(a_city_mw$pcheavy,
                                      breaks=c(0,2,5,10, Inf),
                                      include.lowest=T, right=F,
                                      labels=c("<2%","[2-5%[","[5-10%[", ">=10%"))

# Subset: city, without motorways ----------------------------------------

a_city <- a_city_mw %>%  filter(is.na(motorway))
# 3896 obs more recent than 2009, 3896 excluding the motorways and highways


# Distribution ADT ------------------------------------------------------------

col_inf_10   <- inferno(10, alpha = 1, begin = 0, end = .8, direction = 1)

a_city %>% ggplot(aes(adt))+geom_bar(stat="identity")


a_city %>% filter (adt<50000) %>%
  ggplot(aes(adt))+geom_density(color=col_inf_10[9], fill=col_inf_10[10])+
  labs(title    = "Distribution of average daily traffic (ADT) values for Auckland
City",
       subtitle = "All counts from 2010 and later, between Massey (NW limit) and
Papakura (SE limit); bars: 1,000 and 2,000 vehicles/day (recommended limit/max for
local paths)",
       x        = "Average daily traffic (ADT), [vehicles/day]",
       caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-
daily-traffic-counts")+
  geom_vline(xintercept=1000, color=col_inf_10[3], size=1)+
  geom_vline(xintercept=2000, color=col_inf_10[4], size=1)


summary_adt <- a_city %>% filter(!is.na(adt)) %>%
  group_by(adt_category) %>% summarise(
    n= n(),
    percentage = n/nrow(a_city))
# 16% measures <1,000 vehicles per day, 14% 1,000-2,000


write.csv(summary_adt, file=paste("Summary_ADT_Auckland_2010_2020",.version,
.date,".csv", sep="_"))


# Distribution peak-----------------------------------------------------------

a_city %>% filter (!is.na(peaktraffic)) %>%
  ggplot(aes(peaktraffic))+geom_density(color=col_inf_10[9], fill=col_inf_10[10])+
  labs(title    = "Distribution of peak traffic values for Auckland City (peak h
definition varies)",
       subtitle = "All counts from 2010 and later, between Massey (NW limit) and
Papakura (SE limit); lines: 500 & 1,000 vehicles/h (thresholds, Healthy Streets)",
       x        = "Peak traffic, average of typically 7 days of count [vehicles/h]",
       caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-
daily-traffic-counts")+
  geom_vline(xintercept=500, color=col_inf_10[3], size=1)+
  geom_vline(xintercept=1000, color=col_inf_10[4], size=1)


a_peak_counts <- a_city %>% filter(!is.na(peaktraffic))

summary_peak <- a_peak_counts %>%
```

```
  group_by(peaktraffic_category) %>% summarise(
    n= n(),
    percentage = n/nrow(a_peak_counts))
# 42% measures <500 vehicles per day, 20% 500-1,000


write.csv(summary_peak, file=paste("Summary_peak_Auckland_2010_2020",.version,
.date,".csv", sep="_"))


# Overview HCV ------------------------------------------------------------

summary_HCV <- a_city %>% filter (!is.na(pcheavy_category)) %>%
  group_by(pcheavy_category) %>% summarise(
    n= n(),
    percentage = n/nrow(a_peak_counts))
# 14% <2%HCV, 73% <5%; 27% >=5%

write.csv(summary_HCV, file=paste("Summary_HCV_Auckland_2010_2020",.version,
.date,".csv", sep="_"))


# Test for levels identified through BE measures --------------------------

# Import key values for the different critrical features
Crossings_overview_parameters_v0_draft_15.8.2020_ <- read.csv("C:/Users/user/OneDrive
- AUT University/a2-
STUDY_2_qual/4_BE_survey/3_analysis/1_csv_result/Crossings_overview_parameters_v0_draf
t_15.8.2020_.csv")
xings <- Crossings_overview_parameters_v0_draft_15.8.2020_

Traffic_overview_parameters_v0_draft_15.8.2020_ <- read.csv("C:/Users/user/OneDrive -
AUT University/a2-
STUDY_2_qual/4_BE_survey/3_analysis/1_csv_result/Traffic_overview_parameters_v0_draft_
15.8.2020_.csv")
traffic <- Traffic_overview_parameters_v0_draft_15.8.2020_

Holistic_overview_parameters_v0_draft_15.8.2020_ <- read.csv("C:/Users/user/OneDrive -
AUT University/a2-
STUDY_2_qual/4_BE_survey/3_analysis/1_csv_result/Holistic_overview_parameters_v0_draft
_15.8.2020_.csv")
holistic <- Holistic_overview_parameters_v0_draft_15.8.2020_


# Measures having ADT lower than the min identified

ref <- "Auckland urban area, all measures between 1.1.2010 and 20.8.2020"


### function
p_lower_adt <- function(x) {
  n <- a_city %>% filter (adt< x) %>% count() %>% as.numeric()
  round( n / nrow(a_city[!is.na(a_city$adt),])*100, digits=0)}


p_lower_peak <- function(x) {
  n <- a_city %>% filter (peaktraffic< x) %>% count() %>% as.numeric()
  round( n / nrow(a_city[!is.na(a_city$peaktraffic),])*100, digits=0)}


### thresholds
thresholds_names  <- c("non-signalised crossings", "high traffic volumes", "holistic
environments")
thresholds_adt    <- c(xings$ADT_min, traffic$ADT_min, holistic$ADT_min)
thresholds_peak   <- c(xings$peak_min, traffic$peak_min, holistic$peak_min)

p_Akl_below_adt   <- c(seq(0,0,0))  # variable for storing the proportion of measures
below the threshold, regarding ADT
p_Akl_below_peak  <- c(seq(0,0,0)) # variable for storing the proportion of measures
below the threshold, regarding peak traffic


df_thresholds     <- data.frame(variable= thresholds_names,
                                ADT_min= thresholds_adt, p_Akl_below_adt,
                                peak_min = thresholds_peak, p_Akl_below_peak)
```

```
# Fill the dataframes with the results

for (i in (1:length(thresholds_adt))) {
  x <- thresholds_adt[i]
  df_thresholds$p_Akl_below_adt[i]  <- p_lower_adt(x)
  df_thresholds$p_Akl_below_peak[i] <- p_lower_peak(x)
}


write.csv(df_thresholds,
file="Traffic_thresholds_and_corresponding_proportions_of_Akl_network.csv")


# Print the results


for (i in (1:length(thresholds_adt))) {
  x <- thresholds_adt[i]
  print(paste(p_lower_adt(x),"% measures with ADT below", x, "vehicles/d", ref))
}


for (i in (1:length(thresholds_peak))) {
  x <- thresholds_peak[i]
  print(paste(p_lower_peak(x),"% measures with peak traffic below", x, "vehicles/h",
ref))}


# Association ADT-peak --------------------------------------------------------------


n <- a_city %>% filter (!is.na(peaktraffic)) %>% filter (!is.na(pcheavy)) %>% filter
(pcheavy<25) %>% nrow()

peak_lm <- lm(a_city$peaktraffic ~ a_city$adt)
summary(peak_lm)
# R2:0.951, intercept approx 0, slope: 0.085

confint(peak_lm, level=.99)
# slope, 95% confidence interval: 0.0840 - 0.0858

R2 <- round(summary(peak_lm)$r.squared, digits=2)


a_city %>% filter (!is.na(peaktraffic)) %>% filter (!is.na(pcheavy)) %>% filter
(pcheavy<25) %>%
  ggplot(aes(x=peaktraffic, y=adt, colour=pcheavy))+geom_point(alpha=.3)+
  scale_color_viridis(option = "inferno", begin = 0, end = .8, direction = 1)+
  labs(title    = "Auckland City traffic: daily, peak, heavy vehicles (peak h
definition varies)",
       subtitle = paste("All counts from 2010 and later, between Massey (NW limit) and
Papakura (SE limit); % heavy vehicles limited to 25% (25 cases eliminated);
n=",n,"R^2=",R2),
       x        = "Peak traffic, average of typically 7 days of count [vehicles/h]",
       y        = "Average daily traffic (ADT), [vehicles/day]",
       colour   = "All heavy vehicles as percentage of ADT",
       caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-
daily-traffic-counts")+
  geom_smooth(method="lm")


# HCV distribution on different types of streets (by peak) ----------------


a_city %>% filter (!is.na(peaktraffic)) %>% filter (!is.na(pcheavy)) %>% filter
(pcheavy<25) %>%
  ggplot(aes(x = pcheavy, y = peaktraffic_category, fill = stat(x))) +
  geom_density_ridges_gradient(scale=1.3, bandwidth = 0.5) +
  scale_y_discrete(expand = expand_scale(mult = c(0.01, 0.25))) +
  scale_x_continuous(breaks = seq(0, 20, 5))+
  scale_fill_viridis_c(option = "inferno", direction = -1) +
  labs(
    title = "Auckland City traffic: heavy vehicle traffic and peak traffic",
    subtitle = paste("All counts from 2010 and later, between Massey (NW limit) and
Papakura (SE limit); % heavy vehicles limited to 25% (25 cases eliminated); n=", n),
```

```
    x        = "Heavy vehicles as percentage of average daily traffic (ADT), [%]",
    y        = "Peak hour traffic [vehicles/h]",
    fill     = "Heavy vehicles as % of ADT",
    caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-daily-
traffic-counts"
  ) + theme_ridges(font_size = 13, grid = TRUE)


# Visualise results -------------------------------------------------------

col_cat_traf   <- inferno(length(levels(a_city$peaktraffic_category)), alpha = 1,
begin = 0, end = .8, direction = -1)

theme_white   <-  theme(
  panel.background = element_blank(),
  panel.grid.major = element_blank(),
  axis.ticks       = element_blank(),
  axis.title       = element_blank(),
  axis.text        = element_blank())

a_city_mw %>% filter(!is.na(peaktraffic_category))%>%
  ggplot(aes(x=NZTMX, y=NZTMY))+geom_point(size=1, aes(colour =
peaktraffic_category))+
  scale_colour_manual(values=col_cat_traf)+
  labs(
    title = "Auckland City traffic: peak traffic",
    subtitle = paste("All counts from 2010 and later, between Massey (NW limit) and
Papakura (SE limit); % heavy vehicles limited to 25% (25 cases eliminated); n=", n),
    colour   = "Peak h traffic [vhc/h]",
    caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-daily-
traffic-counts") theme_white +
  theme(legend.position = c(0.2, 0.2)) # legend in the lower left

n_t <- a_city %>% filter(!is.na(adt))%>% filter(adt<50000)%>%nrow()

# Map with continuous colour range for ADT
a_city %>% filter(!is.na(adt))%>% filter(adt<50000)%>%
  ggplot(aes(x=NZTMX, y=NZTMY))+geom_point(size=1, aes(colour = adt))+
  scale_color_viridis(option = "inferno", begin = 0, end = 1, direction = -1)+
  labs(
    title = "Auckland City traffic: average daily traffic",
    subtitle = paste("All counts, 1.1.2010-20.8.2020; limits set to Massey (NW) and
Papakura (SE), motorways/highways excluded; n=", n_t),
    colour   = "ADT [vhc/d]",
    caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-daily-
traffic-counts") theme_white +
  theme(legend.position = c(0.2, 0.2)) # legend in the lower left

# Map by ADT categories

col_cat_adt   <- inferno(length(levels(a_city$adt_category)), alpha = 1, begin = 0,
end = .8, direction = -1)


a_city %>% filter(!is.na(adt))%>% filter(adt<50000)%>%
  ggplot(aes(x=NZTMX, y=NZTMY))+geom_point(size=1, aes(colour = adt_category))+
  scale_color_manual(values=col_cat_adt)+
  labs(
    title = "Auckland City traffic: average daily traffic",
    subtitle = paste("All counts, 1.1.2010-20.8.2020; limits set to Massey (NW) and
Papakura (SE), motorways/highways excluded; n=", n_t),
    colour   = "ADT [vhc/d]",
    caption = "Source: https://data-atgis.opendata.arcgis.com/datasets/average-daily-
traffic-counts") + theme_white +
  theme(legend.position = c(0.2, 0.2)) # legend in the lower left
```

6F: Findings, footpaths design

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
1. Footpath width	**Metric #13, width of continuous, clear walking space; width of the narrowest section** Ideal (score 3): >2m if quiet, <600p/h; >2.5m if 600-1200p/h; >3m if busy, >1200p/h Score 2: 2-2.5m (moderate pedestrian traffic); 2.5-3m (busy) Score 1: 1.5-2m (quiet to moderate); 2-2.5 m (busy) Score 0: <1.5m	Identify the zone likely to be used by pedestrians (through route), excluding areas with street furniture and a 15cm buffer around any object next to the through route. Width of the through route (p. 14-3): 1.5 m: absolute minimum, up to 50 p./min; 1.8 m on collector roads and commercial/industrial, outside of CBD, up to 60 p/min; >2.4 m on arterial roads in pedestrian districts / CBD / alongside schools and other major generators, up to 80 p/min	Through route: • 1.8m on local residential roads, up to 50p/min • 1.8m on neighbourhood collector roads and around public transport hubs, up to 60 p/min • 2.4m minimum on main streets, centres, and alongside pedestrian generators (e.g. schools), up to 80p/min [58]. The dimensions or other footpath zones are also prescribed for the same categories. The manual notes that "Footpaths should include a buffer between the clear path and traffic; presenting a good place for street furniture, utilities and service covers and tree pits." (p. 74) and "ample width to cater for peak hour volumes of pedestrians to pass each other comfortably, including in groups.", "on main streets and near major destinations and interchanges" (p. 69). The Engineering Design Code specifies: "Width should be increased when flow exceeds values shown in the table." or in other situations of higher demand [58] but it is not clear how the widening is calculated.	Ten instances were reported as being narrow. The narrowest section was wider than 2m in two cases, 1.5 to 2m wide in five cases and up to 1.5m in three cases. The narrowest section was 1.3m and above in all cases except one (0.85m, due to overgrown planting). All measures relate to the total footpath area, from which the immediate proximity to kerbs, walls and obstacles should be discounted, as not necessarily usable. Two of the instances were noted as being narrow and close to the traffic, while the other eight were too narrow for the pedestrian flows present (crowding).	The footpaths widths are not available within Auckland Transport's open GIS data [62]. Even if this dataset was available, the measures on the ground show that the theoretical footpath width can be significantly reduced by built in or temporary obstacles, or vegetation. However, the footpaths examined don't seem exceptional for Auckland's streets, typically equipped with concrete 1.3-1-5m footpaths between property edges and a grassy berm. This typical scenario reflects infrastructure as inherited from the second half of the 20th century.
2. Length of the segment <2m and <1.5m	**No specific recommendation**	**No specific recommendation**	There should not be segments below 1.5m except for localised areas where major constraints cannot be solved otherwise [58]. No specific recommendation regarding length under 2m (see through route width prescriptions above).	Proportion of street lengths with at least one footpath narrower than 2m: median 27%, IQR 79%, min 4%, max 100%. Proportion of street lengths with at least one footpath narrower than 1.5m: median 6%, IQR 34%, min 0%, max 1005.	See above.
4. Pedestrian traffic through the narrowest section, peak h	See point 1 above	Minimum widths: see point 1 above. Higher widths are recommended for areas with "high pedestrian volumes and/or high numbers of pedestrians stopping on the path" (p. 14-3).	Minimum footpaths widths are prescribed against maximum peak hour pedestrian volumes – see point 1 above.	On the "crowded" footpaths, the pedestrian flows observed were varied, from 20 to 1,020 people per hour (median 340 p/h, IQR 635 p/h) through the narrowest section. The flow divided by the footpath width (narrowest) was also dispersed (median 262 p/h/m, IQR 413 p/h/m).	Pedestrian flows are not available for Auckland's streets, except for a series of locations in the hyper centre. A formal comparison is therefore not possible.
5. Causes of obstructions	n/a	n/a	The through route should not be obstructed [58]	The participants mostly noted temporary obstructions (e.g. scooters on the footpaths or illegally parked cars) but built in obstructions such as electrical boxes or signs were also mentioned. Visits in situ did not suggest that the remaining space for walking was extremely narrow (the narrowest measured was 1.20 m).	

6G: Findings, car-oriented street design

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
1. Traffic volume, along	**Metric #1 total two-way traffic, peak hour** Ideal (score 3): <500 vehicles/h (v/h) Score 2: 500-1,000 v/h Score 1: > 1,000 v/h, bike lane Score 0: > 1,000 v/h, no bike lane Metric #4 Traffic noise based on peak hour motorised traffic volumes (for London!) Ideal (score 3): <55 v/h Score 2: 55-450 v/h Score 1: > 450 v/h	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) and consider reducing traffic volumes along walking routes as the first priority (p. 5-2); considers the need for wider footpaths "in areas with [...] high adjacent vehicle volumes" (p. 14-3) but without providing metrics for traffic volumes.	**No metrics for assessing quality**. The manual notes that "Streets should be designed to create an attractive, comfortable, pedestrian-scale environment with a range of amenities, including street trees and other vegetation." p. 33 but without providing assessment thresholds regarding traffic volume.	For the examined roads and streets, median daily traffic was 16,700 vehicles/day (IQR 8,800, minimum 8,900 – Hobson Street, in the city centre, maximum 32,700, St Luke's road, by the mall). Peak hour traffic volumes were between 700 and 950 v/h in four cases, and above 1,100 v/h in the remaining six cases, with a maximum at 2,100 v/h (Balmoral road).	The minimum identified value (8,900 v/d) is not exceptional: 61% of the recent measures taken in the urban area correspond to this case (see supplementary file B).
2. Traffic speeds	**Metric #3, speed of motorised traffic** Ideal (score 3): v85 <32 km/h Score 2: v85 32-40 km/h Score 1: v85 40-48 km/h Score 0: v85 >48 km/h	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) and consider reducing traffic speeds along walking routes as the first priority (p. 5-2); considers the need for wider footpaths "in areas with [...] high adjacent traffic speeds" (p. 14-3) but without thresholds.	The buffer between the through route and traffic can be increased in areas where the speed exceeds 50 km/h [58] but it is not specified how the increase varies with traffic speed.	All the indicated locations except one are in areas where speed is limited to 50 km/h. One location (Ian McInnon Drive) is limited to 70 km/h. V85 speed measures were not available from Auckland Transport. A series of test measures were taken on a section of road limited to 50 km/h and having a similar width and layout to those indicated by the participants. With 90 free vehicles examined V85 was estimated to 47 km/h (median: 42, minimum: 31; maximum: 54; IQR 6 km/h).	The speed limit of 50 km/h is typical of Auckland's urban streets and roads and systematic with the exception of the core city centre (30 km/h), localised village centres (30 or 40 km/h) and school areas, during school hours [50].
3. Proportion of heavy vehicles	**No metric regarding interaction of HCV with pedestrians** (metric #2 addresses interaction with bike riders; ideal: <2% HCV) **Metric #5, noise from large vehicles** Ideal (score 3): <5% HV, peak Score 2: 5-10 % HV, peak Score 1: > 10 % HV, peak	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) but without specifying thresholds for heavy traffic.	**No metrics for assessing quality**. The manual notes that "Streets should be designed to create an attractive, comfortable, pedestrian-scale environment with a range of amenities, including street trees and other vegetation." p. 33 and that impacts of freight traffic should be minimised (p. 107) but without providing assessment thresholds regarding heavy traffic.	The values ranged between 3% and 6% of the daily traffic. Peak hour proportions were not available.	The values found are not exceptional for Auckland: 74% of the recent measures of traffic have 3% and more heavy vehicles in the mix, and 42% have 3 to 6%.
4. Street width	**No specific recommendation;** indirectly considered within natural surveillance (metric #20) but without specifics.	**No specific recommendation;** indirectly considered when recommending environments with natural surveillance from buildings and other people (p. 4-6), without specifics.	Street width enters the calculation of street proportions, for which values are recommended (see point 9 below). Street width also contributes positively or negatively to natural surveillance – the manual recommends that streets offer enough oversight both from nearby buildings and footpaths (p. 53)	Street widths between property limits ranged from 20m (four cases) to almost 50m (St Luke's road, by the mall). The visual widths, between fences or buildings, were typically higher, between approximately 27m (three cases) and 70m (St Luke's road and May road, highway overbridge)	No data were available, however the 20m width corresponds to the post-war suburban street design, and arterials are typically wider.
5. Carriageway width	Not directly assessed (indirectly through assessment of crossing facilities)	**No strict rules**. Widths enter the calculation of levels of service for crossing (i.e. delay) and are	**No specific recommendation** but general principle of re-considering the allocation of space to prioritise pedestrians, public	Variable, ranging from 11m (May Road highway overbridge) to 24m (St Luke's by the mall). The median width was 16m (IQR 4m).	The carriageway widths are not exceptional for Auckland, where even residential streets tend to have two

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
		indirectly considered when recommending environments with natural surveillance from buildings and other people (p. 4-6), without specifics.	transport and bicycle users (p. 33). It is for instance recommended to narrow down lanes that are unnecessarily wide, remove flush medians and re-arrange parking, so to unlock space for walking or sojourning (p. 154).		lanes of 3m and above, and roadside parking.
6. Number of lanes	Not assessed (indirectly through assessment of traffic, speeds, and crossing distances)	Not assessed (indirectly through assessment of traffic, speeds, and crossing distances)	**No specific recommendation** but general principle of re-considering the allocation of space to prioritise pedestrians, public transport and bicycle users (p. 33).	Variable: two (two cases) to six (two cases), most often four (five cases). Individual segments can have varying numbers of lanes, for instance a median transforming into a turn lane.	Data are not available across Auckland however it is observed that arterials are typically two to three lanes wide when traversing local activity centres (two lanes + occasional turning lanes, e.g. Dominion Road) and four to six lanes wide across single use areas (e.g. Balmoral or St Luke's roads). Observed widths are therefore not exceptional.
7. Facades transparency - Percentage of transparent facades along the indicated segment	Indirectly: **Metric #20, surveillance, from nearby buildings and footpaths** Ideal (score 3): constant Score 2: intermittent Score 1: poor	**No specific recommendation;** indirectly considered when recommending environments with natural surveillance from buildings and other people (p. 4-6),	Frontages should be as continuous as possible, with buildings overlooking the street (entrances and glazing at ground floor) – p. 53	The percentage of transparent facades ranged from 0 to 21% (New North road, by Kingsland). The median value was 2% (IQR 12%).	No values were available for comparison. However, as land uses tends to be segregated in most of Auckland's suburban area (e.g. residential or industrial/light industrial), except a few "village centres", it is assumed that this situation is not exceptional.
8. Street proportions	**No specific recommendation**	**No specific recommendation**	Enclosure contributes to spaces that are comfortable to pedestrians. The ratio height/width should be > 1:2, possibly 1:3 if large trees are present. p. 52	Except for two streets in the city centre (Hobson St, 1:1; and Nelson St, 1:1.5), all street proportions are lower than 1:3. The minimal values are lower than 1:10 (Balmoral road and May Rd overbridge)	No data were available. However, the typical suburban street, (20m between property limits and single houses built with a set-back), presents a low height to width ratio and limited enclosure.
9. Tree canopies – distances between canopies	**Metric #23, street trees** Ideal (score 3): trees with canopies spaced <15m on average Score 2: trees with canopies spaced >15m on average Score 1: no trees or only one	**No specific recommendation** except that trees shouldn't interfere with lighting (p. 14-9) and should be "collapsible and frangible" if within 4m of a road >40km/h (p. 14-10). Lack of shade is however noted in reasons why people don't walk (p. 3-9).	Trees should be placed at regular intervals, ideally not more than 15-20m (p. 54) – it is not clear how the distance is measured, a priori between trunks and not canopies.	The average canopy gaps ranged from 36-40m for the two central streets (Nelson and Hobson) up to almost 1km (New North Road, Kingsland to Morningside drive). The median value was 120m (IQR 290m).	No data were available for comparison.
10. Availability of safe crossings: average distance between signalised crossings	**Metric #9, availability of midblock crossings** Ideal (score 3): yes, for all desire lines Score 2: yes for some Score 1: none	**No metrics for assessing quality**. Speaks of providing direct access to desired destinations and public transport (p. 4-1) but without providing specific guidance regarding density of crossings or percentage of desire lines that are catered for.	**No metrics for assessing quality**. Makes the case for the importance of pedestrian connectivity, routes options and smaller block sizes (p. 46) but without providing metrics for the size of the blocks.	The availability of safe crossings was very low, ranging from 200m (two cases) to above 1km (Mt Eden Road, no crossing between the lights at Stokes Rd and a zebra crossing at Esplanade Rd, 1230m further north). The median distance to a safe crossing was 427m (IQR 600m).	

6H: Findings, traffic along the path

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
1. Traffic volume (number of vehicles passing along the indicated footpath)	**Metric #1 total two-way traffic, peak hour** Ideal (score 3): <500 vehicles/h (v/h) Score 2: 500-1,000 v/h Score 1: > 1,000 v/h, bike lane Score 0: > 1,000 v/h, no bike lane Metric #4 Traffic noise based on peak hour motorised traffic volumes (for London!) Ideal (score 3): <55 vehicles/h (v/h) Score 2: 55-450 v/h Score 1: > 450 v/h	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) and consider reducing traffic volumes along walking routes as the first priority (p. 5-2); considers the need for wider footpaths "in areas with [...] high adjacent vehicle volumes" (p. 14-3) but without providing metrics for traffic volumes.	**No metrics for assessing quality**. The manual notes that "Streets should be designed to create an attractive, comfortable, pedestrian-scale environment with a range of amenities, including street trees and other vegetation." p. 33 but without providing assessment thresholds regarding traffic volume.	All indicated sections have peak hour traffic volumes above 1,400 v/h and 14,300 v/d. The median traffic volume across the location was 1,700 v/h (IQR 600) and 19,700 v/d (IQR 8,700).	The identified traffic volumes are on the higher end, for Auckland: Considering the 3,860 traffic counts of the last 10 years, in the city, excluding the highways, 25% have a daily traffic above 14,300 v/d (smallest of the traffic volumes identified by the participants as a barrier), and 14% above the median volume (19,700 v/d). The values were extracted from Auckland Transport's open traffic data – see supplementary file B.
2. Traffic speeds	**Metric #3, speed of motorised traffic** Ideal (score 3): v85 <32 km/h Score 2: v85 32-40 km/h Score 1: v85 40-48 km/h Score 0: v85 >48 km/h	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) and consider reducing traffic speeds along walking routes as the first priority (p. 5-2); considers the need for wider footpaths "in areas with [...] high adjacent traffic speeds" (p. 14-3) but without thresholds.	The buffer between the through route and traffic can be increased in areas where the speed exceeds 50 km/h [58] but it is not specified how the increase varies with traffic speed.	All the indicated locations except one are in areas where speed is limited to 50 km/h. One location (Ian McInnon Drive) is limited to 70 km/h. V85 speed measures are not available from Auckland Transport and were estimated to 47 km/h (N=90 free vehicles, median: 42km/h, minimum: 31 km/h; maximum: 54km/h; IQR 6 km/h)).	The speed limit of 50 km/h is typical of Auckland's urban streets and roads and systematic with the exception of the core city centre (30 km/h), localised village centres (30 or 40 km/h) and school areas, during school hours [50].
3. Proportion of heavy vehicles	**No metric regarding interaction of HCV with pedestrians** (metric #2 addresses interaction with bike riders; ideal: <2% HCV) **Metric #5, noise from large vehicles** Ideal (score 3): <5% HV, peak Score 2: 5-10 % HV, peak Score 1: > 10 % HV, peak	**No metrics for assessing quality**. Asks to question traffic noise and fumes (p. 4-1) but without specifying thresholds for heavy traffic.	**No metrics for assessing quality**. The manual notes that "Streets should be designed to create an attractive, comfortable, pedestrian-scale environment with a range of amenities, including street trees and other vegetation." p. 33 and that impacts of freight traffic should be minimised (p. 107) but without providing assessment thresholds regarding heavy traffic.	Seven of the eight measures had a proportion of heavy vehicles in the daily traffic mix between 2% and 6%. One location (Mt Eden Road by Mt Albert Road) had 20% of heavy vehicles in the daily mix. Peak hour levels were not available.	The proportion of heavy vehicles were generally low and not exceptional for Auckland. 78% of measures taken on Auckland's network have proportions of heavy vehicles in the daily mix up to 6%.

6I: Findings, absence of other people

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
1. Pedestrian activity	The methodology relates to the measures of pedestrian traffic in two instances: it examines high pedestrian volumes, regarding footpaths dimensioning (metric #13), and relevantly here: considering surveillance from nearby buildings and footpaths (metric #20). It does not provide figures regarding pedestrians presence but assesses the surveillance altogether qualitatively.	The guideline mentions the need of assessing (1) the current usage (as a question to consider regarding design of footpaths p. 6-8 or crossings 6-24), (2) the possible suppressed demand (p. 6-8); or (3) the likelihood of pedestrians congregating at night (re providing adequate lighting, p. 17-1). There are however no thresholds provided and no indications of "how lonely is too lonely".	The Manual notes that "Footpaths are safe especially where there are sufficient 'eyes on the street' to provide passive surveillance, including having active building frontages facing the street, and having a sufficiently lively street atmosphere." [57]. No metrics are provided, regarding pedestrian activity and other human presence that could contribute to the lively atmosphere.	Twenty-minutes counts were realised (at sunset/dark, for the locations where the absence of people was noted in the evening, and in the afternoon for the one location presented as always empty). The four locations had results ranging between two and thirteen people in 20 minutes.	Pedestrian flows are not available for Auckland's streets, except for a series of locations in the hyper centre. A formal comparison is therefore not possible.
2. Facades transparency - Percentage of transparent facades along the indicated segment	Indirectly: **Metric #20, surveillance, from nearby buildings and footpaths** Ideal (score 3): constant Score 2: intermittent Score 1: poor	**No specific recommendation;** indirectly considered when recommending environments with natural surveillance from buildings and other people (p. 4-6),	Frontages should be as continuous as possible, with buildings overlooking the street (entrances and glazing at ground floor) – p. 53	There was no transparent facades in three of the cases, and 13% of the length was transparent on one side only at maximum (Mt Eden road)	No values were available for comparison. However, as land uses tends to be segregated in most of Auckland's suburban area (e.g. residential or industrial/light industrial), except a few "village centres", it is assumed that this situation is not exceptional.

6J: Findings, lack of light

Selected measures	Best practice recommendation – Healthy Streets [55]	Local guidelines - Pedestrian Design Guideline	Auckland Transport Design Manual [57] and Engineering Design Code [58, 59]	Findings for each individual metric	Findings compared to Auckland's context
1. Intensity of lighting (lux)	**Metric #21 Lighting** Ideal (score 3): footpath and carriageway meet or exceed the standards (BS 5489) Score 2: carriageway meets standard, footpaths not Score 1: standards not met Standard for footpaths: - 20 lx: primary urban walking routes - 7.5 lx: medium usage routes and links - 5 lx: local, residential streets The standards also include minima and maxima, to control for uniformity of lighting	The guideline makes the case for an adequate lighting, regarding safety and sense of place, namely. It refers to standard AS/NZS 1158.3.1 [pedestrian areas]. The standard provides categories, based on pedestrian activity and fear of crime, and associated lighting levels. The prescribed average horizontal illuminance for footpaths is highly variable (p. 22): - 7 lx, high pedestrian activity (PP2) - 0.85 lx, low pedestrian activity (PP5) - 10 lx, high fear of crime (PP1 - regardless the pedestrian activity) Local authorities are to define the category for each street.	Street lighting is described as important and the coverage of lighting is part of the metrics suggested for measuring the quality of the street (p. 123). The manual provides general principles and further refers to the Engineering Design Code. The Engineering Design Code relative to lighting [59] refers to standard AS/NZS 1158.3.1 (see left) for the levels of lighting for each category of footpath. The code indicates that categories are to be agreed between the developer and Auckland Transport, for a given scheme (p. 5). Categories for existing streets have not been identified. It is understood that the update of the Roads and Streets framework [63] could inform this point.	The four locations had average horizontal illuminance of 0.2, 1.1, 1.6 and 8.1 lx. The three low values include vast lengths without any light at all except for occasional spillages from nearby houses.	No data are available. An email conversation with employees from Auckland Transport suggests however the awareness of an inherited infrastructure that had not been designed primarily with pedestrians in mind. Retrofit is being done but faces the challenge of the large extent of the road network that needs to be improved regarding lighting.
2. Type of lighting (functional, atmosphere? Blue or warm?)	**No metrics for assessing quality**	No specific recommendations but suggests human-scale lighting when indicating that lighting should contribute to reassurance and allow people to clearly see potential hazards and other walkers (p. 17-1).	**No precise metrics for assessing quality**. The manual indicates that lighting should be at human scale and contribute to inviting spaces (p. 75).	It wasn't possible to measure the colour of the light; however the type of lamps was in all four cases a simple luminaire placed high (4m or higher). The recommendation of providing a human-scale lighting is hard to follow in the absence of specific metrics, however the height of the luminaires and their spacing, including typically vast areas of darkness, don't seem appropriate for a human scale and pace.	See above.

6K: Recommendations, Healthy Streets approach

Healthy Streets helps assess environments in a straightforward way, through clear indicators and scoring rules. Recent publications recognise that Healthy Streets provides pragmatic decision support for delivering complex policy goals such as health and sustainability [64, 65]. The findings from this study suggest two directions for future developments. Firstly, as noted above, thresholds should be identified regarding natural surveillance (pedestrian traffic and façade transparency), distances between safe crossings, and cornering radii (as a proxy for cornering speeds). Second, the measures for footpath widths should be further developed. And third, guidance should be provided regarding pedestrian counts. Brief recommendations regarding the last two points are presented below.

Footpath widths can be inconsistent, built with varying standards along a same street and narrowed by built-in or temporary obstacles, or even by people standing. Healthy Streets considers the unobstructed, direct walking space, and provides thresholds regarding its narrowest section (metric #13). However, this measure can be misleading as it could relate to very diverse situations. The participants' inputs and measures suggest that a width "x" can be associated to different experiences if (1) it is a localised narrowing on an otherwise wide footpath; (2) it is the constant width of a straight through route; or (3) it is the width of a route slaloming between obstacles on the left and the right side. In this study, a trial was made using percentage of the section length narrower than 1.5 and 2 m but did not yield any pattern. Further, perceptions of narrowness seemed to be influenced by the presence of heavy traffic adjacent to the footpath. It is therefore recommended to develop the measures in two ways. Firstly, amend the thresholds regarding the footpath width, including the widths of buffer areas that should be discounted in presence of walls, bus stops, shop windows or street edges. The buffers relative to street edges should be associated to traffic speeds (e.g. <30 km/h, 30-50 km/h, >50 km/h). Second, the footpath assessment should capture (in)directness of the walking route. A possible way forward would be to calculate route directness [66] applied to the micro-level of a test walk along the given footpath (e.g. straight line with a 30cm buffer on each side and making right angle turns every time it encounters an obstacle).

Pedestrian flows can present a high variability (see supplementary file A) but can also have different peak hours (e.g. school time, in presence of schools, late night in a street with restaurants and bars, or afternoon peak, if the street serves as a main access to bus stops). In the case of this study, the absence of automatic pedestrian counts across the city, except for a few hyper-central locations, meant that the peak hour measured was a best guess and that the manual count, done on one given day, accounts poorly for the expected variability. An additional difficulty regarding the pedestrian flow is that the measure of number of people per hour does not provide any information regarding the potential "clogging" of a footpath. For instance, near schools, the pedestrian flow can be high in the 10-20 minutes before the school start, at what time children might also arrive in groups and take over the footpath. A measure of number of people per hour levels up the peaks that could be the issues (for instance, blind participant reporting that she and her dog find themselves blocked). The guideline should help identify the peak hours (providing for instance a quick guide for running and analysing automatic counts) and specify how to account for peaks such as school start for instance.

6L: Recommendations, local guidelines

The guidelines often speak of a direct and unobstructed pedestrian through route, wide enough for the pedestrian flows and offering buffers to walls and kerbs, or the “furniture areas” (see Figure 6 below). The findings conceptually align with this vision, outlining cases where the through route is not direct, not wide enough, and/or not buffered enough from the traffic circulating along it. It is however noted that the design manual and the accompanying engineering standard do not provide specific widths that are to be provided for the pedestrian traffic (through route) and the adjacent areas, in different circumstances (namely in present of strong traffic).

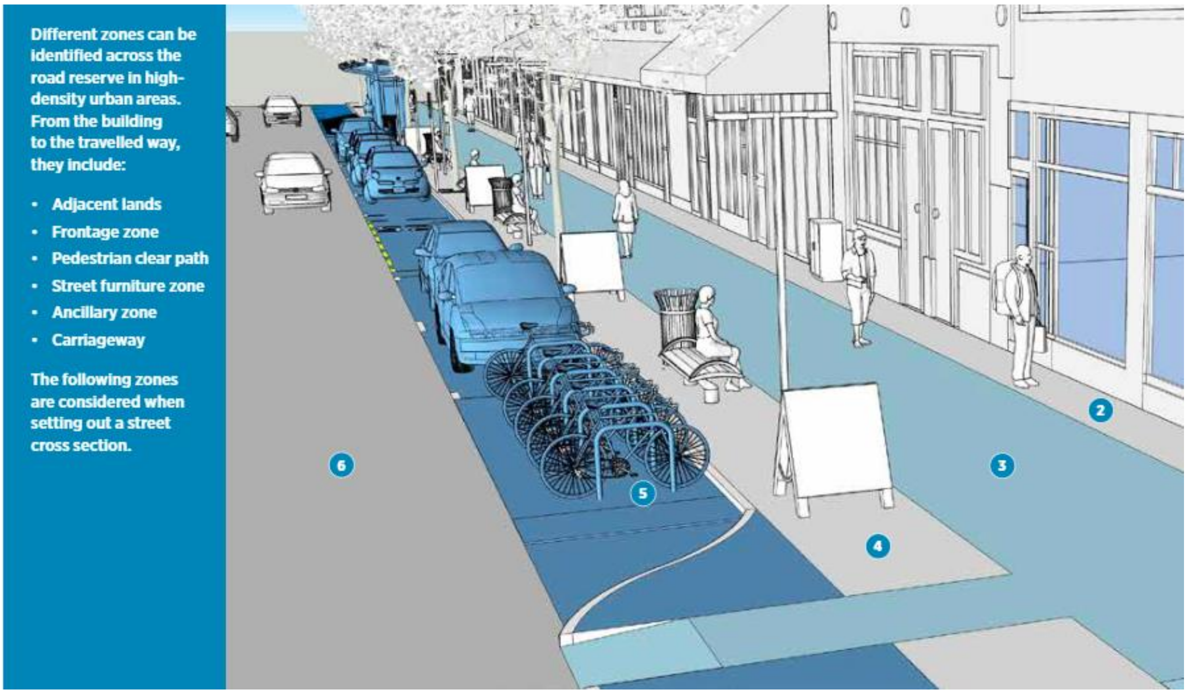


Figure 6: Example of pedestrian through route (number 3) as presented in Auckland Transport's Design manual [57]. The illustration also identifies frontage zones (buffer for the adjacent walls, number 2) and the furniture areas (number 4)

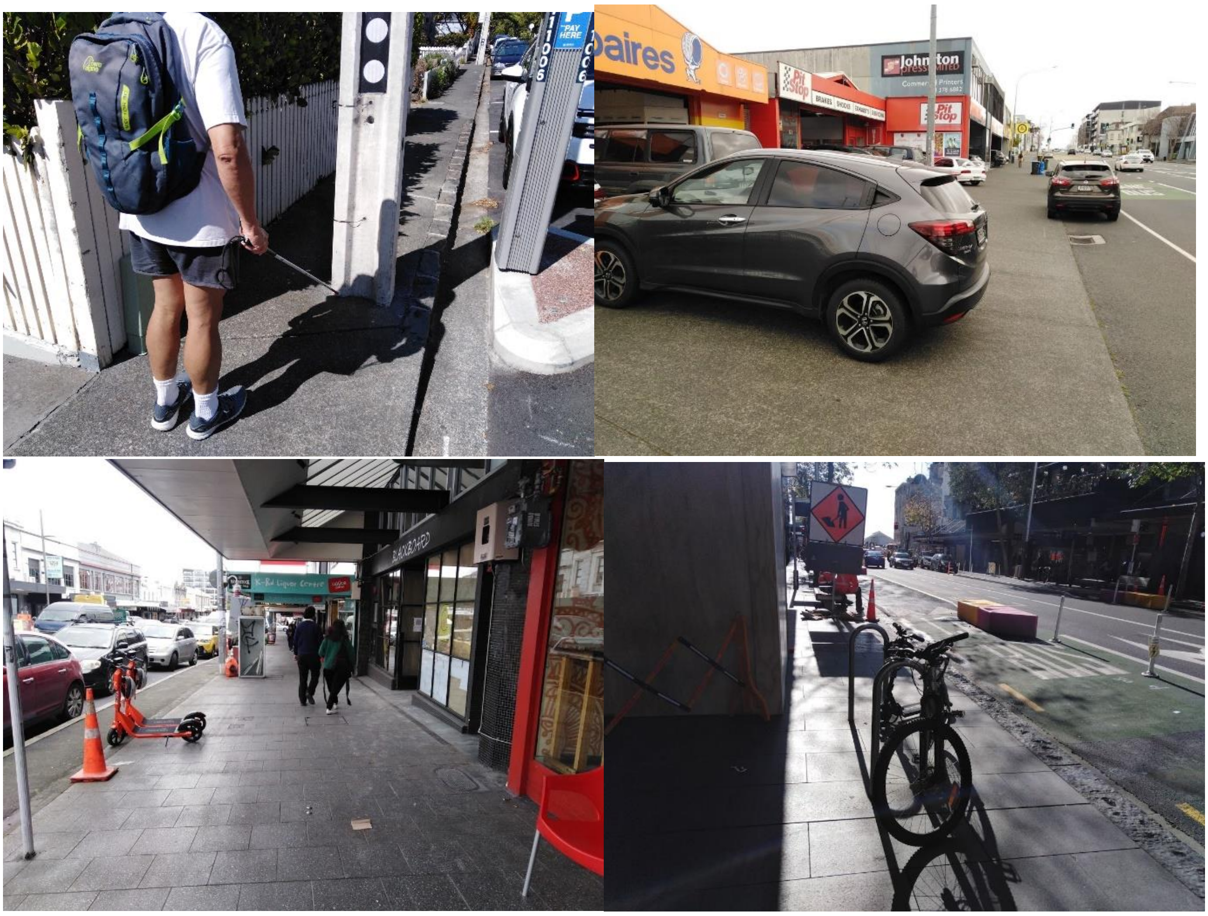


Figure 7: Footpaths through route as observed on the ground, examples

CHAPTER 7

7A: Characterisation of complex socio-technical systems and application to the walking environment

Table 4: Characterisation of complex socio-technical systems and application to the walking environment

Categories of characteristics	**Key aspects** [67]	**Application to the walking realm**
A large number of dynamically interacting elements	The system isn't static but subject to non-linear interactions between components. A "failure" can propagate quickly.	● Everyday variations in traffic and people walking (shops opening hours, schools, buses, events, etc.) impacting on attractiveness ● Private interventions (new cafe, shops, etc) impacting on walking levels ● Alterations to land use or transport systems - new roads, facilities for walking, etc., changing the accessibility / attractiveness, possibly creating barriers and impacting on use ● Possible virtuous or vicious circles leading to different levels of walking (perception of unsafety leading to less people on the street resulting in even lesser perceived safety…)
Wide diversity of elements	The elements belong to diverse categories or types, have different inputs and outputs, and the interactions between them can also have different natures.	● Diversity of users and usages of the public realm ● Diversity of actors, public and private, playing a role in the use ○ Local trip generators - schools, shops… ○ Public sector - transport, planning, building and maintaining infrastructure ○ Public sector - health and economic development, sharing objectives ○ Public sector - environment and conservation, sharing objectives ○ PT operation ○ Developers ● Diversity of professions involved in the inputs or interested in the outcomes (land use, transport, health, etc) ● Diversity of data sources and analysis ● Possible lack of coordination - transport land use, maintenance-building, or across sectors ● Global social, economic and technological evolutions, impacting on travel patterns, affordability, or alternatives
Unanticipated variability	The system interacts with its environment, providing changing inputs, and these inputs coupled with the variety of internal interactions can result in variability that couldn't be predicted.	● Walking as a series of single decisions, based on unique parameters, that can't be captured in a deterministic way based on inputs ● Social and technological trends (mobile phone developments, apps such as Pokémon Go, a pop-up market, a special event...)
Resilience	The system's functioning can be changed through a series of past events, in a form of "self-organisation" and without a top-down command. Systems can thus adapt to their environment in an organic way.	● Alterations of the built environment (e.g. enhanced safety) - Low cost low risk interventions, capital transport improvements ● Adjustment of the signalised crossings phasing, sometimes dynamic ● Police enforcement, school patrols

7B1: Email invitation to survey participants

Email sent by the researcher

Kia ora [Name],

Within my PhD research at Auckland University of Technology, I am investigating **walking/wheelchair use for transport** and examining specifically the **role of the qualities of street environments**. My overarching aim is to provide leverageable insights to practitioners regarding how to improve the walking environments, by identifying most salient features that can deter from walking trips that are within walkable distance.

So far, I have outlined a theoretical model through international evidence, examined Aucklanders' walking patterns and perceptions (quantitative analysis), interviewed 56 Aucklanders for an in-depth insight into their perceptions and choices, and collected measures of the built environment to inform features critical to the choice of walking.

To better understand the needs of practitioners, my last study engages with professionals and decision-makers from five disciplines (transport planning, urban design, public health, road safety, urban strategy and development). An online survey will collect views on what they see as main components of a place supportive of walking/wheelchair use, what they think motivates Aucklanders to walk or deters, what challenges they perceive in delivering accessible environments and what priorities they would set for the next 3 & 10 years.

The invite to participate to the survey is sent to a list of professionals identified by the team, and you are one of them. The survey should take about 10 minutes and will be anonymous. You will find more information in the information sheet attached.

Your insights would be most valuable for this research. If you agree to participate, please follow the link to the survey (you will be asked to confirm that you agree with the terms as presented in the information sheet).

If you have any question, you are welcome to contact the research team:

- Myself (primary researcher): [Name, email, phone number]
- Project Supervisor: [Name, email, phone number]

Thank you in advance.

Ngā mihi,

[Signature]

7B2: Survey invite and questions

The participants filled an online survey. The questions and response formats are reproduced here.

Start of Block: Default Question Block

Project title: Quality of the walking environment and difficulties to access local destinations
Project Supervisor: Professor Erica Hinckson
Researcher: Tamara Bozovic

The survey you are invited to fill examines professionals' opinions on the design and retrofit of the walking environment. Questions cover namely what needs to be done, how it is/should be prioritised and what decision support is available or needed.

This survey is done within a PhD thesis aiming to identify what aspects of the street environments and transport system can deter Aucklanders from accessing local destinations on foot or by wheelchair (further, "walking" refers to both), so to provide elements that can be a useful decision support for the practitioners.

Consent is implied by your completion of the survey. Please read the following and click on the arrow below if you agree to participate. ....
I understand that the information I provide in the online survey will be safely stored and that quotes might be extracted in a way that doesn't identify individual participants. ....
I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study prior to having completed the survey, without being disadvantaged in any way. ....
I understand the survey will not ask for my name or any contact detail. This means that all information provided will be anonymised (never associated to a person) but also that provided inputs cannot be withdrawn, once the survey is completed, because the researchers will not have any indication relative to who answered the survey.
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Erica Hinckson: Erica.hinckson@aut.ac.nz, 09 921 9999 x 7224.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUT's Ethics Committee (AUTEC), Dr Carina Meares[jp1] , Phone +64 9 921 9999 extn: 6038,
Email ethics@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 31.8.2020, AUTEC Reference number 18/431.

If you agree to participate, please click on the arrow below to proceed to the survey.

End of Block: Default Question Block

Q1 A city supportive of walking: what would be its three key characteristics?

- ○ Characteristic 1 (1) ____
- ○ Characteristic 2 (2) ____
- ○ Characteristic 3 (3) ____

Q2 What would you set as the main priority of intervention regarding accessibility on foot/by wheelchair, for Auckland?

- ○ Main priority for the next 3 years (1) ____
- ○ Main priority for the next 10 years (2) ____

Q3 How well do we understand what might cause people not to choose to walk/wheel, or to struggle by doing so?

- ○ Extremely well (1)
- ○ Very well (2)
- ○ Somewhat (3)
- ○ Not well at all (4)
- ○ I don't know (5)

Q4 If you had to present evidence about motivations or barriers to walking, for Aucklanders, what source(s) of data would you use?

____

Q5 **What do you think motivates Aucklanders to choose to walk?**
Please indicate up to three aspects and give them weights that add up to 100.

- ○ Item 1; weight (1) ____
- ○ Item 2; weight (2) ____
- ○ Item 3; weight (3) ____

Q8 **What do you think deters Aucklanders from walking?**
Please indicate up to three aspects and give them weights that add up to 100.

- ○ Item 1; weight (1) ____
- ○ Item 2; weight (2) ____
- ○ Item 3; weight (3) ____

Q9 What is the single biggest challenge regarding the improvement of street environments?

____

Q10 **Considering the planning and delivery of the walking environments, how much do you agree with the following statements?**

Q11 **1. There are many dynamically interacting elements** (e.g. different disciplines influence the challenges and activities of others', emphasis changes over time); [slider, 0: Disagree entirely; 100: Entirely agree]
Q13 **2. There is a wide diversity of elements** (e.g. users with varied needs, technical requirements, guidelines, organizations and disciplines involved, hierarchy levels); [slider, 0: Disagree entirely; 100: Entirely agree]

Q15 **3. There is unexpected variability** (e.g. decisions on streets environments are made within uncertainty, as the information is not always available; activities are not always clearly linked with purposes; there can be vicious circles where interventions amplify issues for walking/wheeling; the causes and effects of streets design on walking/wheeling are not fully known and can generate effects that are poorly monitored); [slider, 0: Disagree entirely; 100: Entirely agree]
Q17 **4. There is resilience** (e.g. there are numbers of ways to achieve higher levels of walking or address safety issues for people on foot/by wheelchair, the way we deliver the streets environments changes and can change in the future based on experiences made); [slider, 0: Disagree entirely; 100: Entirely agree]

Q19 What discipline(s) do you relate with?

- ☐ Urban design (1)
- ☐ Road safety (2)
- ☐ Transport planning (3)
- ☐ Public health (4)
- ☐ Urban development (5)

Q21 How would you define your current role?

- ☐ Technical specialist (1)
- ☐ Decision-maker (2)
- ☐ Researcher (3)
- ☐ Other (please specify) (4)

Q23 Is there anything you would like to add?

____

End of Block: Default Question Block

Start of Block: Default Question Block

Q1 **Thank you very much for your time and insights.**
A focus group will be organised to discuss the findings, and a technical report will be available at the end of the project. Please let us know your preferences.
This form is dissociated from the survey you filled, and the research team will have no information allowing to associated contact details provided here to survey answers.

Q2 I am interested in participating to the focus group (practitioners will be selected by order of expression of interest, and the focus group will include one person for each area of expertise)

- ○ Yes - please indicate the email address we should use to contact you: (1) ____
- ○ No (2)

Q3 I would like to be sent the technical report when published (you can also receive the report by requesting it by email, and don't need to provide information detail here if you don't wish to).

- ○ Yes - please indicate the email address we should use: (1) ____
- ○ No (2)

End of Block: Default Question Block

7C: Information pack for the focus group participants

The following elements were sent to the focus group participants four days ahead of the meeting.

Context and aim

This focus group is part of a PhD research project at Auckland University of Technology. The project investigates walking/wheelchair use for transport (further: walking) and examines specifically the role of the qualities of street environments. The overarching aim is to provide professionals with leverageable insights regarding how to improve the walking environments. For this, the project seeks to identify the most salient features that can deter from walking trips that are within walkable distance.

So far, a theoretical model has been outlined through international evidence; Aucklanders' perceptions of their environments were quantitatively associated with walking patterns; 56 Aucklanders were interviewed for an in-depth insight into their perceptions and choices; and measures of the built environment were collected to inform features critical to the choice of walking. Six of the interview participants continued being involved in the project as Citizen Scientists, collecting data and discussing findings.

To better understand the needs of practitioners, the last study engaged with professionals and decision-makers from five disciplines (transport planning, urban design, public health, road safety, urban strategy and development). Through an online survey, views were collected regarding (1) main components of a place supportive of walking/wheelchair use; (2) perceived motivators and deterrents to walking; (3) challenges perceived in delivering accessible environments; and (4) priorities the next 3 & 10 years.

This focus group aims to discuss and better understand two topics identified from the survey. They relate to aspects where there was no large consensus and identified systemic challenges. We would like to better understand the reasons of a lack of consensus and ways how challenges might be overcome.

Focus group agenda

- **Welcome**
- **Context and aim**: brief reminder
- **Round table**: brief introductions
- **Topics**: brief intro (what was found) and discussion
- **Wrap up**

Topics

User experience and users' needs
The responses to the question how well the barriers to walking in Auckland are understood were very diverse, ranging from "not well at all" to "extremely well". Street environments were a major topics: for the participants, a city that supports walking has inviting environments, while "hostile" environments are seen as a barrier to walking. Some participants specified that the environments need to be adapted to people of all ages and abilities, and others took the users' perspective, saying that people should feel safe and comfortable.
The responses didn't provide however a clear picture of the "what" should be addressed: when participants spoke of specific features of the walking environment, they referred to diverse aspects. Traffic and crossing facilities were the biggest cluster of responses, noted by 13 participants. Sometimes, only perceptions were noted (e.g. "hostile" environment), raising the question what it is, that is associated with poor safety or comfort? The challenges cited had a strong focus on transforming a car-oriented environment, which again calls for an agreement regarding what should be done and how the expected long "to-do list" should be prioritised.
When asked what evidence participants would use, to inform users' needs, there was no document widely referred to, and most participants referred to sources that don't speak directly of users' needs

(e.g. census). The lack of evidence regarding users' views didn't come up as a major challenge to implementation of walkable environments.

How might we explain the diversity of views regarding what users need? Why is this lack of consensus not on the radar, when we speak about what to deliver, and challenges to implementation?

Lack of prioritisation for walking in the policy and the practice

The lack of priority given to walking was described as a challenge for delivering more walkable environments. The lack of priority was described as both technical and political (e.g. "Aside from budget, I think there is an underlying car-centric mindset amongst designers and policy makers which reflects on the streetscape. […] The language is still car centric; for example, highway and intersection design levels of service are centred around vehicle delay and travel time. Even though pedestrians use the same intersection, their time is valueless and is not captured in the design.").

High level visions present a future Auckland that is liveable and accessible (e.g. Auckland Plan / "we […] need to make sure that people of all ages and abilities, including people with reduced mobility levels, can go about their daily lives and get from one place to another easily, affordably and safely ", p. 6). How are these objectives delivered, given the noted lack of priority but also the relative mismatch of views regarding what users need?

7D: Codes used in the deductive content analysis

Dimension	Category	Subcategory
Destinations	Distance to desired end destinations	
	Distance to public transport stops	
Walking network	Street connectivity / block size	
	Stairs	
	Topography	
Walking environment quality	Footpaths	design (width, directness)
		materials, execution
		absence
		temporary obstruction/ clutter
		maintenance
	Traffic	volumes and speeds
		noise and pollution
		Traffic across the footpaths
		Sharing space with bicycle riders
	Crossing facilities	non-signalised: layout, geometry
		signalised, waiting time
		signalised, layout, geometry
		signalised, drivers' behaviour
		availability of appropriate crossing facilities
	Conjunction: crossing facilities AND traffic conditions	
	Activation: presence of other people, "eyes on the street"	
	Street furniture	presence (benches, …)
		layout
	Use of the space by other people, (in)civilities	
	Landscape	architectural quality
		views
		greenery
	Holistic design quality	
	Lighting (presence, quality)	
	Shelter (presence, quality)	
	Availability of toilets/water	
Broader transport	Public transport	availability and efficiency of public transport services
		accessibility of public transport bus stops (design)
		cost
		comfort and lighting of PT stops
	Driving	ease, overall
		availability of parking
		cost of parking
		travel times
		environmental pollution
	Other modes	efficiency of rideshare
		cost of rideshare
		bicycle - travel time
		bicycle - good infrastructure available
		bicycle - ease of parking
Internal motivations/deterrents		
External motivations/deterrents		
No choice		
Habit		

7E: Detailed results

Incentives and deterrents to walking

Table 5: Incentives to walking as mentioned by the professionals

Dimension	N mentions	% all	Category	N mentions	% all
Broader transport system	**23**	**31%**	Convenience of walking	10	14%
			Cost of parking	3	4%
			Driving, pollution	1	1%
			Driving, travel times	2	3%
			PT, efficiency	3	4%
			Walking free / saves money	4	5%
Destinations	8	11%	Distance to destinations	7	9%
			Distance to PT stop	1	1%
External motivations/deterrents	4	5%	Socialising	2	3%
			Walking the dog	1	1%
			Weather	1	1%
Internal motivations/deterrents	16	22%	Enjoyment of walking	1	1%
			Health and fitness	15	20%
Perceptions	8	11%	Perceived accessibility	1	1%
			Perceived comfort	1	1%
			Perceived pleasant experience	3	4%
			Perceived safety	3	4%
Street environment - quality	14	19%	Footpaths design	1	1%
			Greenery	1	1%
			Holistic design quality	8	11%
			Presence of other people	1	1%
			Shelter (presence, quality)	1	1%
			Signalised crissings - waiting time	1	1%
			Traffic intensity	1	1%
Walking network	1	1%	Connectivity	1	1%
Total	**74**	**100%**		**74**	**100%**

Table 6: Deterrents to walking as mentioned by the professionals

Dimension	N mentions	% all	Category	N mentions	% all
Broader transport system	**7**	**9%**	Convenience of walking	1	1%
			Ease of driving	5	7%
			PT, efficiency	1	1%
Destinations	**15**	20%	Distance to destinations	15	20%
External motivations/deterrents	12	16%	Social norms	1	1%
			Transporting someone or something	1	1%
			Weather	10	13%
Internal motivations/deterrents	2	3%	Walking is too much effort	2	3%
Perceptions	14	19%	Perceived accessibility	2	3%
			Perceived safety	12	16%
Street environment - quality	23	31%	Holistic design quality	10	13%
			Non-signalised crossings layout	1	1%
			Signalised crossings - waiting time	1	1%
			Traffic intensity	4	5%
			Traffic noise & pollution	2	3%
			Crossings and traffic conditions	4	5%
			Crossings, availability	1	1%
Walking network	2	3%	Connectivity	1	1%
			Topography	1	1%
Total	**75**	**100%**		**75**	**100%**

Table 7: Professionals vs users - comparison of frequency of mentions relative to the environment and system, excluding perceptions, "other" and unclear inputs

	Incentives, mentions					**Deterrents, mentions**				
	Professionals, N=28		**Users, N=56**			**Professionals, N=28**		**Users, N=56**		
Dimension	**N**	**%**	**N**	**%**	**Chi2 p**	**N**	**%**	**N**	**%**	**Chi2 p**
Broader transport system	**17**	**35%**	22	**51%**	<.05	**7**	**15%**	1	**2%**	<.01
Destinations	15	**31%**	9	**21%**	<.1	15	**32%**	13	**25%**	ns
Street environment - quality	15	**31%**	11	**26%**	ns	23	**49%**	30	**59%**	ns
Walking network	1	**2%**	1	**2%**	ns	2	**4%**	7	**14%**	<.1
Total mentions	**48**	**100%**	**43**	**100%**		**47**	**100%**	**51**	**100%**	

CHAPTER 8

8A: Citizen Scientists' information sheet

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet for Citizen Scientists

Date Information Sheet Produced:

10.11.2018

Project Title: Quality of the walking environment and difficulties to access local destinations.

An invitation

Tena koe,

My name is Tamara Bozovic, I am a PhD student at Auckland University of Technology. You have already participated to the interviews within the project "Quality of the walking environment and difficulties to access local destinations". We thank you again for your time and would like to invite you to further participate in the research, as a Citizen Scientist. This participation is optional. Working with a team of 10 to 15 Citizen Scientists is a way for us to involve those residents who wish throughout the research, from the data collection to the dissemination of the results to the local authorities. This information sheet gives you the detail about this process. Thank you in advance for reading it and letting us know if you are interested.

What is the purpose of this research?

This research aims to contribute to the efforts of improving the urban environment. It is important because the streets' environments can cause difficulties that discourage walking. Aucklanders' levels of walking are rather low, and strategies such as the Auckland Plan aim to encourage accessing local destinations on foot or by wheelchair, for all. Understanding the difficulties can help the local authorities improve the streets environments by addressing those aspects that matter most. This research will provide insights into what these difficulties are and how they influence people's choices for moving around. The results will be shared with all the participants, presented to the local authorities responsible for the redesign of existing components of urban environments, and submitted for publication to scientific journals and conferences.

What are Citizen Scientists and what will be their role?

Citizen Scientists (CSs) are adults who have participated in the first phase of this research, the face-to-face interviews. They don't need to have any specific training. They experience some difficulties accessing their local environment on foot or by wheelchair, and are interested in being involved in this research as co-investigators. We aim to recruit 10 to 15 CSs.

The CSs will have following roles:

- **Data collection**: The CSs will capture insights of walking routes they choose, using a specialized app (Stanford Neighbourhood Discovery tool, see detail below). Through the app, they will capture photos of the streets' characteristics, add short explanations for each photo (recorded voice messages). The app will also record the route taken and the places where the photos were taken. The CSs will be trained to use the app. They will have the choice to either walk those routes in pairs, or be accompanied by the primary researcher, so to discuss in vivo the elements observed. Each trip will be entirely decided by each CSs (destination, route, pace, time…). If a participant cannot use an app, arrangements will be sought, for instance walking with the primary researcher who captures the elements indicated by the participant.
- **Data analysis**: CSs will be invited to discuss the topics and themes found through the analysis of the data coming from the Household Travel Survey data, the interviews, and the insights captured from the app. Their will have the opportunity to comment on the interpretation of the findings and suggest further analyses they would find useful to bring to the local authorities. A focus group will be organized with the local practitioners working in the field of the streets design – within this focus group, the participants and practitioners will be invited to discuss the results of an anonymous survey previously filled by the practitioners, asking them about the priorities regarding the improvement of the streets environments and the challenges.
- **Data dissemination**: At the end of the research process per se, the CSs will be offered to bring the findings to their local authorities, and express their own views, supported by the primary researcher. The primary researcher will act in this case as a technical consultant, ready to help and answer questions, but not the person leading the discussions.

How will the research be measured?

The research will be measured partly by the use of an app called "*The Stanford Neighbourhood Discovery Tool*". As a Citizen Scientist, you would use this app to take pictures of your surroundings and note things that you find difficult or easy (see picture below). This is an app on a smartphone/tablet which is made by the Stanford University in California – USA to measure aspects of someone's environmental neighbourhood. If you would like more information about the tool, visit this website: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3601583/

A 30 minutes training session will be organized to help you familiarize yourself with the app, and answer questions you might have. An important thing to note for now is that you will be asked to take only photos of street characteristics (e.g. a crossing you find difficult or easy) and avoid photographing people unless necessary (for instance, you would like to capture a lively plaza you like). In this case you will be asked to avoid close-ups or anything that makes one person easy to identify. This research examines streets design features and not people's behaviours, so we would like to avoid bothering the users of public spaces unnecessarily.

How was I identified and why am I being invited to participate in this research?

All the interview participants are invited to join the research team as CS. The applications are taken by order of arrival, and the only limit is that the CSs team cannot have more than 15 participants.

What will happen in this research?

Participants' roles are described above. Please note that every aspect is voluntary. Namely:

- The participants choose how many walks they would like to make, using the app.
- They choose the destination, route and time of the walks, and decide if they would like to do the walk in pairs or with the principal researcher.
- The results will be discussed in three work meetings and one focus group with the practitioners (each meeting up to one hour, at AUT City campus). The participants can choose to which meetings they participate, without any obligation. Those participants who cannot attend a meeting will receive a memo of the points discussed.

The meetings will be audio-taped for transcription purposes. Only the primary researcher will access the audio tapes.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

If you wish to participate, please contact me by email or telephone. To participate, you will be asked to sign a Consent Form. You will find this document at the end of this letter. You can either send me a scanned signed copy with your email, or you can sign this document when we meet for the interview.

What are the discomforts and risks?

It is not anticipated that participants will encounter any risk from participating in this research. Capturing the insights during usual walks includes the risks inherent of being in the street environment. The participants are advised to respect the road code and not to do anything that puts them in danger regarding traffic or other sources.

Due to the nature of a working group made of participants, other people may know that you are participating. However, should you prefer not to provide information to any of the questions, you will not be disadvantaged in any way. All questions are voluntary, and participants can withdraw from the study at any time.

What are the benefits?

To date, the understanding on how the streets environment possibly hinders or prevents trips on foot or by wheelchair is very poor. Internationally, the quantity of data is weak, and presents many biases. This research will contribute to local authorities' effort to improve existing urban environments. Having a good evidence is important in order to target the biggest difficulties for residents and visitors (e.g. people with disabilities, parents with prams, older people). Beyond Auckland, the findings could be useful for other New Zealand or Australian urban areas, given that the issues are likely to be linked to system design practices, being similar. Ultimately, addressing main barriers to access improves everyone's ability to participate, and helps create a more supportive environment for an ageing population. We also hope that the results will be useful to the local practitioners working on the streets' design. For me, this research will contribute to the obtention of a PhD and allow me to submit findings to academic journals and conferences. Beyond this, I feel privileged to be able to leverage users' insights to help improve the transport planning and urban design practices.

We value your time and will offer a koha ($30 supermarket voucher) in sign of appreciation at the third work meeting.

How will my privacy be protected?

All information that you give us will be treated as private and confidential. Only me and the researchers involved in the study will have access to the records. Research records will be kept in a locked file and sorted by number codes, not by names. In any sort of report we publish, information will be presented in a way that doesn't allow to identify you or any other participant in any way. Data will be stored on AUT premises for 6 years and will be permanently destroyed after this period.

What are the costs of participating in this research?

There are no costs except for your personal time, for participating to this research. Participating as CS represents an estimate of 8 to 10 hours, spread over the year 2019. This includes 30' training for the use of the app for capturing photos and comments (Neighbourhood Discovery Tool), three one-hour meetings, and one to three hours of data collection, and the participation to the focus group with the practitioners. All the modules are optional, and the participants choose which meetings they want to participate to, and how many walks using the Neighbourhood Discovery Tool they wish to make.

What opportunity do I have to consider this invitation?

If you are happy to participate in this research, please let me know your decision by the 15 January 2020.

Will I receive feedback on the results of this research?

Yes, you will receive a summary of the findings unless you indicate in the Consent Form that you do not wish to receive them.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor Erica Hinckson: Erica.hinckson@aut.ac.nz, +64 9 921 9999 ext 7224.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , +64 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Tamara Bozovic, AUT City Campus, Auckland, E-mail: rfq8954@aut.ac.nz, Ph: 021 212 35 03

Project Supervisor Contact Details:

Professor Erica Hinckson: Erica.hinckson@aut.ac.nz, +64 9 921 9999 ext 7224.

Approved by the Auckland University of Technology Ethics Committee on 12 December 2018, AUTEC Reference number 18/431.

Consent Form for Citizen Scientists

Project title:	***Quality of the walking environment and difficulties to access local destinations***
Project Supervisor:	***Professor Erica Hinckson***
Researcher:	***Tamara Bozovic***

○ I have read and understood the information provided about this research project in the Information Sheet dated 10.11.18.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that the Citizen Science process involves (a) meetings during which notes will be taken and audio-tapes recorded; (b) field surveys during which I will be able to capture insights of my usual trips; (c) a focus group with street design practitioners

○ I understand that I will be free to choose to which part(s) I wish to participate.

○ I understand that the field survey relates to trips in my usual environment, walked together with another participant or the researcher, where I will choose the route and destinations while respecting the road code. I understand that I am not asked to do anything that puts me in danger regarding traffic or other sources.

○ I understand that I can appear in the list of people participating to the focus group either with my real name or with a pseudonym. I understand that nothing I say will be attributed to me, and that everything that is said will be transcribed in an anonymised way (e.g.: "Resident"). I agree to respect this, and not disclose who has said what.

○ I accept to be identified by my real name in the participants' list (please tick one):
Yes ○ No: identify me as User choosing to remain anonymous, age … ○

○ I understand that notes will be taken during the focus group and that it will also be audio-taped and transcribed.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

……………………………………………………………………………………..

……………………………………………………………………………………..

……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 12 December 2018, AUTEC Reference number 18/431.

Note: The Participant should retain a copy of this form.

REFERENCES

1. Fancello, G., Congiu, T., & Tsoukiàs, A. (2020). Mapping walkability. A subjective value theory approach. *Socio-Economic Planning Sciences*, *72*. https://doi.org/10.1016/j.seps.2020.100923
2. Nakamura, K. (2020). Experimental analysis of walkability evaluation using virtual reality application. *Environment and Planning B: Urban Analytics and City Science*, 2399808320980747. https://doi.org/10.1177/2399808320980747
3. TRA. (2018, May). Measuring and growing active modes of transport in Auckland. Auckland Transport. Retrieved from https://at.govt.nz/media/1977266/tra_at_activemodes_publicrelease-1.pdf
4. Forsyth, A. (2015). What is a walkable place? The walkability debate in urban design. *URBAN DESIGN International*, *20*(4), 274–292. https://doi.org/10.1057/udi.2015.22
5. Guell, C., Panter, J., Jones, N. R., & Ogilvie, D. (2012). Towards a differentiated understanding of active travel behaviour: Using social theory to explore everyday commuting. *Social Science & Medicine*, *75*(1), 233–239. https://doi.org/10.1016/j.socscimed.2012.01.038
6. Di, X., Liu, H. X., Zhu, S., & Levinson, D. M. (2017). Indifference bands for boundedly rational route switching. *Transportation*, *44*(5), 1169–1194. https://doi.org/10.1007/s11116-016-9699-1
7. Stradling, S., Anable, J., & Carreno, M. (2007). Performance, importance and user disgruntlement: A six-step method for measuring satisfaction with travel modes. *Transportation Research. Part A, Policy and Practice*, *41*(1), 98–106. https://doi.org/10.1016/j.tra.2006.05.013
8. Abley Transportation Engineers. (n.d.). Traffic Counts New Zealand Traffic Data - Abley. Retrieved March 27, 2020, from http://www.trafficcounts.co.nz/
9. Washington Group on Disability Statistics. (2017, October 23). The Washington Group Short Set on Functioning (WG-SS). Washington Group on Disability Statistics. Retrieved from http://www.washingtongroupdisability.com/

10. Ministry of Transport. (n.d.). New Zealand Household Travel Survey, 2015-16 Questionnaire. Retrieved October 7, 2018, from https://www.transport.govt.nz/assets/Uploads/Research/Documents/NZHTS-2015-16-Combined-Questionnaire-v4-9July2018.pdf

11. Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. SAGE Publications, Inc. Retrieved from https://au.sagepub.com/en-gb/oce/naturalistic-inquiry/book842

12. Barnett, D. W., Barnett, A., Nathan, A., Cauwenberg, J. V., & Cerin, E. (2017). Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 103. https://doi.org/10.1186/s12966-017-0558-z

13. Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D. W., & Barnett, A. (2017). The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition & Physical Activity*, *14*, 1–23. https://doi.org/10.1186/s12966-017-0471-5

14. Eisenberg, Y., Vanderbom, K. A., & Vasudevan, V. (2017). Does the built environment moderate the relationship between having a disability and lower levels of physical activity? A systematic review. *Preventive Medicine*, *95S*, S75–S84. https://doi.org/10.1016/j.ypmed.2016.07.019

15. McCormack, G. R., & Shiell, A. (2011). In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 125. https://doi.org/10.1186/1479-5868-8-125

16. Walk Score. (n.d.). WalkScore TM. *Walk Score*. Retrieved August 29, 2018, from https://www.walkscore.com/

17. Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). The development of a walkability index: application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine*, *44*(13), 924–933. https://doi.org/10.1136/bjsm.2009.058701

18. Orstad, S. L., McDonough, M. H., Stapleton, S., Altincekic, C., & Troped, P. J. (2017). A Systematic Review of Agreement Between Perceived and Objective Neighborhood Environment Measures and Associations With Physical Activity Outcomes. *Environment and Behavior*, *49*(8), 904–932.

https://doi.org/10.1177/0013916516670982

19. Moura, F., Cambra, P., & Gonçalves, A. B. (2017). Measuring walkability for distinct pedestrian groups with a participatory assessment method: A case study in Lisbon. *Landscape and Urban Planning*, *157*, 282–296. https://doi.org/10.1016/j.landurbplan.2016.07.002
20. Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association*, *76*(3), 265–294. https://doi.org/10.1080/01944361003766766
21. Grasser, G., Dyck, D. V., Titze, S., & Stronegger, W. (2013). Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review. *International Journal of Public Health*, *58*(4), 615–625. https://doi.org/10.1007/s00038-012-0435-0
22. Salvo, G., Lashewicz, B. M., Doyle-Baker, P. K., & McCormack, G. R. (2018). Neighbourhood Built Environment Influences on Physical Activity among Adults: A Systematized Review of Qualitative Evidence. *International Journal of Environmental Research and Public Health*, *15*(5). https://doi.org/10.3390/ijerph15050897
23. Vale, D. S., Saraiva, M., & Pereira, M. (2015). Active accessibility: A review of operational measures of walking and cycling accessibility. *Journal of Transport and Land Use*, *9*(1). https://doi.org/10.5198/jtlu.2015.593
24. Hasan, R., & Napiah, M. (2017). Utilization of footbridges: Influential factors and improvement proposals. *Advances in Transportation Studies*, *43*, 43–60. https://doi.org/10.4399/97888255077374
25. Edwards, N., & Dulai, J. (2018). Examining the relationships between walkability and physical activity among older persons: What about stairs? *BMC Public Health*, *18*(1). https://doi.org/10.1186/s12889-018-5945-0
26. Hutabarat Lo, R. (2009). Walkability: what is it? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, *2*(2). Retrieved from https://www.tandfonline.com/doi/abs/10.1080/17549170903092867
27. Bigonnesse, C., Mahmood, A., Chaudhury, H., Mortenson, W. B., Miller, W. C., & Ginis, K. A. M. (2018). The role of neighborhood physical environment on mobility and social participation among people using mobility assistive technology. *Disability & Society*, *33*(6), 866–893.

https://doi.org/10.1080/09687599.2018.1453783

28. Mindell, J. S. (2017). *Street Mobility Project Toolkit: Measuring the effects of busy roads on local people* (p. 53). London: UCL. Retrieved from http://discovery.ucl.ac.uk/1542993/1/Mindell_Street_Mobility_Project_Toolkit_updated.pdf
29. Jacobsen, P. L., Racioppi, F., & Rutter, H. (2009). Who owns the roads? How motorised traffic discourages walking and bicycling. *Injury Prevention (1353-8047)*, *15*(6), 369–373. https://doi.org/10.1136/ip.2009.022566
30. Sze, N. N., & Christensen, K. M. (2017). Access to urban transportation system for individuals with disabilities. *IATSS Research*, *41*(2), 66–73. https://doi.org/10.1016/j.iatssr.2017.05.002
31. Jacobs, J. (1961). *The Death and Life of Great American Cities*. Vintage Books.
32. Gehl, J. (2010). *Cities for People*. Washington DC: Island Press. Retrieved from https://www.goodreads.com/work/best_book/13424577-cities-for-people
33. Appleyard, D., & Lintell, M. (1972). The Environmental Quality of City Streets: The Residents' Viewpoint. *Journal of the American Institute of Planners*, *38*(2), 84–101. https://doi.org/10.1080/01944367208977410
34. Maurer Braun, L., & Reed, A. (2015). *Benefits of Street-Scale Features for Walking and Biking*. Retrieved from https://www.planning.org/nationalcenters/health/streetscale/
35. Haselwandter, E. M., Corcoran, M. P., Folta, S. C., Hyatt, R., Fenton, M., & Nelson, M. E. (2015). The Built Environment, Physical Activity, and Aging in the United States: A State of the Science Review. *Journal of Aging and Physical Activity*, *23*(2), 323–329. https://doi.org/10.1123/japa.2013-0151
36. Ashmead, D. H., Grantham, D. W., Maloff, E. S., Hornsby, B., Nakamura, T., Davis, T. J., … Rushing, E. G. (2012). Auditory perception of motor vehicle travel paths. *Human Factors*, *54*(3), 437–453. https://doi.org/10.1177/0018720811436083
37. Langlois, J. A., Keyl, P. M., Guralnik, J. M., Foley, D. J., Marottoli, R. A., & Wallace, R. B. (1997). Characteristics of older pedestrians who have difficulty crossing the street. *American Journal of Public Health*, *87*(3), 393–397. https://doi.org/10.2105/AJPH.87.3.393
38. Mindell, J. S., & Karlsen, S. (2012). Community Severance and Health: What Do We Actually Know? *Journal of Urban Health*, *89*(2), 232–246. https://doi.org/10.1007/s11524-011-9637-7

39. Kerr, J., Norman, G., Millstein, R., Adams, M. A., Morgan, C., Langer, R. D., & Allison, M. (2014). Neighborhood Environment and Physical Activity Among Older Women: Findings From the San Diego Cohort of the Women's Health Initiative. *Journal of Physical Activity & Health*, *11*(6), 1070–1077.

40. Kramer, D., Lakerveld, J., Stronks, K., & Kunst, A. E. (2017). Uncovering How Urban Regeneration Programs May Stimulate Leisure-time Walking Among Adults in Deprived Areas: A Realist Review. *International Journal of Health Services*, *47*(4), 703–724. https://doi.org/10.1177/0020731417722087

41. Carr, K., Weir, P. L., Azar, D., & Azar, N. R. (2013). Universal design: A step toward successful aging. *Journal of Aging Research*, *2013*. https://doi.org/10.1155/2013/324624

42. Bozovic, T., Stewart, T., Hinckson, E., & Smith, M. (2021). Clearing the path to transcend barriers to walking: Analysis of associations between perceptions and walking behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, *77*, 197–208. https://doi.org/10.1016/j.trf.2021.01.003

43. Daniels, R., & Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use*, *6*(2), 5–20. https://doi.org/10.5198/jtlu.v6i2.308

44. Walton, D., & Sunseri, S. (2007). *Impediments to walking as a mode choice* (Research Report No. 329) (p. 48). Land Transport New Zealand. Retrieved from https://www.nzta.govt.nz/resources/research/reports/329/index.html

45. Rafferty, A. P., McGee, H. B., Petersmarck, K. A., & Miller, C. E. (2004). Proportion of Trips Made by Walking: Estimating a State-Level Baseline for Healthy People 2010 Objective 22–14. *American Journal of Health Promotion*, *18*(5), 387–391. https://doi.org/10.4278/0890-1171-18.5.387

46. Badland, H. M. (2007, September 9). *Transport-related physical activity, health outcomes, and urban design: descriptive evidence* (Thesis). Auckland University of Technology. Retrieved from http://aut.researchgateway.ac.nz/handle/10292/350

47. Waka Kotahi NZ Transport Agency. (2009). *Pedestrian planning and design guide* (Guidance and guidelines) (p. 188). Wellington, Aotearoa New Zealand: NZ Transport Agency. Retrieved from

https://www.nzta.govt.nz/resources/pedestrian-planning-guide/

48. Auckland Transport. (n.d.). Average Daily Traffic Counts. *Auckland Transport Open GIS Data*. Database. Retrieved September 6, 2020, from https://data-atgis.opendata.arcgis.com/datasets/average-daily-traffic-counts

49. TomTom. (n.d.). Auckland traffic report. *TomTom Traffic Index*. Database. Retrieved September 6, 2020, from https://www.tomtom.com/en_gb/traffic-index/auckland-traffic/

50. Auckland Transport. (n.d.). Speed Limits. *Auckland Transport Open GIS Data*. Retrieved September 6, 2020, from https://data-atgis.opendata.arcgis.com/datasets/speed-limits

51. Auckland Council. (n.d.). Auckland Council GeoMaps. *GeoMaps Public*. Database. Retrieved September 6, 2020, from https://geomapspublic.aucklandcouncil.govt.nz/viewer/index.html

52. Heart of the City: Auckland's city centre business association. (n.d.). Pedestrian counts. Database. Retrieved October 13, 2020, from https://www.hotcity.co.nz/city-centre/results-and-statistics/pedestrian-counts

53. Richard Fanning, G. V. (n.d.). *Guide to Road Design Part 3: Geometric Design*. *ISBN: 978-1-922382-00-9*. Austroads. Retrieved from https://austroads.com.au/publications/road-design/agrd03

54. Applied Concepts, Inc. (2018). ATS II The STALKER Acceleration Testing System. Applied Concepts, Inc. Retrieved from https://stalkerradar.com/sportsradar/documents/006-0471-00_ATS_II_Brochure.pdf

55. Mayor of London, T. for L. (2017). *Healthy Streets for London, Prioritising walking, cycling and public transport to create a healthy city*. Transport for London. Retrieved from https://www.tfl.gov.uk/corporate/about-tfl/how-we-work/planning-for-the-future/healthy-streets

56. Gehl Studios. (n.d.). People Moving Count. Retrieved January 30, 2021, from https://gehlpeople.com/tools/people-moving-count/

57. Auckland Transport. (2020, February). Transport Design Manual (TDM) - Urban Street and Road Design Guide. Auckland Transport. Retrieved from https://at.govt.nz/about-us/manuals-guidelines/roads-and-streets-framework-and-the-transport-design-manual/

58. Auckland Transport. (2020). Engineering Design Code - Footpaths and the Public Realm. In *TDM Engineering Design Code* (p. 87). Auckland Transport. Retrieved from https://at.govt.nz/about-

us/manuals-guidelines/roads-and-streets-framework-and-the-transport-design-manual/

59. Auckland Transport. (2020). Engineering Design Code - Street Lighting. In *TDM Engineering Design Code* (p. 19). Auckland: Auckland Transport. Retrieved from https://at.govt.nz/media/1982229/engineering-design-code-street-lighting.pdf

60. *Australasian Pedestrian Crossing Facility Selection Tool*. (2020). Sydney: Austroads Ltd. Retrieved from https://austroads.com.au/network-operations/active-travel/pedestrian-facility-selection-tool

61. Auckland Transport. (n.d.). Controlled Intersections. *Auckland Transport Open GIS Data*. Retrieved October 2, 2020, from https://data-atgis.opendata.arcgis.com/

62. Auckland Transport. (n.d.). Auckland Transport Open GIS Data. Retrieved October 3, 2020, from https://data-atgis.opendata.arcgis.com/

63. Auckland Transport. (2020). *Roads and Streets Framework, version 2* (Guidance and guidelines) (p. 31). Auckland: Auckland Transport. Retrieved from https://at.govt.nz/about-us/transport-plans-strategies/roads-and-streets-framework/

64. Plowden, B. (2020). Creating healthy streets for sustainable cities – delivering public health benefits through redesigning London's streets. *Cities & Health*, *4*(2), 156–161. https://doi.org/10.1080/23748834.2019.1685852

65. Ede, J., & Morley, A. (2020). Review of transport for London's 'Healthy Streets Approach' and its potential contribution to biophilic cities. *Cities & Health*, *0*(0), 1–8. https://doi.org/10.1080/23748834.2019.1698937

66. Stangl, P. (2019). Overcoming flaws in permeability measures: modified route directness. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, *12*(1), 1–14. https://doi.org/10.1080/17549175.2017.1381143

67. Righi, A. W., & Saurin, T. A. (2015). Complex socio-technical systems: Characterization and management guidelines. *Applied Ergonomics*, *50*, 19–30. https://doi.org/10.1016/j.apergo.2015.02.003

PEER-REVIEWED JOURNAL PUBLICATIONS RELATED TO THIS THESIS

Bozovic, T., Stewart, T., Hinckson, E., & Smith, M. (2021). **Clearing the path to transcend barriers to walking: Analysis of associations between perceptions and walking behaviour**. Transportation Research Part F: Traffic Psychology and Behaviour, 77, 197–208. https://doi.org/10.1016/j.trf.2021.01.003

Bozovic, T., Hinckson, E., Stewart, T., & Smith, M. (2021). **How to improve the walking realm in a car-oriented city? (Dis)agreements between professionals**. Transportation Research Part F: Traffic Psychology and Behaviour, 81, 490–507. https://doi.org/10.1016/j.trf.2021.06.011

Bozovic, T., Hinckson, E., & Smith, M. (2020). **Why do people walk? Role of the built environment and state of development of a social model of walkability**. Travel Behaviour and Society, 20, 181–191. https://doi.org/10.1016/j.tbs.2020.03.010

Travel Behaviour and Society 20 (2020) 181–191

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Why do people walk? role of the built environment and state of development of a social model of walkability

T. Bozovic[a], E. Hinckson[a,*], M. Smith[b]

[a] Auckland University of Technology, New Zealand
[b] The University of Auckland, New Zealand

1. Introduction

Technological development is contributing to new forms of mobility (e.g. shared vehicles or scooters); its ease of use (information, payment); and possibilities to replace trips altogether (Lyons et al., 2018). While the concept "mobility as a service" (i.e. shift from privately owned vehicles to shared solutions that are consumed on a subscription base) is gaining traction, walking and walkable places appear to be high on the priority list of cities and citizens (Giles-Corti, 2017; Lowe et al., 2015; UN DESA, 2016; UN-HABITAT, 2014, 2016). The broad benefits of walking are well established, namely in terms of equity of access and independent mobility (Burdett, 2018; Gibson et al., 2012; NZIER, 2014; Rose et al., 2009); social and economic participation (Bigonnesse et al., 2018; Eisenberg et al., 2017; Fomiatti et al., 2014; Hoenig et al., 2003; Mindell, 2017); physical activity (Alidoust & Bosman, 2015; Annear et al., 2014; Eisenberg et al., 2017; Haselwandter et al., 2015; Webber et al., 2019); and urban economic efficiency (Davis & Golly, 2017; McCann, 2009). A modal shift towards walking and other low carbon modes is also a key part of the response to the global climate crisis and meeting sustainable development goals (C40 Cities, 2018; United Nations, 2015). In a rapidly urbanizing world (UN DESA, 2018), "walking as a choice" is therefore likely to be an increasingly important topic. The underlying question will be what to build, retrofit and provide, for diverse people to choose walking against alternatives?

Research on walking has made significant progress in understanding the dimensions influencing individual choices. The socio-ecological framework is widely accepted as a sound theoretical approach to human activity behaviours, capturing the importance of the Built Environment (BE) in conjunction with individual; social/cultural; organizational; community; and policy dimensions (Alfonzo, 2005; Forsyth, 2015; Sallis, 2009; Sallis et al., 2016). The framework provides an overall principle of multiple dependencies under which to develop a specific model for walking (Alfonzo, 2005; Sallis, 2009). Multiple calls for a better understanding of pathways through which BE correlates with walking behaviours have been made (Alfonzo, 2005; Badland, 2007; Forsyth, 2015; Franckx, 2017; Kerr et al., 2016; McCormack & Shiell, 2011).

There is at the moment no commonly agreed model explaining walking as a choice. As recently as 2016, Buckley and colleagues examined the question why people walk (Buckley et al., 2016) and in 2018, Read and colleagues studied two well-defined pedestrian situations (road crossing and railway level crossing), comparing walking as done by study participants and as imagined by transport practitioners. They noted that "a gulf exists between pedestrian activity 'as imagined' and 'as done'" (p. 82) and showed that the real pedestrian behaviour was both much more diverse and complex than anticipated by practitioners (Read et al., 2018).

The understanding of a "walkable" place remains debated (Forsyth, 2015; Kashef, 2011; Talen & Koschinsky, 2013). A variety of indices offer to measure environmental "walkability", using diverse sets of metrics (Adams et al., 2009; Frank et al., 2010; Gehrke & Transportation Research Board, 2012; WalkScore, 2018). Existing evidence generally focuses on able-bodied people, and there is a need to better understand the barriers experienced by people with lower levels of functioning due to specific impairments or old age (Bigonnesse et al., 2018; Eisenberg et al., 2017; Gray et al., 2012; Rimmer, 2017; Stafford & Baldwin, 2017). The notion of "walking" further fully encompasses wheelchair use, crutches and other mobility devices.

Cities with an inherited car-oriented BE seems to contribute to difficulties for habitual walking (Gehl, 2010, 2011; Jacobs, 1961; Speck, 2012). Retrofit and better design offer important potentials towards providing places that support human well-being and walking as a choice (Gehl, 2010; Gunn et al., 2017; Speck, 2012). However, certain confusion remains as to the best way to improve environments for walking, health and wellbeing.

It is not clear if a single definitive model linking walking to the built environment is a reasonable quest, given the evolution of the alternatives to walking (Lyons et al., 2018) or the simple fact that a "perfectly walkable" environment might not exist. However, better understanding the influences of BE on the choice of walking would help assess what is non-walkable, and aid specifying the *"minimal definition of physical walkability"* (Forsyth, 2015).

* Corresponding author at: Auckland University of Technology, Faculty of Health and Environmental Sciences, School of Sport and Recreation, Auckland 92006, New Zealand.

E-mail address: Erica.hinckson@aut.ac.nz (E. Hinckson).

https://doi.org/10.1016/j.tbs.2020.03.010
Received 5 May 2019; Received in revised form 9 February 2020; Accepted 24 March 2020
Available online 12 April 2020

The main objectives of this paper are to (1) examine how the BE has been conceptually related to walking behaviours; (2) examine how the posited models are supported by evidence; and (3) present a new version of a social model of walkability based on the findings. The framework linking BE to walking has been named Social Model of Walkability, terminology loosely referring to the Social Model of Disability (Oliver, 2013).

In addressing the four main objectives the following questions were asked:

1. How is the notion of "walkability" understood, and what are the elements of consensus / disagreement? Are theoretical models linking BE features to walking behaviour identified?

2. Which correlations between specific BE features and walking behaviour have been examined, and what are the results?

3. How are the BE features measured, and to what extent are they comparable across studies?

4. How does the available evidence inform the possible cofounding factors of impairments, old age, or self-selection?

Given the volume of research produced in the last decade, stemming from different fields and the scope of the questions, conduct a critical umbrella review otherwise known a review of reviews. This format is useful for compiling findings relative to broad questions into one usable document (Grant & Booth, 2009). This approach was complemented by examining more specifically the theoretical models identified in the reviews, as well as empirical studies citing those models considered to be particularly relevant. This critical umbrella review (Grant & Booth, 2009) focuses on (1) adults, with the aim of better understanding the choice of walking and suggesting a model; (2) and post-industrialised urban environments.

The paper is structured as follows: the method and methodology of the review are described. Then research findings are presented and discussed, in relation to each of the four questions. Finally, the research findings are summarised in the Conclusion section.

2. Materials and methods

2.1. Search strategy

Scopus and Science Direct databases were chosen for this critical Umbrella review because they offered a large coverage of the published literature across disciplines specifically related to the research question (Forsyth, 2015; Kashef, 2011) including health, urban design, sociology and transport planning. The search terms were:

(walkability AND built AND environment), and

(walking AND (choice OR neighbourhood OR neighborhood OR parameters OR determinants)).

We searched for literature reviews published in the 10 years up to 18.4.19.

2.2. Selection of reviews

Articles were first screened on titles and abstracts, before a full text review. The inclusion criteria were: (1) adult population, or results for adults; (2) urban or suburban environments, or mixed, with specific results; (3) provides correlations between BE aspects and walking, or examines critically the notion of walkability; (4) refers to environments that can be compared to post-industrialised car-dominated societies, defined as having a high or very high human development index (HDI); and having a car ownership over 200/1,000 residents.

2.3. Data extraction

Two types of data were extracted for each study:

a. Focus and scope, noting (1) what aspects of built environment were considered (destinations availability and/or quality of walking realm, objective and/or perceived); (2) if these aspects correlated to walking levels or experienced barriers and facilitators; (3) if disability, old age and self-selection were controlled for; (4) if a theoretical model was developed or tested; and (5) if walkability as a concept was examined. For detail please see Additional file A.
b. Reviews findings linking BE and walking, detailed in Additional file B.

It was expected that the volume of evidence for the correlations between BE and walking would be both low and difficult to compare across reviews, given namely (1) the absence of a commonly agreed set of indicators of walkability that are specific, comprehensive, and mutually exclusive; and (2) the diversity of measures of outcomes (walking distances, times, trips, etc.). After the full text review of the papers, it was decided to harness the strength and volume of evidence provided by the two recent *meta*-analyses sharing the same methodology (Barnett et al., 2017; Cerin et al., 2017) by keeping both their BE categories and their method for the synthesis of findings, i.e.: categorising BE-walking associations as significantly positive (P), significantly negative (N), or not statistically significant (Ø); allowing single articles to contribute several findings; and giving fractional weights in case of multiple associations found by a study for a same BE attribute (e.g. if one attribute is positively associated for walking in men but non-significant for women, it will be noted as P: 0.5, and Ø: 0.5). Where p values were provided, results significant at $p < 0.05$ were recorded. BE categories were assimilated to those of the *meta*-analyses unless they referred to a slightly different or more specific BE feature (for instance: the *meta*-analyses speak of "safety from traffic", while others speak of "safe and convenient crossings" (Salvo et al., 2018)). Categories were re-ordered under the broad topics of feasibility, safety from crime, accessibility, comfort and pleasure, posited by Alfonzo as levels of walkers' needs. The needs range from the most basic to the most sophisticated (Alfonzo, 2005). Statistically significant positive and negative correlations were noted, as well as non-significant findings ($p > 0.05$).

2.4. Data processing

Positive, negative, and non-significant (where reported) findings for each BE category were summed separately for overall walking and walking for transport. Ratios of positive, negative, and non-significant findings were calculated for all studies, as well as ratios of findings in unexpected directions.

3. Results and discussion

The search identified 194 titles. After screening of titles and abstracts, 54 reviews were retained for full review. Of these, 17 met the inclusion criteria. The screening and filtering process of the papers is presented in Fig. 1 below.

Of the identified 17 reviews, eight analysed the notion of walkability, and nine focused on the BE-walking correlates. From these, three were specific to urban or suburban environments, while six others (including the two recent *meta*-analyses) included also some rural contexts and did not differentiate the findings for both groups. Given the limited evidence identified specific to urban/suburban areas, it was decided to broaden the scope, keeping for analysis the reviews that were not exclusively urban. To limit the risk of bias, differences by type of setting were investigated and reported.

3.1. Question 1 – How is the notion of "walkability" understood?

The eight identified reviews provide essential and in-depth insights into the definitions and meanings of the term walkability (Hutabarat Lo, 2009) along with the concept of walkable suburbs (Kashef, 2011) and neighbourhoods (Talen & Koschinsky, 2013); the different dimensions of "walkability" (Forsyth, 2015); the understanding of barriers to

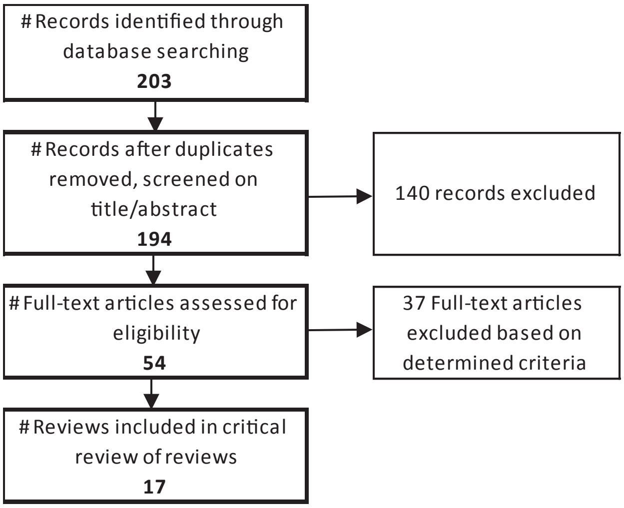


Fig. 1. . PRISMA diagram for article screening and inclusion process.

walking for diverse population groups (Mindell, 2017; Stafford & Baldwin, 2017); and a critical analysis of the professional practices (Andrews et al., 2012; Kashef, 2011) and operational measures of accessibility (Vale et al., 2015). The findings are synthetized below under four aspects: complexity, elements of consensus, dissensions, and contributions to a theoretical model.

3.1.1. Walkability as a complex phenomenon

Authors agree on complexity, noting that "overall, walkability is a complex and contested phenomenon" (Forsyth, 2015), or that *"the research landscape now crowded with competing claims about what the walkable neighborhood can be expected to do"* (Talen & Koschinsky, 2013). A vast array of potential benefits is described, ranging from enhancing social interaction and the sense of community (Kashef, 2011) to improving liveability and equity of access (Stafford & Baldwin, 2017) or supporting residents' daily activities (Talen & Koschinsky, 2013). Different professions such as urban design, health, or transport were also found to focus on different aspects of walkability such as the outcomes in terms of physical activity or the quality of design (Andrews et al., 2012; Forsyth, 2015). This is problematic when attempting to identify specific assets that should be built or improved, as diverse aspirations and focuses can contribute to the diversity of recommendations for delivering "walkability" (Forsyth, 2015).

Acknowledging this diversity of views, Talen and Koschinsky nonetheless had an attempt at defining the "walkable neighbourhood" as *"a safe, well-serviced neighborhood, imbued with qualities that make walking a positive experience*."(Talen & Koschinsky, 2013). Beyond a broader dissension on what a "neighbourhood" is and how it is defined (Andrews et al., 2012; Hwang, 2017; Loo et al., 2017; Stafford & Baldwin, 2017), a pertinent question is what does "positive experience" look like, and does this differ across ages, disabilities or other characteristics?

3.1.2. Elements of consensus

A general consensus was found on (1) destinations within a walkable distance (Hutabarat Lo, 2009; Kashef, 2011; Vale et al., 2015); (2) absence of barriers to access (Mindell, 2017; Stafford & Baldwin, 2017) and (3) a form of safety from crime and traffic (Forsyth, 2015; Hutabarat Lo, 2009; Talen & Koschinsky, 2013). These are in a way minimum requirements (Forsyth, 2015). Taking a holistic perspective, the reviews note (1) the importance of users' perceptions of difficulties or barriers for the choice of routes or the decisions to avoid walking altogether (Eisenberg et al., 2017; Mindell, 2017; Stafford & Baldwin, 2017); (2) the current high levels of difficulties of walking in car-oriented environments, with high traffic exposure and limited appropriate crossings (Hutabarat Lo, 2009; Mindell, 2017); and (3) inequities of access (Eisenberg et al., 2017; Hutabarat Lo, 2009; Stafford & Baldwin, 2017). These elements of consensus align with evidence regarding the barrier effect caused by traffic, identified since the 1960 s (Appleyard & Lintell, 1972; Jacobs, 1961).

People's decisions to walk and their determinants need to be better understood, for providing street environments supportive of walking and positive experiences. (Andrews et al., 2012; Eisenberg et al., 2017; Forsyth, 2015; Hutabarat Lo, 2009; Stafford & Baldwin, 2017).

3.1.3. Lack of consensus: Quality of the walking environment

Lack of consensus has been noted mainly around the quality of the walking realm and its importance for walking (Forsyth, 2015; Hutabarat Lo, 2009; Kashef, 2011). The users' perceptions are not clearly linked with objective parameters, and therefore often considered less legitimate than the objective measures (Andrews et al., 2012).

There is no one holistic and consensual model integrating the different components of walking, and no overview of what matters. Scales or tools assessing the quality of the BE are diverse (e.g. (Gehl, 2010; Mayor of London, 2017; Mindell, 2017; Pikora et al., 2002; Saelens et al., 2003)). While specific aspects of quality are usually positively associated with walking, there is no guarantee that those characteristics assumed to be important cover indeed all that matters to people in a non-redundant way (Forsyth, 2015). Studies tend to correlate assumed features from also assumed and arbitrary areas (e.g., 400 m from home) with levels of walking or physical activity. There is a lack of understanding of why these features matter, how much they matter (Vale et al., 2015), and how individual characteristics might moderate this importance (Eisenberg et al., 2017; Mindell & Karlsen, 2012; Stafford & Baldwin, 2017). Andrews and colleagues speak of 'neo-environmental determinism' (Andrews et al., 2012) to describe this vast array of assumptions. Major methodological issues are noted in ways walkability is assessed and measured. They are discussed under Question 3, below.

3.1.4. Identified contributions to a theoretical model of walkability

Forsyth outlined the work of Alfonzo as a major contribution to the understanding of the relationship between BE and walking (Alfonzo, 2005; Forsyth, 2015). Alfonzo posited a hierarchy of pedestrian needs, referring to Maslow's pyramid of human needs (Alfonzo, 2005). The posited needs range from the most basic (feasibility and accessibility) to a higher order (pleasure); safety and comfort are placed in between – (see (Alfonzo, 2005), p. 817–829).

Further, the model considers that objective BE characteristics are filtered by users' perceptions; perceptions inform the satisfaction of needs for walking; and the decision to walk depends on the satisfaction of needs but also on individual characteristics (Alfonzo, 2005). People first assess the satisfaction of most basic needs, before considering higher order ones. The perceptions of each of the needs moderate the outcome.

Alfonzo noted that the (non) satisfaction of the needs would probably be associated with walking behaviour but through the moderating effects of individual constraints, available options, trip purposes or preferences (Alfonzo, 2005). The model was further developed and tested by Mehta (Mehta, 2008), and more recently by Buckley and colleagues (Buckley et al., 2016). Their findings supported the framework and identified the additional contribution of individual motivations. The three approaches confirmed the relevance of the socio-ecological framework, the basic requirement of having destinations within reachable distance, and, the importance of the perceived safety, accessibility and pleasantness as facilitators or barriers. While these studies progressed the understanding of walking as a behaviour, they had several limitations: Mehta assessed main street environments only, and his results were possibly biased by (1) an unique type of environment; (2) a small sample; (3) a cohort including few older and no disabled adults; and (4) the lack of consideration of the trip purpose, or the availability and comparative advantage of transport options (Mehta, 2008). Buckley and colleagues examined 15 motivators that were not necessarily mutually exclusive or complete; interviewed people who did undertake the walk, with the risk of missing people who were unable to do so; and did not consider adults with impairments (Buckley et al., 2016). Buckley and colleagues concluded there was a need to expand this body of research and “to adequately address factors related to higher order needs that are often beyond the attention of pedestrian planning” (Buckley et al., 2016), p. 129. These works form however a theoretical backdrop to be further developed and informed through evidence. An important potential exists namely for qualitative research examining the decision pathways through users’ unique perspectives (Andrews et al., 2012).

3.2. Question 2 - which correlations between specific BE features and walking behaviour have been examined?

3.2.1. Identified reviews and scopes

Nine reviews examining the correlations between BE and walking were identified. Seven reported walking for all purposes (Barnett et al., 2017; Cerin et al., 2017; Eisenberg et al., 2017; Ewing & Cervero, 2010; Haselwandter et al., 2015; McCormack & Shiell, 2011; Salvo et al., 2018), three reported walking for transport (Ewing & Cervero, 2010; Grasser et al., 2013; McCormack & Shiell, 2011) and two for recreation (Ewing & Cervero, 2010; McCormack & Shiell, 2011). Two recent reviews (Barnett et al., 2017; Cerin et al., 2017) stand out for being *meta*-analyses with sophisticated methods for weighting articles by quality and sample size, a control for non-duplication of primary findings, and estimates of strengths of associations between each examined BE construct and walking. This effort is of high importance, given the difficulty to compare primary data as it shows a vast diversity in ways BE or walking as an outcome are operationalised (Cerin et al., 2017; Van Cauwenberg et al., 2011). Both reviews focused on older adults (defined as mean population age higher than 65 years) and examined how objective and self-reported measures of BE compared, as correlates to walking.

Overall, the identified reviews considered specific sets of BE attributes and operationalised them in different ways. None of the reviews claimed to have a set of attributes that was comprehensive, minimal, and non-redundant. They generally tested aspects identified by previous studies as being potentially correlated with walking, with the caveats that those studies themselves warned against potential bias, redundancy or gaps (e.g. Frank’s 3D walkability index (Frank et al., 2010)). The variety of scopes is summarized in Table 1 against the broad types of attributes and the ways they were measured.

The five reviews that examined both high level and qualitative attributes included the two *meta*-analyses focusing on older adults (Barnett et al., 2017; Cerin et al., 2017). The other three examined able-bodied adults (McCormack & Shiell, 2011; Salvo et al., 2018) and adults with disabilities (Eisenberg et al., 2017).

Table 1
Numbers of reviews considered split by the attributes and the type of measure they considered; the two *meta*-reviews are noted in bold.

Attributes considered Type of measure	Both high level (a) and street-scale (b)	High level (a) only	Street-scale (b) only	Total
Objective only	1	2	–	3
Perceived only	1	–	–	1
Objective or perceived	1	1	1	3
Objective and perceived	2	–	–	2
Total	5	3	1	9

Notes: (a): Neighbourhood or area-level aggregate measures such as land use mix, street connectivity or number of destinations; (b) Street-scale (micro-scale) attributes such as presence of street furniture or traffic volumes/speeds.

The overall poor quality of the primary studies is to be noted: for instance, only 9% of the 100 papers examined by Barnett and colleagues were considered “high quality” (Barnett et al., 2017). Both *meta*-analyses noted that two thirds of the papers could not demonstrate representativeness of the population, and that papers had diverse levels of adjustment for socio-economic characteristics or appropriateness of analytical methods. Findings are further difficult to compare directly across reviews, given (1) the differences of approaches (weighting of findings as done in the *meta*-analyses vs simple reporting of findings); (2) the widely diverse ways BE was operationalised (see above); and (3) the potential redundancies of primary data. The issue of quality had been previously outlined (Benton et al., 2016; Loo et al., 2017).

Built environment correlates with walking

The BE characteristics were classified using the Neighbourhood Environment Walking Scale (NEWS) (Adams et al., 2009) in the *meta*-analyses (Barnett et al., 2017; Cerin et al., 2017), while the other reviews used own categories and definitions. The results are here examined using the NEWS categories complemented with additional dimensions that were examined. It should be noted that the results are influenced by (1) a strong focus of the reviews on the domains of feasibility of walking trips and safety from crime, with less investigation into aspects relative to comfort and pleasure; (2) same primary data were sometimes included in more than one reviews.

Overall, strong support was found for the elements of trip feasibility and some of the elements of street environment quality. When different reviews examined the same BE aspect, their conclusions were sometimes a mix of statistically significant and non-significant findings. When examining constructs individually, the reported findings from the primary studies show generally large proportions of non-significant findings (for instance, “overall access to destinations” is noted as strongly and positively significant in both studies but respectively 77% and 54% of weighted primary inputs are non-significant). Counter-intuitive results were also found, such as negative influence of safety from crime and of residential density (Barnett et al., 2017), or positive influence of littering, vandalism and decay (Cerin et al., 2017).Some examined aspects are not part of the NEWS scale. They were: retail floor area ratio (Ewing & Cervero, 2010); presence of jobs (Ewing & Cervero, 2010; Grasser et al., 2013); connected pedestrian infrastructure as a better measure of connectivity than road centre lines (Ewing & Cervero, 2010; Salvo et al., 2018); presence of other people walking, different possible barriers to walking, adequate crossing facilities, and air pollution and noise pollution (Salvo et al., 2018). All were supported as correlates of walking without counter-intuitive primary findings but based on low numbers of primary studies. Importantly, many of the qualitative aspects that are associated with walking outcomes (e.g. accessibility, availability of green spaces, aesthetics) have also been associated with the broader quality of place and further outcomes in terms of health, social connectedness, or neighbourhood satisfaction (Carmona, 2019).

Overview results for total and transport walking are detailed in Table 2, while details are in Additional file B.

3.3. Question 3 – How are the BE features measured, and to what extent are they comparable across studies?

Major methodological issues are noted in ways walkability is assessed and measured. Three types were identified: the use of proxies, the assessment of BE quality, and the consideration of needs of disabled and older people. Firstly, elements such as connectivity index or residential density can be considered as proxies: while the direct causal link might be absent (i.e. someone might not choose to walk because there are 230 people per square hectare in their neighbourhood), correlations might be found with levels of walking because these proxies code for other aspects not considered, such as for instance availability of destinations or difficulty of driving (Talen & Koschinsky, 2013). Second, the quality of the walking environments is poorly assessed

Table 2
Associations BE- walking.

			Total walking (a)	Walking for transport (a)								
			Barnett et al 2017 (c, c)	Cerin et al 2017 (b, c)	Salvo et al 2018	Ewing, Cervero, 2010 (d)	Eisenberg et al 2017 (e)	Mccormack et al 2011 (f)	Haselwandter et al 2015	Ewing, Cervero, 2010 (d)	Grasser et al, 2013	Mccormack et al 2011 (f)
		3D - Destinations availability										
	!	Composite walkability index(?)	P	P	na	na	Ø	na	P	na	P	P
	!	Residential density/ urbanisation(?)	P	P	na	∅	Ø	na	na	na	P	P
		Land-use mix—destination diversity(?)	Ø	P	na	P	na	P	na	P	Ø	P
		Retail floor area ratio	na	na	0	P	0	0	0	P	na	na
Hierarchy level 1 - Feasibility		Street connectivity(?)	Ø	P	na	P	Ø	P	∅	na	P	na
		Connected pedestrian infrastructure(?)	na	na	P	P	na	na	na	P	na	P
		Overall access to destinations & services (distance, availability)(?)	P	P	na	na	P	P	na	na	na	N
		Access to public transport (distance to, availability)(?)	P	P	P	na	na	∅	na	na	na	na
		Parks/public open space (distance to, availability)(?)	P	P	P	na	na	∅	na	na	na	na
		Detail - distance to, availability of specific destinations(?)										
		Shops/commercial(?)	P	P	P	na	Ø	na	na	P	na	na
		Food outlets(?)	Ø	∅	na	na	na	na	na	na	na	na
		Education(?)	Ø	∅	na	na	na	na	na	na	na	na
		Health & aged care(?)	Ø	∅	na	na	na	na	na	na	na	na
		Recreational facilities(?)	P	∅	na	na	na	na	na	na	na	Ø
		Social recreational facilities(?)	P	P	na	na	na	∅	na	na	na	na
		Jobs(?)	na	na	na	P	na	∅	na	na	P	na
		Street environment										
Hierarchy level 2 -												
	!	Safety from crime(?)	P	∅	na	na	na	na	na	na	na	na
		Design - “eyes on the street”, active facades(?)	na	na	na	na	na	na	na	na	na	na
		Lighting(?) (! Could be also comfort)	na	∅	P	na	na	P	na	na	na	na
		Littering, vandalism, decay(?) (g)	na	N	N	na	na	na	na	na	na	na
		Presence of people seen as threatening(?)	na	∅	N	0	na	na	na	na	na	na
		Presence of other people walking(?)	na	na	P	na	na	na	na	na	na	na
		Presence of other people walking OR driving(?)	na	P	na	na	na	na	na	na	na	na
		Presence of police(?)	na	na	∅	na	na	na	na	na	na	na
Hierarchy level 3 - Accessibility	!	Barriers to walking(?)	na	na	0	0	na	na	0	na	na	na
		Barriers - incomplete walking infrastructure(?)	na	na	N	na	na	na	na	na	na	na
		Barriers - not sufficient crossing facilities(?)	na	na	N	na	na	na	na	na	na	na
		Barriers - footpaths design(?)	na	na	na	na	na	na	na	na	na	na

(continued on next page)

Table 2 (*continued*)

			Total walking (a)	Walking for transport (a)								
		Barriers - footpaths maintenance / cluttering(?)	na	na	N	na	na	na	na	na	na	na
		Detours, lack of convenience	na	na	na	na	na	na	na	na	na	na
Hierarchy level 4 - Comfort		Safety from traffic(?)	Ø	∅	na	na	na	∅	na	na	na	P
		Safe and convenient crossing facilities(?)	na	na	P	na	na	na	na	na	na	na
		Room for walking	na	na	na	na	na	na	na	na	na	na
		Possibility to sit	na	P	na	na	na	na	na	na	na	na
		Availability of public toilets	na	∅	na	na	na	na	na	na	na	na
		Protection from sun/rain/wind	na	na	na	na	na	na	na	na	na	na
		Low levels of noise	na	na	na	na	na	na	na	na	na	na
		Air pollution	na	na	N	na	na	na	na	na	na	na
		Noise	na	na	N	na	0	na	0	na	na	na
Hierarchy level 5 -Pleasurability		Greenery, landscaping, "aesthetically pleasing" scenery (?)	P	∅	P	na	na	na	na	na	na	Ø
		Attractive zones for sitting / public spaces(?)	na	na	na	na	na	P	na	na	na	na
		Liveliness, activation, diversity, complexity(?)	na	na	na	na	na	na	na	na	na	na
	!	"Walk-friendly infrastructure" or features(?)	P	P	na	na	Ø	∅	na	na	na	Ø
	!	Good design (e.g. human scale, right enclosure)	na	na	na	na	na	na	na	na	na	na

Notes

[a]Directions of associations after full adjustment for sample size and study quality; P = positive ($p < 0.05$), Ø = non-significant, N = negative ($p < 0.05$). Bold: 5 or more findings.

[b]Meta-analysis.

[c]Population: older adults (median age above 65).

[d]Urban or suburban only.

[e]Adults with disabilities.

[f]Urban only.

[g]Classified in "aesthetics", in Haselwandter et al.

!indicators not referring to a specific BE feature but rather a cluster of features; the associations with walking do not allow to assess the relative importance of specific features.

[(?)]Indicators reflecting the authors' categories; caution, authors' clustering and primary studies' ways of measuring components might vary, and some overlaps exist (e.g. "safe and convenient crossing facilities" is part of a broader "safety from traffic construct).

overall, often capturing only the presence/absence of assets assumed to be important and failing to build a picture of convenience or pleasantness (Andrews et al., 2012). Third, the needs of disabled people and older people are broadly overlooked, while it is known that these groups can be sensitive to specific environmental attributes such as for instance the presence of physical barriers (Stafford & Baldwin, 2017).

BE characteristics were reported under different "labels" by different reviews, making them difficult to compare. Specific BE attributes were often clustered under umbrella-terms – e.g. presence of graffiti, litter or abandoned buildings against the construct "safety" (Won et al., 2016). The heterogeneity in ways primary studies assessed similar constructs was also widely outlined: investigations based on objective and/or perceived measures, and the objective measurements themselves could vary (e.g. "connectivity" - sometimes also called "design" (Ewing & Cervero, 2010)- can relate to block sizes, intersection densities, or a ratio of four- or three-way intersections to all intersections, while the land use mix can be calculated as the entropy index, the - Herfindahl–Hirschman index or other measures such as the number of different land uses (Grasser et al., 2013)). The measures also relate to diverse perimeters, e.g. various distances from home, an administrative area, or else a perceived territory reachable within 10 or 20 min (Barnett et al., 2017; Cerin et al., 2017).

The analysis of objective versus perceived measures showed significant differences between the two constructs. Findings from Cerin et al. (Cerin et al., 2017) are summarised in Table 3. For the six overall significant correlations, only the residential density and the access to public transport were significantly correlated with both objective and perceived measures. For land use mix diversity and availability of parks, only the perceived measure was significant, and the objective measure was the only correlated with street connectivity.

Overall, a high level of "noise" was observed resulting of comparing results of associations between BE and walking. A possible explanation relates to primary findings, representing an extraordinarily vast number of possible combinations between BE constructs and walking measures. This complexity is illustrated in Fig. 2.

3.4. Question 4 –How does the available evidence inform the possible cofounding factors of impairments, old age, or self-selection?

Multiple types of moderators or cofounders of the BE-walking association were examined. Below, dimensions identified as potentially important (see above, discussion on walkability) have been assessed, namely: typology of residential area, age, impairments, trip purposes, driver status, and self-selection.

3.4.1. Typology of residential area

Cerin et al (Cerin et al., 2017) detailed one study that analysed possible moderating effects on walking and reported that for older adults living in urban or rural areas there were no significant associations between access to destinations/services; availability and accessibility of public transport; public toilets; benches/sitting facilities; safety from traffic and crime; pedestrian-friendly features; street lights; littering/vandalism/decay; pollution; and greenery and aesthetically pleasing scenery with total walking, The only significant difference related to the availability of shops, it was less important for those aged less than 75 years living in rural areas, in comparison with younger people and those living in urban areas 75 years living in rural areas, in comparison with younger people and those living in urban areas. In the examined studies, two focused on urban areas specifically (Ewing & Cervero, 2010; McCormack & Shiell, 2011), but the low numbers of primary findings reported and the fact that the other reviews mixed the results of both urban and rural realms did not enable conclusions to be drawn.

3.4.2. Age

The influence of age was noted against both the proximity to destinations and the quality of the environment (Haselwandter et al., 2015; Salvo et al., 2018). The proximity to destinations was noted as more important for older adults (Haselwandter et al., 2015; Salvo et al., 2018), especially when they don't drive or anticipate not being able to drive anymore. Distance related to the ability to participate in the life of the community(Salvo et al., 2018). Within cohorts with a median age above 65 years, those aged 75 and over were also more sensitive to the presence of nearby parks (Cerin et al., 2017). Overall, older adults also found safety from the traffic (Salvo et al., 2018), good footpath conditions (Haselwandter et al., 2015; Salvo et al., 2018), and possibilities to sit (Cerin et al., 2017; Haselwandter et al., 2015) more important than younger populations. However, those preferences might be influenced by a lower self-efficacy and/or frailty, and not be an exclusive outcome of age (Salvo et al., 2018).

3.4.3. Impairments

The quality of the built environment is critically important in the notion of disability itself: in the widely accepted Social Model of Disability, BE is seen as a determinant of a person's ability to function, alongside the person's impairments (Oliver, 2013). Disability thus

Table 3
Associations BE-walking from Cerin et al, 2017, detailed by type of measure, objective/perceived.

Expected direction of association (b)		Directions of associations (a) by type of measure		
		Objective or perceived, mix	Objective only	Perceived only
P	Residential density/urbanisation(?)	P	P	P
P	Land-use mix—destination diversity(?)	P	∅	P
P	Street connectivity(?)	P	P	∅
P	Access to public transport (distance to, availability)(?)	P	P	P
P	Parks/public open space (distance to, availability)(?)	P	∅	P
P	Safety from traffic(?)	∅	∅	∅
P	Greenery, landscaping, "aesthetically pleasing" scenery(?)	∅	∅	∅
P	"Walk-friendly infrastructure" or "pedestrian-friendly features"(?)	P	∅	∅

Notes
[a]Directions of associations after full adjustment for sample size and study quality; P = positive ($p < 0.05$), Ø = non-significant, N = negative ($p < 0.05$). Bold: 5 or more findings.
[b]Expected direction of association: P (positive) or N (negative).
[!]Indicators not referring to a specific BE feature but rather a cluster of features; the associations with walking do not allow to assess the relative importance of specific features.
[(?)]Indicators reflecting the authors' categories; caution, authors' clustering and primary studies' ways of measuring components might vary, and some overlaps exist (e.g. "safe and convenient crossing facilities" is part of a broader "safety from traffic construct).

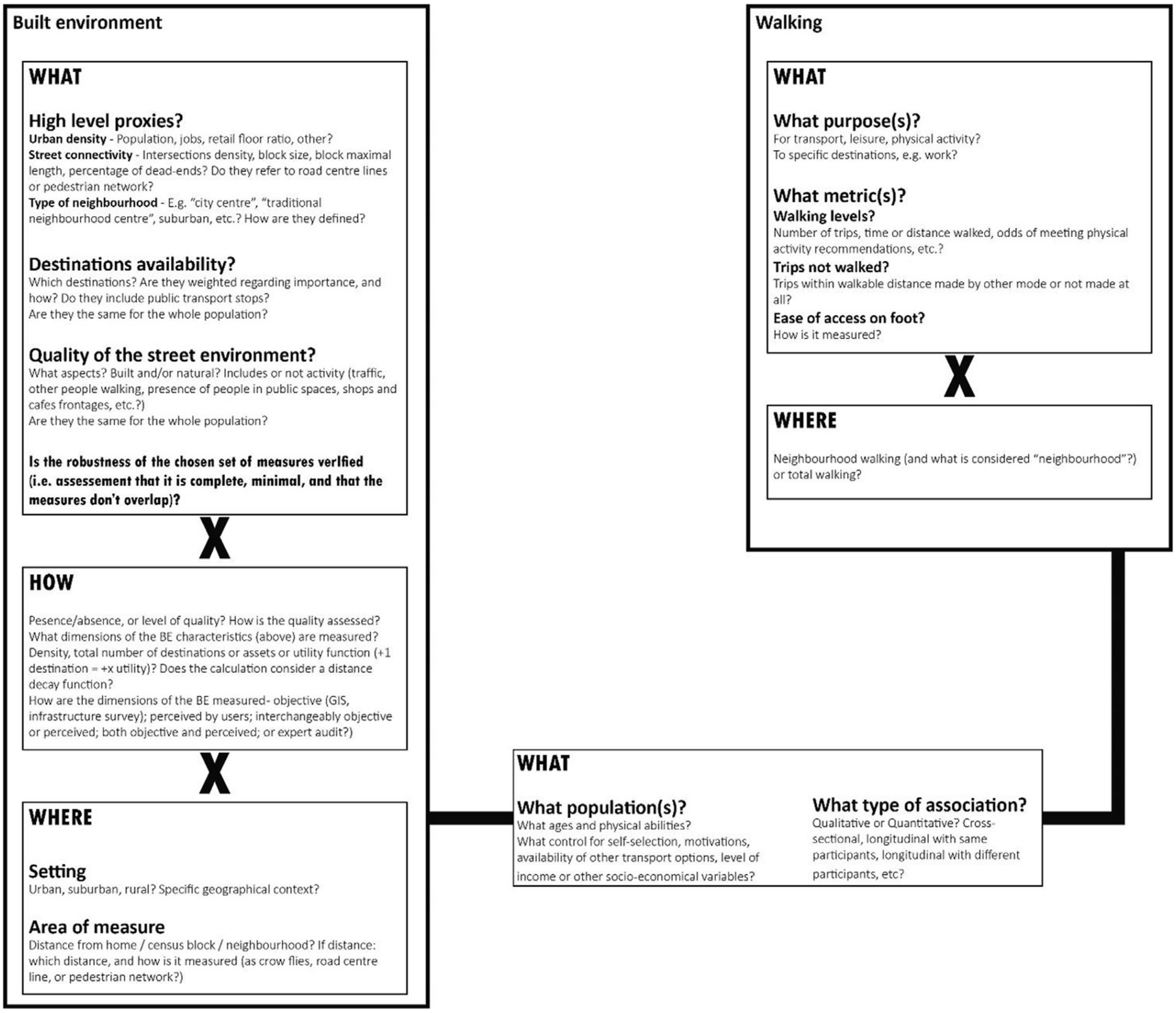


Fig. 2. . Complexity of the BE-walking behaviour correlations as informed by the evidence: diversity of measurement of BE characteristics and walking behaviours; multiplying the possible choices considered here, and considering that 5 options are possible for open questions such as "what destinations are considered", the indicative number of possibilities is nearly 800 billion.

relates to the interaction between a person and their environment. Eisenberg and colleagues studied adults with disabilities specifically, noting that (1) the presence of local destinations is an incentive to neighbourhood walking/wheeling; but (2) the quality of the built environment can discourage individuals from making the journey; and (3) the qualitative aspects that represent barriers to access are still not well understood (Eisenberg et al., 2017). It is however not clear how different types and levels of impairments influence the ease of access: there is a lack of data for disabilities other than ambulatory (Eisenberg et al., 2017); insufficient consideration of different forms of ambulatory impairments (Bigonnesse et al., 2018); and no agreed overview of potential barriers and their potencies (Alfonzo, 2005; Bigonnesse et al., 2018; Eisenberg et al., 2017; Wee & Lysaght, 2009).

3.4.4. *Trip purposes*

Trip purposes were globally poorly accounted for. Distinct associations between BE characteristics and different types of walking were however noted: (1) the availability of reachable destinations might be correlated with walking for transport but not recreation, in older adults (Hwang, 2017); and (2) the level of acceptance of barriers to walking might be higher for important trips – for instance, disabled people are likely to find strategies to achieve necessary trips, while the optional ones might be foregone (Eisenberg et al., 2017). When comparing proxies such as land use mix or street connectivity however, Ewing and Cervero found however little differences between associations with walking for transport or recreation (Ewing & Cervero, 2010). A study by Salbach and colleagues supports the importance of purpose on walking, for older adults, identifying that the distances could significantly vary (Salbach et al., 2014).

3.4.5. *Driver status*

Little evidence about the driver status or the availability of transport options (and their relative qualities to walking) has been found. The findings of one study on older adults (Ding et al., 2014) were reported (Cerin et al., 2017). While the proximity of destinations and public transport, and pedestrian-friendly features were important regardless the driver status, proximity of parks and street connectivity was more important for those who do drive.

3.4.6. *Neighbourhood Self-selection*

In 2010, Ewing and Cervero had noted that at least 38 studies had tried to control for self-selection as a moderating factor between BE and travel choice in general; the overall finding is that self-selection tended to attenuate the association, which typically remained statistically significative, also when examining walking specifically as an outcome (Ewing & Cervero, 2010). More recently, and examining walking in older adults, Cerin and colleagues found that self-selection was poorly controlled for (it had been done in only 4 of the 42 studies they identified) (Cerin et al., 2017).

3.4.7. Confounders, summary

In summary, individual characteristics were diversely and not systematically accounted for. It seems important to ensure a robust control of impairments, trip purposes, driver status or self-selection, characteristics that can moderate the relationship between the walking environment and walking behaviours. This idea had been supported by Gebel and colleagues in their recommendations for better quality systematic reviews in this field (Gebel et al., 2015).

3.4.8. Updated social model of walkability

Contributions to a theoretical framework linking BE to walking behaviours have been outlined under Question 1. Most findings from the reviews report associations between walking behaviour and BE (considering its objective and/or perceived characteristics). Some elements also helped better understand the decision pathways relative to walking. These are:

- Objective characteristics can contribute to perceptions of non-feasibility or poor safety, leading to journeys foregone or diverted routes (Eisenberg et al., 2017; Mindell & Karlsen, 2012; Salvo et al., 2018). These align with warnings against interchangeable use of objective and perceived aspects (Orstad et al., 2017) and support the sequence linking objective characteristics to users' perceptions and further their decisions.
- Trip purposes can moderate the relationship between perceived quality and decisions to walk: Eisenberg and colleagues report that adults with disabilities are likely to find ways to achieve a journey or forego it, depending on if it is seen as necessary or not (Eisenberg et al., 2017).
- Further, some evidence outlined individual characteristics as possible cofounding factors, namely age, availability of alternatives, impairments and self-selection. There is, however, a broad lack of evidence on how these characteristics moderate the BE-walking relationship.

The findings were used to propose an updated version of the framework originally developed by Alfonzo, Mehta, Buckley and colleagues. In Fig. 3, posited associations are noted in grey, while findings from this review of reviews have been added with black lines. A need to better understand users' decision pathways is identified.

4. Conclusion

A critical review of reviews has been realised to examine the current understanding of "walkability" as a concept and of Built Environment (BE) characteristics as determinants of walking behaviours. "Walkability" appears as a complex phenomenon, having various possible outcomes and components. Studies of "walkable places" examine different aspects of the BE and use diverse ways of measuring and assessing them, making it difficult to grasp the relative importance of different characteristics. Often, studies assume what characteristics matter ("neo-environmental determinism" (Andrews et al., 2012)), and test them against walking behaviours, without guarantee that the set of characteristics is comprehensive and non-redundant. This practice is problematic given that the street space of each city is finite and requires therefore a consensus on what needs to be adapted and how.

Overall, the analysis of the BE is skewed towards objective aspects, often high-level measures used as proxies (e.g. residential density). Quality is overall poorly assessed and valued, and some dimensions that have been known to be important for decades now routinely get missed (e.g. traffic volumes and speeds (Appleyard & Lintell, 1972; Jacobs, 1961); active facades, right level of enclosure and presence of other people walking (Gehl, 2010, 2011; Jacobs, 1961)). Findings from previous studies have often been inconclusive or inconsistent. An explanation could be that the approaches used are not methodologically sound (for instance, considering interchangeably objective and perceived aspects of BE, or considering some characteristics such as "littering" but leaving aside aspects that could counter-balance them, such as the presence of an active night life). Another difficulty is the comparing of results relating to diverse BE characteristics in diverse ways to diverse types and levels of walking. Due to the lack of a theoretical framework to be tested and measures that offer sufficient comparability and control for cofounders, causal links between the walking environment and walking behaviour are still not clear. Severance (i.e. inability to participate due to difficulties of access) is even less understood, because of a lack of evidence and of the difficulty of capturing trips that could have been walked but were not. The inability to provide clear outputs regarding walkability represents a key issue if research is to

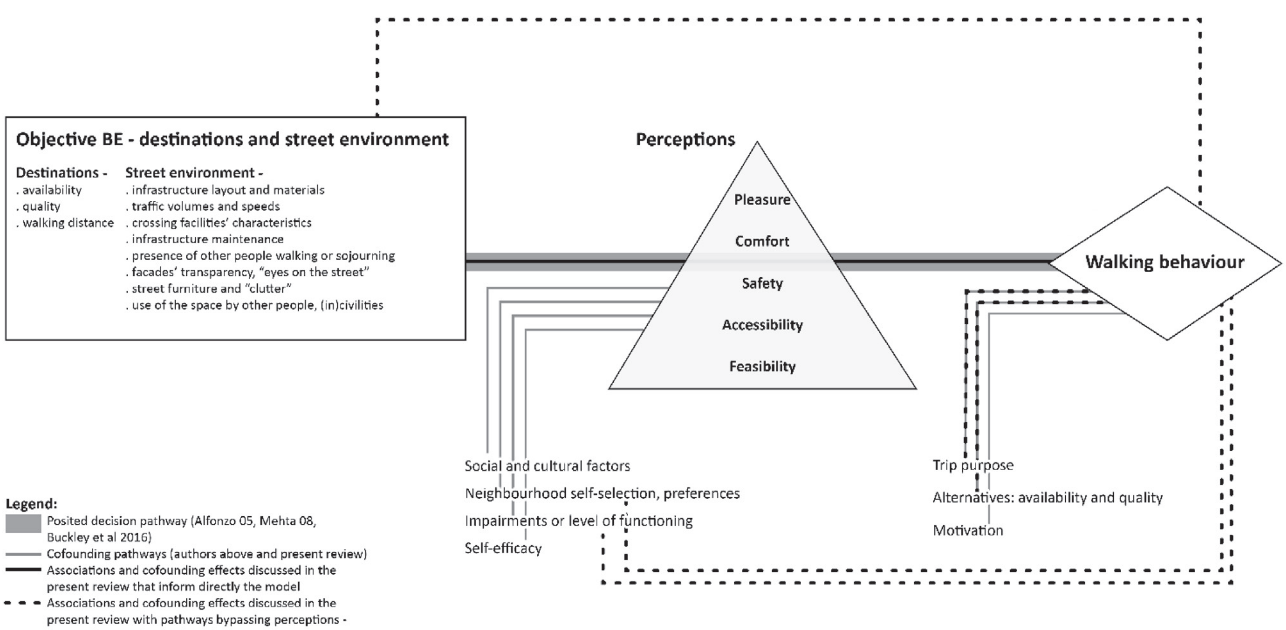


Fig. 3. . Draft "Social Model of Walkability", developed from the works of Alfonzo (2005), Mehta (2008), Buckley and colleagues (2016).

support cities providing environments supportive of walking as a choice, for all populations, regardless of their age, level of income or physical ability. However, the identified associations between BE quality and walking and broader outcomes such as health and participation, strengthen the case for better understanding how the walking environment can support or deter walking as a behaviour and choice.

The main strength of this paper is that it presents an overview of the understanding and conceptualisation of walkability, basing on a systematic review of reviews and bridging across various disciplines. A robust stocktake on this question is particularly important now, given the importance of urban retrofit supportive of walking as a mode of transport and further public health, liveability and lower environmental impacts.

This paper has also limitations. Firstly, as per nature of the umbrella review, it relies on the pre-existence of narrower component reviews (Grant & Booth, 2009). However, this aspect can also bring an interesting insight regarding needs for targeted component reviews. Second, the quality of the papers has not been formally assessed, although limitations encountered have been described above. Lastly, the analysis is constrained by the mentioned limitations. Again, this aspect can provide a useful stocktake of the body of component reviews, echoing recommendations for an improved practice such as outlined by Gebel and colleagues (Gebel et al., 2015).

The present investigation pointed towards the urgent need of a systemic approach to walking, as suggested in the socio-ecological model. The roles of built environment, social context, individual characteristics, motivations and needs should therefore be considered together in relation to walking behaviours. For that, the theoretical model outlined by Alfonzo, Mehta, Buckley and colleagues appears as a sound platform to be informed through findings and further developed. The model has been informed through the identified evidence and named Social Model of Walkability. However, an overall lack of established causal relationships is noted. Understanding users' needs and expectations will be a core element of investigation, and participatory methods are recommended as a way forward, as previously recommended by Andrews and colleagues, amongst others (Andrews et al., 2012). This approach would reflect practices that have been developed and employed by the consumer market with great success, in the last decades (Sen & Kenyon, 2012; Stradling et al., 2007).

Funding and conflicts of interest

The authors declare no specific funding and no conflicts of interest. MS is supported by a Health Research Council of New Zealand and a Sir Charles Hercus Health Research Council of New Zealand Research Fellowship (grant number 17/013). TB is supported by the Auckland University of Technology Doctoral Scholarship.

CRediT authorship contribution statement

T. Bozovic: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - original draft. **E. Hinckson:** Conceptualization, Methodology, Supervision, Validation, Writing - review & editing. **M. Smith:** Conceptualization, Methodology, Supervision, Validation, 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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2020.03.010.

References

Adams, M.A., Ryan, S., Kerr, J., Sallis, J.F., Patrick, K., Frank, L.D., Norman, G.J., 2009. Validation of the neighborhood environment walkability scale (NEWS) items using geographic information systems. J. Phys. Activity Health 6 (s1), S113–S123. https://doi.org/10.1123/jpah.6.s1.s113.

Alfonzo, M.A., 2005. To walk or not to walk? the hierarchy of walking needs. Environ. Behav. 37 (6), 808–836. https://doi.org/10.1177/0013916504274016.

Alidoust, S., Bosman, C., 2015. Planning for an ageing population: Links between social health, neighbourhood environment and the elderly. Australian Planner 52 (3), 177–186.

Andrews, G.J., Hall, E., Evans, B., Colls, R., 2012. Moving beyond walkability: On the potential of health geography. Soc. Sci. Med. 75 (11), 1925–1932. https://doi.org/10.1016/j.socscimed.2012.08.013.

Annear, M., Keeling, S., Wilkinson, T., Cushman, G., Gidlow, B., Hopkins, H., 2014. Environmental influences on healthy and active ageing: A systematic review. Ageing & Society 34 (4), 590–622. https://doi.org/10.1017/S0144686X1200116X.

Appleyard, D., Lintell, M., 1972. The environmental quality of city streets: the residents' viewpoint. J. Am. Inst. Planners 38 (2), 84–101. https://doi.org/10.1080/01944367208977410.

Badland, H. M. (2007). Transport-related physical activity, health outcomes, and urban design: Descriptive evidence [Thesis, Auckland University of Technology]. http://aut.researchgateway.ac.nz/handle/10292/350.

Barnett, D.W., Barnett, A., Nathan, A., Cauwenberg, J.V., Cerin, E., 2017. Built environmental correlates of older adults' total physical activity and walking: A systematic review and meta-analysis. Int. J. Behav. Nutrition Phys. Activity 14 (1), 103. https://doi.org/10.1186/s12966-017-0558-z.

Benton, J.S., Anderson, J., Hunter, R.F., French, D.P., 2016. The effect of changing the built environment on physical activity: A quantitative review of the risk of bias in natural experiments. The International Journal of Behavioral Nutrition and Physical Activity 13 (1), 107. https://doi.org/10.1186/s12966-016-0433-3.

Bigonnesse, C., Mahmood, A., Chaudhury, H., Mortenson, W.B., Miller, W.C., Ginis, K.A.M., 2018. The role of neighborhood physical environment on mobility and social participation among people using mobility assistive technology. Disability & Society 33 (6), 866–893. https://doi.org/10.1080/09687599.2018.1453783.

Buckley, P., Stangl, P., & Guinn, J. (2016). Why people walk: Modeling foundational and higher order needs based on latent structure. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10(2). https://www-tandfonline-com.ezproxy.aut.ac.nz/doi/abs/10.1080/17549175.2016.1223738.

Burdett, B. (2018). Transport, participation and wellbeing: Evidence and recommendations (No. 12513917). https://www.waikatoregion.govt.nz/services/publications/technical-reports/2018-technical-reports/tr201818/.

C40 Cities. (2018). Summary for Urban Policymakers: What the IPCC Special Report on Global Warming of 1.5°C means for Cities. C40 Cities. https://www.c40.org/researches/summary-for-urban-policymakers-what-the-ipcc-special-report-on-global-warming-of-1-5-c-means-for-cities.

Carmona, M., 2019. Place value: Place quality and its impact on health, social, economic and environmental outcomes. J. Urban Design 24 (1), 1–48. https://doi.org/10.1080/13574809.2018.1472523.

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D.W., Barnett, A., 2017. The neighbourhood physical environment and active travel in older adults: A systematic review and meta-analysis. Int. J.Behavioral Nutrition Phys. Activity 14, 1–23, ccm. https://doi.org/10.1186/s12966-017-0471-5.

Davis, D., Golly, T., 2017. The Business Case for Walking—Counting Walking to Make Walking Count in Auckland, New Zealand (breakout presentation). J. Transport Health 7, S53–S54. https://doi.org/10.1016/j.jth.2017.11.088.

Ding, D., Sallis, J.F., Norman, G.J., Frank, L.D., Saelens, B.E., Kerr, J., Conway, T.L., Cain, K., Hovell, M.F., Hofstetter, C.R., King, A.C., 2014. Neighborhood environment and physical activity among older adults: Do the relationships differ by driving status? J. Aging Phys. Activity 22 (3), 421–431. https://doi.org/10.1123/japa.2012-0332.

Eisenberg, Y., Vanderbom, K.A., Vasudevan, V., 2017. Does the built environment moderate the relationship between having a disability and lower levels of physical activity? A systematic review. Prev. Med. 95S, S75–S84. https://doi.org/10.1016/j.ypmed.2016.07.019.

Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Planning Assoc. 76 (3), 265–294. https://doi.org/10.1080/01944361003766766.

Fomiatti, R., Moir, L., Richmond, J., Millsteed, J., 2014. The experience of being a motorised mobility scooter user. Disability and Rehabilitation: Assistive Technology 9 (3), 183–187. https://doi.org/10.3109/17483107.2013.814171.

Forsyth, A., 2015. What is a walkable place? The walkability debate in urban design. URBAN DESIGN International 20 (4), 274–292. https://doi.org/10.1057/udi.2015.22.

Franckx, L. (2017, July 28). Status quo bias and travel behaviour – MIND-sets Knowledge Center. MIND-Sets Knowledge Centre. https://mobilitybehaviour.eu/2017/07/28/status-quo-bias-and-travel-behaviour/.

Frank, L.D., Sallis, J.F., Saelens, B.E., Leary, L., Cain, K., Conway, T.L., Hess, P.M., 2010. The development of a walkability index: Application to the Neighborhood Quality of Life Study. Br. J. Sports Med. 44 (13), 924–933. https://doi.org/10.1136/bjsm.2009.058701.

Gebel, K., Ding, D., Foster, C., Bauman, A.E., Sallis, J.F., 2015. Improving Current Practice in Reviews of the Built Environment and Physical Activity. Sports Medicine 45 (3), 297–302. https://doi.org/10.1007/s40279-014-0273-8.

Gehl, J., 2010. Cities for People. Island Press. https://www.goodreads.com/work/best_

book/13424577-cities-for-people.
Gehl, J., 2011. Life Between Buildings. Island Press. https://islandpress.org/book/life-between-buildings.
Gehrke, S. R., & Transportation Research Board, 2012. A Review of Walkability Measures and the Proposal of a Standardized Classification. Scheme 01366195, 15p.
Gibson, B.E., Secker, B., Rolfe, D., Wagner, F., Parke, B., Mistry, B., 2012. Disability and dignity-enabling home environments. Soc. Sci. Med. 74 (2), 211–219. https://doi.org/10.1016/j.socscimed.2011.10.006.
Giles-Corti, B., 2017. October 12). What makes a city more liveable? Policy. Forum.
Grant, M.J., Booth, A., 2009. A typology of reviews: An analysis of 14 review types and associated methodologies. Health Information and Libraries Journal 26 (2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x.
Grasser, G., Dyck, D.V., Titze, S., Stronegger, W., 2013. Objectively measured walkability and active transport and weight-related outcomes in adults: A systematic review. Int. J. Public Health 58 (4), 615–625. https://doi.org/10.1007/s00038-012-0435-0.
Gray, J.A., Zimmerman, J.L., Rimmer, J.H., 2012. Built environment instruments for walkability, bikeability, and recreation: Disability and universal design relevant? Disability and Health Journal, 5(2), 87–101. Scopus. https://doi.org/10.1016/j.dhjo.2011.12.002.
Gunn, L.D., Mavoa, S., Boulangé, C., Hooper, P., Kavanagh, A., Giles-Corti, B., 2017. Designing healthy communities: Creating evidence on metrics for built environment features associated with walkable neighbourhood activity centres. Int. J. Behavioral Nutrition .Phys. Activity 14, 164. https://doi.org/10.1186/s12966-017-0621-9.
Haselwandter, E.M., Corcoran, M.P., Folta, S.C., Hyatt, R., Fenton, M., Nelson, M.E., 2015. The built environment, physical activity, and aging in the United States: a state of the science review. J. Aging and Phys. Activity 23 (2), 323–329. https://doi.org/10.1123/japa.2013-0151.
Hoenig, H., Landerman, L.R., Shipp, K.M., George, L., 2003. Activity restriction among wheelchair users. J. Am. Geriatr. Soc. 51 (9), 1244–1251. https://doi.org/10.1046/j.1532-5415.2003.51408.x.
Hutabarat Lo, R. (2009). Walkability: What is it? Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 2(2). https://www.tandfonline.com/doi/abs/10.1080/17549170903092867.
Hwang, E., 2017. Impacts of objective neighborhood built environment on older adults' walking: Literature review. Housing and Society 44 (1–2), 141–155. https://doi.org/10.1080/08882746.2017.1384993.
Jacobs, J., 1961. The Death and Life of Great American Cities. Vintage Books.
Kashef, M. (2011). Walkability and residential suburbs: A multidisciplinary perspective. Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 4(1). https://doi-org.ezproxy.aut.ac.nz/10.1080/17549175.2011.559955.
Kerr, J., Emond, J.A., Badland, H., Reis, R., Sarmiento, O., Carlson, J., Sallis, J.F., Cerin, E., Cain, K., Conway, T., Schofield, G., Macfarlane, D.J., Christiansen, L.B., Van Dyck, D., Davey, R., Aguinaga-Ontoso, I., Salvo, D., Sugiyama, T., Owen, N., Natarajan, L., 2016. Perceived Neighborhood Environmental Attributes Associated with Walking and Cycling for Transport among Adult Residents of 17 Cities in 12 Countries: The IPEN Study. Environ. Health Perspect. 124 (3), 290–298. https://doi.org/10.1289/ehp.1409466.
Loo, B. P. Y., Lam, W. W. Y., Mahendran, R., & Katagiri, K. (2017). How Is the Neighborhood Environment Related to the Health of Seniors Living in Hong Kong, Singapore, and Tokyo? Some Insights for Promoting Aging in Place. Annals of the American Association of Geographers, 107(4), 812–828. sih.
Lowe, M., Whitzman, C., Badland, H., Davern, M., Aye, L., Hes, D., Butterworth, I., Giles-Corti, B., 2015. Planning Healthy, Liveable and Sustainable Cities: How Can Indicators Inform Policy? Urban Policy and Research 33 (2), 131–144. https://doi.org/10.1080/08111146.2014.1002606.
Lyons, G., Mokhtarian, P., Dijst, M., Böcker, L., 2018. The dynamics of urban metabolism in the face of digitalization and changing lifestyles: Understanding and influencing our cities. Resour. Conserv. Recycl. 132, 246–257. https://doi.org/10.1016/j.resconrec.2017.07.032.
Mayor of London, T. for L. (2017). Healthy Streets for London, Prioritising walking, cycling and public transport to create a healthy city. Transport for London. https://www.tfl.gov.uk/corporate/about-tfl/how-we-work/planning-for-the-future/healthy-streets.
McCann, P., 2009. Economic geography, globalisation and New Zealand's productivity paradox. New Zealand Economic Papers 43, 279–314. https://doi.org/10.1080/00779950903308794.
McCormack, G.R., Shiell, A., 2011. In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behavioral Nutr. Phys. Activity 8 (1), 125. https://doi.org/10.1186/1479-5868-8-125.
Mehta, V., 2008. Walkable streets: Pedestrian behavior, perceptions and attitudes. J. Urbanism: Int. Res. Placemaking and Urban Sustainability 1 (3), 217–245.
Mindell, J. S. (2017). Street Mobility Project Toolkit: Measuring the effects of busy roads on local people (p. 53). UCL. http://discovery.ucl.ac.uk/1542993/1/Mindell_Street_Mobility_Project_Toolkit_updated.pdf.
Mindell, J.S., Karlsen, S., 2012. Community severance and health: what do we actually know? J. Urban Health 89 (2), 232–246. https://doi.org/10.1007/s11524-011-9637-7.
NZIER. (2014). Big city life? Challenges and trade-offs for Auckland city. https://nzier.org.nz/publication/big-city-life-challenges-and-trade-offs-for-auckland-city-nzier-public-discussion-paper-201402.
Oliver, M., 2013. The social model of disability: thirty years on. Disability & Society 28 (7), 1024–1026. https://doi.org/10.1080/09687599.2013.818773.
Orstad, S.L., McDonough, M.H., Stapleton, S., Altincekic, C., Troped, P.J., 2017. A systematic review of agreement between perceived and objective neighborhood environment measures and associations with physical activity outcomes. Environ. Behavior 49 (8), 904–932. https://doi.org/10.1177/0013916516670982.
Pikora, T.J., Bull, F.C.L., Jamrozik, K., Knuiman, M., Giles-Corti, B., Donovan, R.J., 2002. Developing a reliable audit instrument to measure the physical environment for physical activity. Am. J. Prev. Med. 23 (3), 187–194.
Read, G.J.M., Stevens, E.L., Lenné, M.G., Stanton, N.A., Walker, G.H., Salmon, P.M., 2018. Walking the talk: Comparing pedestrian "activity as imagined" with "activity as done". Accident; Analysis and Prevention 113, 74–84. https://doi.org/10.1016/j.aap.2018.01.016.
Rimmer, J.H., 2017. Equity in active living for people with disabilities: Less talk and more action. Prev. Med. 95, S154–S156. https://doi.org/10.1016/j.ypmed.2016.12.037.
Rose, E., Witten, K., & McCreanor, T. (2009). Transport related social exclusion in New Zealand: Evidence and challenges. Kotuitui: New Zealand Journal of Social Sciences Online, 4(3), 191–203. https://doi.org/10.1080/1177083X.2009.9522454.
Saelens, B.E., Sallis, J.F., Black, J.B., Chen, D., 2003. Neighborhood-Based Differences in Physical Activity: An Environment Scale Evaluation. Am. J. Public Health 93 (9), 1552–1558. https://doi.org/10.2105/AJPH.93.9.1552.
Salbach, N.M., O'Brien, K., Brooks, D., Irvin, E., Martino, R., Takhar, P., Chan, S., Howe, J.-A., 2014. Speed and Distance Requirements for Community Ambulation: A Systematic Review. Arch. Phys. Med. Rehabil. 95 (1), 117–128.e11. https://doi.org/10.1016/j.apmr.2013.06.017.
Sallis, J. F. (2009). Measuring Physical Activity Environments: A Brief History. American Journal of Preventive Medicine, 36(4, Supplement), S86–S92. https://doi.org/10.1016/j.amepre.2009.01.002.
Sallis, J.F., Bull, F., Burdett, R., Frank, L.D., Griffiths, P., Giles-Corti, B., Stevenson, M., 2016. Use of science to guide city planning policy and practice: How to achieve healthy and sustainable future cities. The Lancet 388 (10062), 2936–2947. https://doi.org/10.1016/S0140-6736(16)30068-X.
Salvo, G., Lashewicz, B.M., Doyle-Baker, P.K., McCormack, G.R., 2018. Neighbourhood Built Environment Influences on Physical Activity among Adults: A Systematized Review of Qualitative Evidence. Int. J. Environ. Res. Public Health 15 (5). https://doi.org/10.3390/ijerph15050897.
Sen, K., Kenyon, G., 2012. A model for assessing consumer perceptions of quality. Int. J. Quality .Service Sciences 4 (2), 175–188. https://doi.org/10.1108/17566691211232909.
Speck, J. (2012). Walkable City: How Downtown Can Save America, One Step at a Time (Reprint). North Point Press.
Stafford, L., Baldwin, C., 2017. Planning walkable neighborhoods: are we overlooking diversity in abilities and Ages? J. Planning Literature. https://doi.org/10.1177/0885412217704649.
Stradling, S., Anable, J., Carreno, M., 2007. Performance, importance and user disgruntlement: a six-step method for measuring satisfaction with travel modes. Transp. Res. Part A, Policy Practice 41 (1), 98–106. https://doi.org/10.1016/j.tra.2006.05.013.
Talen, E., & Koschinsky, J. (2013). The Walkable Neighborhood: A Literature Review. International Journal of Sustainable Land Use and Urban Planning, 1(1). https://doi.org/10.24102/ijslup.v1i1.211.
UN DESA. (2016). Good Practices of Accessible Urban Development. https://www.un.org/development/desa/dspd/2016/10/good-practices-of-accessible-urban-development/.
UN DESA. (2018). 2018 Revision of World Urbanization Prospects | Multimedia Library—United Nations Department of Economic and Social Affairs. https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html.
UN-HABITAT. (2014). 7th World Urban Forum Medellín Declaration. https://unhabitat.org/7th-world-urban-forum-medellin-declaration/.
UN-HABITAT. (2016). Cities 2030, Cities for All: Implementing the New Urban Agenda. United Nations. http://wuf9.org/theme/.
United Nations. (2015, September 25). Cities—United Nations Sustainable Development Action 2015. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/cities/.
Vale, D.S., Saraiva, M., Pereira, M., 2015. Active accessibility: A review of operational measures of walking and cycling accessibility. Journal of Transport and Land Use 9 (1). https://doi.org/10.5198/jtlu.2015.593.
Van Cauwenberg, J., De Bourdeaudhuij, I., De Meester, F., Van Dyck, D., Salmon, J., Clarys, P., Deforche, B., 2011. Relationship between the physical environment and physical activity in older adults: A systematic review. Health & Place 17 (2), 458–469. https://doi.org/10.1016/j.healthplace.2010.11.010.
Walk Score. (n.d.). WalkScore TM. Walk Score. Retrieved August 29, 2018, from https://www.walkscore.com/.
Webber, S.C., Ripat, J.D., Pachu, N.S., Strachan, S.M., 2019. Exploring physical activity and sedentary behaviour: Perspectives of individuals with osteoarthritis and knee arthroplasty. Disability And. Rehabilitation 1–8, cmedm. https://doi.org/10.1080/09638288.2018.1543463.
Wee, J., Lysaght, R., 2009. Factors affecting measures of activities and participation in persons with mobility impairment. Disabil. Rehabil. 31 (20), 1633–1642. https://doi.org/10.1080/09638280902736346.
Won, J., Lee, C., Forjuoh, S.N., Ory, M.G., 2016. Neighborhood safety factors associated with older adults' health-related outcomes: A systematic literature review. Soc. Sci. Med. 165, 177–186.

Transportation Research Part F 77 (2021) 197–208

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Clearing the path to transcend barriers to walking: Analysis of associations between perceptions and walking behaviour

T. Bozovic [a,*], T. Stewart [a], E. Hinckson [a], M. Smith [b]

[a] Auckland University of Technology, Faculty of Health and Environmental Sciences, Auckland 92006, New Zealand
[b] School of Nursing, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

ARTICLE INFO

Article history:
Received 30 September 2020
Received in revised form 19 December 2020
Accepted 2 January 2021

Keywords:
Walking
Barriers
Perceptions
Car-dominated environment
Motivations
Walkability
Active travel

ABSTRACT

Walkability is much studied, but the relative importance of perceptions and motivations is still not consensual. This study took a holistic approach to examine the comparative importance of a range of possible perceptions, motivations and individual characteristics on walking levels.

Data from Auckland Transport's Active Modes online survey (AT survey, N = 4,114) captured environmental perceptions and travel behaviour. Machine learning (gradient boosting) was used to predict walking levels from perceptual data and individual characteristics and determine the relative importance of each variable. Strong predictors of walking included the use of public transport, walking perceived as saving money and avoiding parking hassle, age group, and overall satisfaction with walking. Surprisingly, the importance of expected dimensions such as perceived availability of destinations or internal motivations was null in the general model.

These findings suggest a more holistic view of walking behaviour is needed, one that moves beyond the pure availability of destinations.

1. Introduction

In response to major threats such as climate change, exclusion, or sedentary lifestyle-related illnesses, cities are increasingly focused on liveability, health, or equality of access (C40 Cities, 2018; Glazener & Khreis, 2019; UN-HABITAT, 2014, 2016; World Health Organization, n.d.). Everyday walking is gaining traction globally as a policy goal (Auckland Council, 2018b; Giles-Corti, 2017; Lowe et al., 2015; UN Desa, 2016; UN-HABITAT, 2014, 2016), given its contributions to equity of access (Burdett, 2018; Gibson et al., 2012; NZIER, 2014; Rose, Witten, & McCreanor, 2009), participation (Bigonnesse et al., 2018; Eisenberg, Vanderbom, & Vasudevan, 2017; Fomiatti, Moir, Richmond, & Millsteed, 2014; Hoenig, Landerman, Shipp, & George, 2003; Mindell, 2017), physical activity (Alidoust & Bosman, 2015; Annear et al., 2014; Badland, 2007; Eisenberg et al., 2017; Haselwandter et al., 2015; Webber, Ripat, Pachu, & Strachan, 2019), urban economic efficiency (Davis & Golly, 2017; McCann, 2009), and lower greenhouse gas emissions (C40 Cities, 2018; United Nations, 2015). The potential of retrofit and better urban design for encouraging and enabling walking are now well understood (Gehl, 2010; Gunn et al., 2017; Macmillan et al., 2020; Speck, 2012). The question authorities around the world battle with is *how* to improve urban environments to make the biggest difference, bearing in mind pragmatics such as economic and time constraints (Burdett, 2018; The Landscape Architecture Foundation (LAF), 2016; UN-HABITAT, 2016).

* Corresponding author.
E-mail address: tamara.bozovic@aut.ac.nz (T. Bozovic).

https://doi.org/10.1016/j.trf.2021.01.003
1369-8478/

Walkability research has made important progress in understanding walking behaviour and barriers to walking. It is now widely accepted that walking is simultaneously influenced by the urban environment (UE) – encompassing buildings, greenery, and traffic, but also by individual, organisational or community factors (socio-ecological framework) (Alfonzo, 2005; Forsyth, 2015; Sallis et al., 2016; Sallis, 2009). There is, however, no consensus on the *relative* importance of diverse UE characteristics on walking (Alfonzo, 2005; Badland, 2007; Forsyth, 2015; Franckx, 2017; Kerr et al., 2016; McCormack & Shiell, 2011). Promising theoretical developments have been made and some testing has been done (Alfonzo, 2005; Buckley, Stangl, & Guinn, 2016; Mehta, 2008). While it is unclear if a unique and robust model for understanding walking behaviour exists, it is important to also understand what is *not* walkable and might shift people to use another mode or avoid trips within walking distance (Alfonzo, 2005; Buckley et al., 2016; Forsyth, 2015).

A recent systematic umbrella review examined the development of the conceptual framework linking the built environment and walking behaviours (Bozovic, Hinckson, & Smith, 2020). Briefly, the Social Model of Walkability posits that the relationship between the UE and an individual's walking behaviour is moderated conjointly by (1) people's perceptions of their environment (namely their perceptions of the satisfaction of their walking needs: how feasible, accessible, safe, comfortable or pleasant a trip is); (2) individual characteristics (e.g. disability[1], constraints, preferences or available alternatives); (3) trip purpose, and (4) internal motivations. The review concluded that little attention has been given to environmental perceptions in both research and in the modernist approaches to urban design and transport planning.

This study builds on the findings of the realised umbrella review (Bozovic et al., 2020), exploring the associations between perceptions, individual characteristics and walking behaviour. This exploration considers Tamaki Makaurau-Auckland, Aotearoa-New Zealand, a city of 1.66 million residents (2018) (Auckland Council, 2018a). Auckland's transport infrastructure and low density are comparable to those of other car-oriented cities (Nunns, 2014).

Auckland Transport is the agency charged with urban transport planning and operations. Data from Auckland Transport's Active Modes online survey (AT survey) were used. The AT survey aims to understand behaviours, attitudes and perceptions of different modes of travel, over time (TRA, 2017), capturing perceptions of the walking environments, as well as a vast array of possible motivators and deterrents, and travel behaviour.

The aim of this study is to compare the importance of (1) perceptions of the walking environments and namely those perceptions relative to the satisfaction of the walking needs; (2) public transport use; and (3) individual characteristics in the prediction of walking levels. The individual variables used as inputs all relate conceptually to walking, however the novelty of the present approach is to consider them simultaneously against the walking behaviour. The assumption is that all three aspects play a role in predicting walking levels, the focus being on their relative importance.

2. Methodology

2.1. Setting and data

Auckland's development has had a strong focus on traffic infrastructure and urban sprawl (Auckland Council, 2018b; Gehl Architects, 2010). Jan Gehl saw a fantastic location and natural environments but described the city as "a rush hour 'traffic machine'", referring to a car-centric design (Gehl Architects, 2010). The car-centric design contributes to the high rates of pedestrian deaths and serious injuries (Howard, 2018), social isolation (Rose et al., 2009), reduced affordability for the end users of transport systems and the communities (Mattingly & Morrissey, 2014; B. McCann et al., 2000), loss of economic productivity (Davis & Golly, 2017; McCann, 2009), difficulties of access and low walking levels (Auckland Council, 1999, 2018b; Auckland Council Strategic Advice Unit, 2018). Adults walk about 450 m (6 min) on average per day for transport (Ministry of Transport, 2017) and 17% of trip legs are done on foot (NZ Ministry of Transport, 2015), versus for instance 25–28% of all trips for the cities of London (Mayor of London & Transport for London, 2019), Vancouver (City of Vancouver, 2017) or Vienna (City of Vienna, 2015). Walking is often perceived as complicated or stressful (Ministry of Transport, Transport Knowledge Hub, n.d.; TRA, 2016). For non-disabled people, identified deterrents include environments that people perceive as unpleasant (e.g. car-dominated environments) (Bean, Kearns, & Collins, 2008; Gehl Architects, 2010), or dangerous regarding traffic and crime (Auckland Council, 2016b; Bean et al., 2008; Houghton, Nettleship, & Johnstone, 2017; Ministry of Transport & Auckland Council, 2018). For the disabled people, evidence indicates acute barriers to access (Auckland Disability Research Group, 2009), similarly to the situation across New Zealand (Brennan, 2016; Human Rights Commission, 2005; NZ Transport Agency, 2018).

The systemic issues experienced in Auckland are similar to those experienced in other post-industrialised cities (Fry, 2017; Gehl, 2011; Jacobs, 1961; Miller et al., 1966; The Landscape Architecture Foundation (LAF), 2016). However, potentials exist, as a quarter of car trips are shorter than 1 km (Ministry of Transport, 2017), and walking is perceived as an important activity (Bean et al., 2008). Like many other cities in the global North, Auckland aspires to safer streets and a shift in people's preferences towards walking and public transport (Auckland Council, 1999, 2016a, 2018b; Healthy Auckland Together, 2017; Ministry of Transport & Auckland Council, 2018). Auckland therefore constitutes an interesting environment for studying how to improve conditions for walking in car-dominated environments.

[1] For the ease of reading, the notion of "walking" further fully encompasses wheelchair use, crutches and other mobility devices.

The Auckland Transport's Active Modes online survey (AT survey) survey is conducted on an annual basis. The complete survey methods are provided elsewhere (TRA, 2018). Briefly, participants are contacted by an independent organisation through email invitations. Representativeness is sought by age, gender, and neighbourhood of residence.

In this study, data collected between 2016 and 2018 (inclusive, N = 4,114) were examined. The authorisation to analyse the data was received from Auckland Transport, provided aggregate results were presented. Table 1 shows the characteristics of the dataset relative to the total Auckland population.

2.2. Survey questions

The 2018 survey included 28 questions on cycling and 16 on walking. Questions of specific interest for this study include: (1) walking behaviour – number of trips for transport in the previous week, walked or done by other modes, by purpose; (2) attitudes to walking and overall satisfaction; (3) perceptions of the walking environment: perceived safety and agreement/disagreement with 14 possible deterrents to walking; (4) internal motivations for walking (potential motivations presented with options to agree or disagree); as well as individual characteristics. A subsample of survey questions is presented in Table 2. The ten survey questions that were examined in relation to the points above are presented in Supplementary file A, and a few examples are presented below for illustration.

Most variables were dichotomous (yes/no), while for some, participants were asked to give a rating between 0 and 10 (for instance, for the question B14, about the perceived safety, 0 corresponds to "Not at all safe" and 10 to "Extremely safe"). The ten considered survey questions correspond to a total of 41 variables: for instance, the question Q10, "From the list below, what are the key reasons you choose to walk? Please select all that apply", offers 14 possible items, responded yes or no. Each item is considered as one variable. Two limitations should be noted: (1) "walking" doesn't include using a wheelchair; and (2) respondents with "any disability or impairment (affecting their ability to walk)" or those who don't walk at least monthly were not asked about walking/wheeling behaviour and barriers.

2.3. Data preparation and analysis

Prior to analysis, participants were excluded if they reported difficulties walking or declared walking 'never' or 'almost never', as these individuals were not asked questions about their perceptions of the environment or their motivations. An upper threshold of 30 trips walked was set, excluding 2.9% of observations (103 observations) which were likely data entry errors (for instance, one participant noted 486 trips walked in a week). Next, walking was dichotomised into "low" and "high" levels of walking by first splitting the data into tertiles and retaining the first and third tertiles. The first tertile corresponds to 0 trips walked in the previous week (n = 1343, 39% of the sample), while the third tertile corresponds to five or more walking trips in the previous week (n = 1223, 35%). This split was chosen to maximise the heterogeneity between groups: those who didn't walk, and those who walk on most days of the week. This meant that 3,456 of the initial 4,114 participants were included in the analysis.

First, pairwise associations among perceptions, motivations, individual characteristics, and walking behaviour were examined using a series of Chi-squared tests. All 41 candidate variables were examined after having been dichotomised (variables measured on a 1–10 Likert were dichotomised as either "poor" (below 4/10) or "high" (above 6/10). The middle values (4–6) were excluded to highlight differences between lower or higher characteristics.

Secondly, machine learning was used to predict "low" or "high" walking behaviour from the variables related to perceptions, motivations, and individual characteristics. Machine learning is seen as a promising tool to address the inherent complexity of walking, related namely to a multiplicity of dimensions and variables having associations with each other (Farrahi et al., 2020), but also to the uncertainty around their relative importance (Buckley et al., 2016; Forsyth, 2015).

Table 1
Overview of the survey population vs. total Auckland population.

Data category	N	N%	Total Auckland population
Participants (aged > 14 years)	4,114		1.26 m[a,b]
... with difficulties walking	398	9.7	13% (Statistics New Zealand, 2014)[c]
... aged > 18 years	3,996	97.1	95%[a,d]
... aged > 65 years	317	13	15%[a]
Number of trips made [e]	92,071		
... walked	23,814	26	
... driven	52,616	57	

[a] Census 2018, http://nzdotstat.stats.govt.nz.
[b] 0.33% of Auckland's 2018 population aged 15+.
[c] The NZ 2018 Census data on disability types and levels for Auckland are not available at this stage (July 2020). Data from the 2013 Disability survey are noted for reference.
[d] Auckland: proportion relative to the population aged above 15, for comparability with the survey data.
[e] Survey: trips made in the previous week; 3.2 trips per person per day. These cannot be directly compared with the total trips made in Auckland as the survey methods differ. The driving age limit is 16, therefore the 25 participants aged 15 were not drivers.

Table 2
Subsample of survey questions, for illustration (see supplementary file A for the full list).

Code	Question	Possible answers
S7_1	Do you have any disability or impairment that affects your ability to walk?	y/n
Q10	From the list below, what are the key reasons you choose to walk? Please select all that apply ■ There's no other way to get where I need to go ■ Keeps me fit / helps me get fitter ■ It's fun ■ Saves money ■ Saves time ■ More consistent travel time ■ Avoids parking hassles ■ Availability of paths / walking routes ■ Helps reduce traffic congestion ■ Helps address environmental concerns ■ Provides me with some 'me time' ■ Allows me to enjoy the weather ■ Better routes are available than previously ■ Other (please specify)	y/n for each possible motivator
B8	Which of the following statements best describes you when it comes to walking, and the amount of walking you do?	Please select one only I only walk if I have to I would like to walk less I am happy with the amount of walking I do I would like to walk more

From the 41 variables identified as conceptually related to our question, a subset of 33 were chosen to (1) avoid redundancy or replication of information (e.g. the number of trips walked and the declared frequency of walking were seen as redundant, and declared frequency was therefore removed), and (2) omit variables that had large numbers of missing values (e.g. question asked in only one edition of the survey). A gradient-boosting machine (GBM) algorithm was selected given its ability to identify patterns from a large array of variables, selecting those that are most relevant for improving prediction accuracy (Friedman, 2001). These characteristics set GBM apart from traditional methods such as logistic regression, generally incompatible with a high number of independent variables, particularly those with a high level of internal association (see results of pairwise associations below). A GBM consists of multiple decision trees which are fit sequentially, each one improving accuracy by explaining the error resulting from the previous tree (Friedman, 2001).

Prior to training the model, the observations were randomly assigned to a training set (80% of the data) for model development and a test set (20% of the data) for model evaluation. Using the training set, the optimal model hyperparameters were identified. Firstly, several tree depths (1 to 5) were evaluated using the area under the receiver operating characteristic curve (AUC) metric. A depth of 2 was selected as it maximised the AUC (0.80). To avoid overfitting the model, the number of iterations (i.e. the number of trees) was dictated by a stopping criterion, found using 20-fold cross-validation (Friedman, 2001; Singh, 2018). This method automatically selects the inflection point where performance on the validation data starts to decrease while performance on the training data continues to improve. The predictive accuracy of the optimal model was then evaluated by using the model to predict walking behaviour using the 20% of data reserved for testing.

The relative importance of each variable for predicting walking behaviour was also computed during the model training process. This metric is based on the reduction in error every time a given variable is included in a tree (Friedman, 2001), and is represented on a 0–100% scale, with all variables summing to 100%. A variable with a relative importance of 30% can be interpreted as accounting for 30% of the reduction in model error, given this set of variables. As the importance of all variables adds to 100, their relative influence can be established. Given the predominant observed importance of the use of public transport, the modelling process was then stratified by public transport use, with separate models trained for users (n = 822) and non-users (n = 1,744) of public transport. As a last step, we fit two further models stratified by the availability of alternative travel modes (i.e. those who answered "Yes" and "No" to the question "I walk because there is no other way for me to get around"). All analyses were performed using the R software (R Core Team, 2019) and the *gbm* package was used to fit the GBM models (Greenwell, 2019). To aid reproducibility, the analysis code is provided in the supplementary file B, while the results of the tree depth optimisation for all five models (all participants, users and non-users of public transport, availability and non-availability of walking alternatives) are presented in supplementary file C.

3. Results

3.1. Pairwise associations

Multiple pairwise associations were noted between perceptions, motivations, individual characteristics, and walking behaviour. Each of the 41 variables were significantly associated with 12–33 other variables. Walking levels and safety at night as a barrier were both associated with 33 other variables. The chi-squared test results are presented in the Table 3 below.

Table 3
Variables examined and number of variables associated at p < .05. Full questions: see supplementary file A.

Question	Variable examined - explanation	Number of variables associated, p<.05
Q2 Travel behaviour	Levels of walking: tertile 1 or 3	33
	Did use the car in the previous week (driver or passenger)	22
Q11 Key barriers to walking in Auckland; list of items with answers y/n	**Safety, night time**	33
	Too much stuff to carry	28
	Boring routes	28
	Safety, day time	27
	Hills	26
	Weather	26
	Live too far	24
	Doesn't know how long it would take	24
	Other reason	24
	Need transport others	22
	Walking adds too much time to the journey	22
	Walking is not quick	21
	Footpaths condition	21
	Walking is too much effort	20
Q10 Key reasons for choosing to walk; list of items with answers y/n	Save money	27
	Fitness	26
	No other choice	26
	To reduce traffic congestion	26
	Walking is “me time”	26
	Contributes to address environmental concerns	25
	Allows to enjoy the weather	26
	Travel time is more consistent, when walking	24
	Less parking hassle	24
	Better walking paths are now available	22
	Save time	22
	Fun	19
	Other	15
B15 Perceived safety in relation to traffic, crime, or tripping and falling, by night time	Traffic; rated "low" or "high"*	26
	Crime; rated "low" or "high"*	27
	Tripping/falling; rated "low" or "high"*	16
S2 Age	Age 65 and over, true/false	26
B14 Perceived safety in relation to traffic, crime, or tripping and falling, by day time	Traffic; rated "low" or "high"*	20
	Crime; rated "low" or "high"*	18
	Tripping/falling; rated "low" or "high"*	12
D1 Employment	Working, studying, house duties or retired, vs not employed currently	20
D4 Level of income	Income <50,000 $ per year before tax, y/n	17

* low: <4/10; high: >6/10

The identified multicollinearity confirmed the strategy of using machine learning for modelling walking as an outcome based on diverse perceptions. The results of the test for pairwise associations were not used to select variables to be held out. As noted above, a selection of variables to be used was however performed based on redundancy of information (e.g. number of trips walked and self-declared frequency of walking) and on availability of data (excluding variables that were in large part empty because related to questions that had not been asked at every edition of the survey). The variables used for analysis are reminded in supplementary file A.

3.2. Predicting walking behaviour

The best model for predicting walking behaviour was formed using 59 trees with a maximum tree depth of 2 (AUC = 0.80). When stratified by public transport use, the performance of the models decreased for both non-users of public transport (AUC = 0.69; tree depth = 2, n trees = 45), and users of public transport (AUC = 0.61; tree depth = 1, n trees = 51). For each of these three models, the relative importance of each variable for predicting walking behaviour is shown in Fig. 1.

3.2.1. All respondents

The use of public transport in the previous week was the most important variable with 44% of the total influence. 33% of participants who didn't use public transport walked 5 or more trips per week, as compared to 77% of public transport users. The other variables displaying high importance were motivation to walk because it saves money or avoids parking hassles (both 9%), age group the motivation to help reduce traffic (both 5%), motivation to walk because it saves time (4%), and overall satisfaction with the conditions for walking and perception of safety regarding traffic (both 3.5%). Although the importance of the motivation of protecting the environment was low (1%), it was observed that the volume of walking was

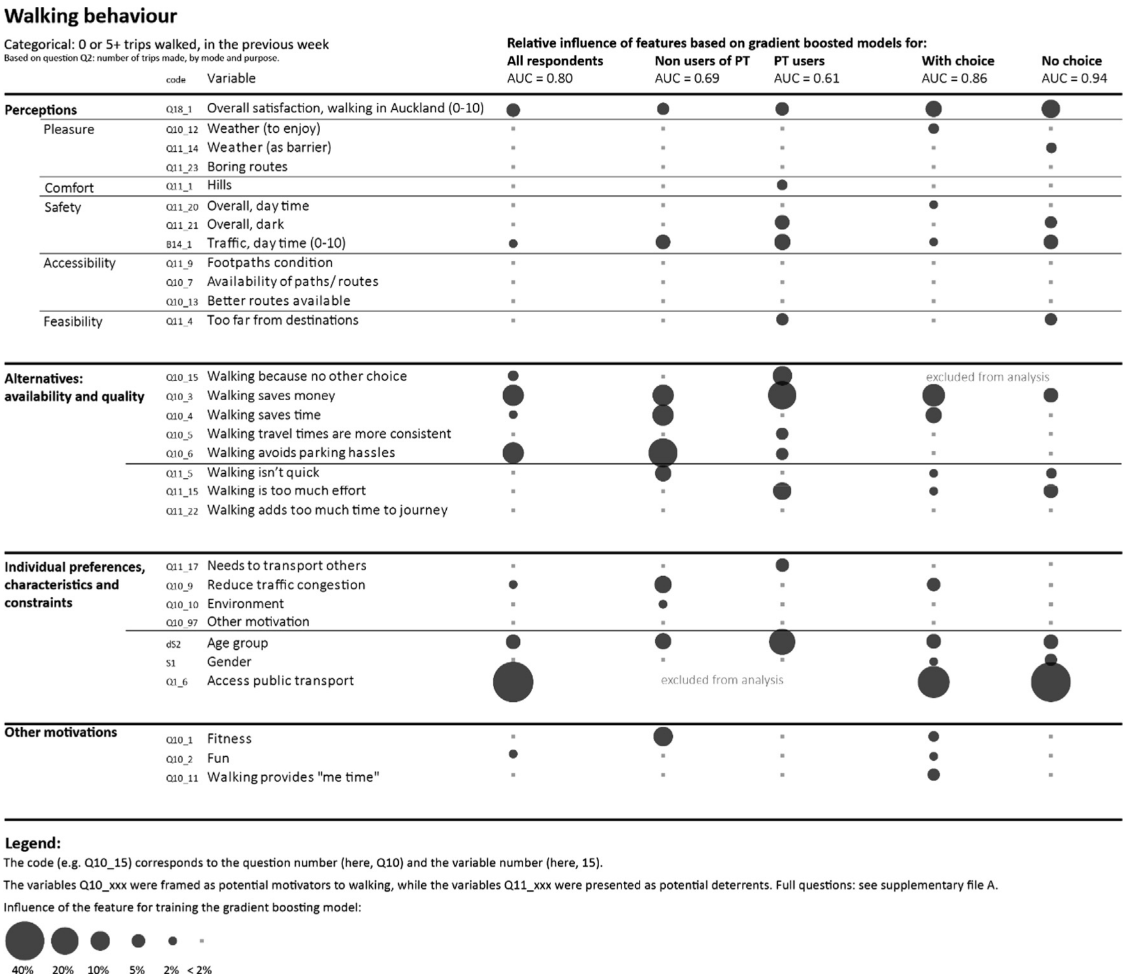


Fig. 1. Relative influences of features for the whole population and the specific models for: users / non-users of public transport, and those with / without alternative modes of transport available.

higher for those who care for the environment. The proportions of those motivated by the environment was higher for younger participants (17% of those aged 15–24, vs 9% for the 45–54-year olds). The importance of perceptions of the qualities of UE was below 2.5%.

3.2.2. Users and non-users of public transport

The relative importance of variables varied between users and non-users of public transport to each other, but also between both groups and the overall population. These variable importance measures must be interpreted with respect to each model's accuracy. As the AUC of these models was comparatively low, a high importance score doesn't necessarily mean that variable is a good predictor of walking behaviour. For the non-users of public transport, it can be implied that walking was compared to driving. Motivation regarding avoiding parking hassles had the highest comparative importance (22%), followed by saving money or saving time (both 12%), seeing walking as fun (10%), the perceived barrier of a less attractive travel time (7%) and the motivation to protect the environment (2%). For public transport users, motivation to walk because it saves money (21%), age group (18%), and lack of choice (10%) were the most important variables. Perceived barriers played a more important role in this group, namely too much effort (9%), safety by night (6%), the need to transport others (5%), or living too far for walking to be practical (4%).

3.2.3. Users with and without alternative travel mode options

A surprising finding was that although there were relatively few respondents declaring not having the choice (n = 337, 13% of the total sample), the model fitted for them had a high accuracy (AUC = 0.94). Some notable differences were observed between the models for respondents with and without choice: public transport use had a larger importance for those "without choice" (42% vs. 26%). Further, interesting differences are noted in the relative importance of variables, when comparing those with choice and those without: motivation of reducing congestion (5% vs 0%); saving money (14% vs 6%); living too far from destinations (1% vs 4%); fun, fitness and "me time" (2–4% vs 0%); or perceived safety at night time (0% vs 4%). The detailed results are presented in supplementary file D.

4. Discussion

The study assessed the relative importance of users' perceptions, motivations, and individual characteristics in relation to walking levels. Walking levels were predominantly explained by perceived qualities of walking within the transport system. Surprisingly, the importance of the perception of living too far for walking to be practical was marginal for predicting the walking levels (3.6% for PT users, 1% for non-users and 0.6% for the total population). We observed a multiplicity of associations with walking behaviour. This is consistent with recent research, showing for instance that individual characteristics are associated with both perceptions and travel behaviour (Ma & Cao, 2019). The number of relationships between perceptions is also consistent with the concept of walking environments as complex systems, with interactions between different components (e.g. traffic, carriageway width, and type of traffic controls are all related to difficulty crossing (Gehl, 2011; Speck, 2012)). Further, individual characteristics play a role given that certain features can be perceived diversely by different users (e.g. disabled or older people (Bigonnesse et al., 2018; Eisenberg et al., 2017; Mindell & Karlsen, 2012; Rosenberg, Huang, Simonovich, & Belza, 2013)).

The strongest association with walking behaviour was the use of public transport, which aligns with the growing awareness of the synergies between walking and public transport use (Hillnhütter, 2016; Hutabarat Lo, 2009; National Institute for Health and Care Excellence (NICE), 2018; Speck, 2012; Van Cauwenberg et al., 2018), the potential for better synergy in cities like Auckland (Bean et al., 2008) and the need to provide efficient integrated alternatives to driving. Delivering efficient travel solutions is also crucial for populations relying on public transport and accessible environments, such as disabled people (Brennan, 2016; Burdett, 2016; Human Rights Commission, 2005; C. Smith & Dixon, 2018). Disabled people were not included in this sample and understanding their barriers of access is a key research direction. People with temporary or permanent disabilities are likely to perceive and experience more barriers in their environment (Bigonnesse et al., 2018; Eisenberg et al., 2017; Kirchner, Gerber, & Smith, 2008; Rosenberg et al., 2013; M. Smith et al., n.d.; Stafford & Baldwin, 2017).

Developing separate models for users and non-users of public transport revealed differences regarding what matters for walking and how much. Non-users of public transport implicitly compare walking to driving, putting importance on variables such as parking hassles or traffic congestion. Interestingly, the users of public transport put a higher importance on saving money than the non-users of public transport. This could relate to a difference of sensitivity to paying a ticket now as opposed to incurring sunken costs of owning a car (Kahneman, 2012), but also to a difference of socio-economic status between the two groups.

Further, important differences were noted between those declaring having/not having alternatives to walking. Those who declare having the choice implicitly compared walking with driving (e.g. noting parking hassles or putting emphasis on fitness). For those without choice, walking behaviour was closely associated with the use of public transport, suggesting walking as a "first/last mile" solution and an alternative to public transport. In the model for those without the choice, to the importance of perceived barriers was higher than in other models, while the importance of fitness and well-being factors disappeared, suggesting trips foregone if public transport is not available and walking environment not supportive.

These considerations raise the question of equity: populations living in areas with lower quality of walking environments and a poorer public transport service (e.g. car-dominated sprawl) are at risk of being car-dependent or excluded, if they cannot drive or afford to own or run a car (Ciommo & Shiftan, 2017).

Saving money or avoiding parking hassles had considerable importance in the specific models, while environmental characteristics such as footpath quality and – surprisingly - the availability of destinations (i.e. declaring not having destinations within walkable distance) did not. This last element appears as a challenge to commonly used walkability assessment tools revolving around destinations and street connectivity (e.g. Walkscore™ (Walk Score, n.d.)).

Overall, the results suggest that walking is assessed in the light of the availability of alternatives, their comparable qualities and probably the familiarity with them. This is significant as it implies that the absolute qualities of the walking environment aren't sufficient to predict behaviour.

These findings align with past research. They support the outlined Social Model of Walkability (Alfonzo, 2005; Bozovic et al., 2020; Buckley et al., 2016; Mehta, 2008) and are consistent with the existing literature outlining the role of public transport (Hillnhütter, 2016; Koschinsky, Talen, Alfonzo, & Lee, 2017; Rosenberg et al., 2013; Speck, 2012; Van Cauwenberg et al., 2018) and other alternatives (Rafferty, Stanton, & Walker, 2013; Sen & Kenyon, 2012; Walton & Sunseri, 2007) in the assessment of walkability. However, these aspects are inconsistently considered in walkability assessments and are formally absent from "3D" models considering density, diversity of destinations, and street connectivity. It has previously been shown that the density of destinations can be a proxy for quality and pedestrian friendliness (Koschinsky et al., 2017). Indeed, higher densities are generally found in central areas, where public transport availability and walking amenity could also be higher. Taking the view that these high level indices can be correlated with quality, the results identified here also align with the large and growing body of evidence associating "3D" types of walkability indices with walking levels (e.g. (Barnett, Barnett, Nathan, Cauwenberg, & Cerin, 2017; Day, 2016; Hwang, 2017)). The results of the present study contribute to the understanding of walking behaviours by simultaneously examining a wide range of perceived quality in a car-dominated environment.

The significance of findings is threefold: (1) the Social Model of Walkability is supported in its claim that perceptions, motivations, and individual characteristics are key explanatory factors of walking (Alfonzo, 2005; Bozovic et al., 2020; Buckley et al., 2016; Mehta, 2008); (2) the low relative importance of the availability of destinations challenges commonly used methodologies such as WalkScore™ (Walk Score, n.d.) (based on the availability of destinations within a certain perimeter), at least in a car-dominated realm; and (3) the identified importance of a broader transport system (i.e. alternatives available and their qualities) prompts to develop the posited Social Model of Walkability, adding explicitly this dimension. This is at odds with common walkability models that put emphasis on the contributions of the walking environment and often ignore the "competition" of other modes (Alfonzo, 2005; Bozovic et al., 2020; Buckley et al., 2016; Mehta, 2008).

The finding prompted revisiting the Social Model of Walkability, proposing four important new changes:

1. **The wider transport system** is now explicitly included, within the objective environmental attributes;
2. **Two new levels are integrated in the hierarchy of needs: convenience and ethics** – convenience relates to the ease of use, and had already been identified in ITDP's recommendation for walkable cities (Institute for Transportation and Development Policy, 2018), while ethics regroups attributes such as "helps reduce traffic congestion" or "environment";
3. **Two new dimensions are added to the hierarchy of walking needs:** (1) the relative qualities of walking, as compared with the alternatives at hand, and (2) the qualities of walking in combination with another mode – typically public transport.
4. **The availability of other modes of transport** has been re-positioned between the transport system and the hierarchy of walking needs. This is linked to the two new dimensions added to the hierarchy: only if an alternative exists, walking might be compared with this mode (e.g. to walk or to drive?) or assessed in combination (e.g. walk + bus).

Arguably, the relative importance of different dimensions could vary in different contexts (e.g. car-dominated or not) and demographics. More research is needed to better understand the importance of individual characteristics, namely disability and constraints, as well as to clarify the role of motivations and habits, possibly influencing choices (Di, Liu, Zhu, & Levinson, 2017; Gärling & Axhausen, 2003; Klöckner & Friedrichsmeier, 2011; Samuelson & Zeckhauser, 1988). It should be examined for instance if individuals concerned about the environment consider the "ethics" level differently than others. This aspect should be particularly important considering societal changes, such as for instance a higher importance given to the environment and readiness to change for the younger populations (Anable, 2005).

The findings are also important for the planning practice. For the retrofit of the built environment, the results help inform the approach proposed by Stradling and colleagues (Stradling, Anable, & Carreno, 2007): identifying what matters to users, and focusing on improving those aspects first. Several important barriers that could qualify for the "first fixes" were identified. These barriers include traffic safety, overall safety at night, walking seen as too much effort, and the comparative qualities of alternatives, namely driving. Second, the findings encourage developing holistic strategies and interventions, considering walking within the transport system and the built environment, improving integration, and building positive synergies (e.g. strategic walking network taking into account public transport stops and their importance, based on patronage).

Strengths of the present study: firstly, it considered the associations between different types of perceptions and walking behaviour, which are generally overlooked in studies that directly link environmental attributes to walking. Second, the analysed data provide travel behaviour and a broad range of motivations and perceptions. Third, the analysis of the relative importance of explanatory variables on the levels of walking with machine learning allowed of examination of all the potential dimensions of interest, despite their association, so to identify which combination worked best for predicting walking levels. Arguably, the association of any one of the variables with walking would be trivial, because they all have conceptual relationships to walking as a behaviour. However, the novelty in this analysis was the holistic approach undertaken that highlighted strong effects of some variables and absence of signal for others. Fourth, the findings suggest developing the Social model of Walkability by considering explicitly (1) the relative roles of perceptions and motivations; and (2) the qualities of walking in the context of the broader transport system. Lastly, it demonstrated the application of machine learning methods for dealing with complex data, such as the multiplicity of associations between explanatory variables. Despite the potential of machine learning for exploring complex patterns, it remains underutilised when examining the associations of built environment and walking – for instance, Scopus retuned only seven results for the search for "machine learning" AND "built environment" AND walking (Deng & Yan, 2019; Ding, Chen, & Jiao, 2018; Hou, Zhang, Li, Zhang, & Wang, 2019; Naderi & Raman, 2005; Procter et al., 2018; Tao, Wang, & Cao, 2020; Yang et al., 2019). Three of those results, all published after 2005, analysed the associations between built environment and walking behaviour (Naderi & Raman, 2005; Tao et al., 2020; Yang et al., 2019).

There are also important limitations. Firstly, the available data did not include people having difficulties walking or using a wheelchair. This population is known to be diverse and have higher barriers to access (Bigonnesse et al., 2018; Eisenberg et al., 2017; Kirchner et al., 2008; Oliver, 2013; Rosenberg et al., 2013; Stafford & Baldwin, 2017). Second, the inputs are relative to Auckland New Zealand, requiring caution before extrapolation to other environments, particularly those with different driving, public transport and built environments. Third, the format of the available data (respondents offered only yes/no answers to questions about motivations and barriers) may have prevented a more nuanced understanding of how people perceive barriers. Fourth, the distance to and quality of destinations was not considered, but they are known to affect the choice to walk and access public transport (Daniels & Mulley, 2013; Hillnhütter, 2016). Lastly, the participants declaring not walking have not been included. This was a methodological choice aimed at considering those people who are regularly exposed to their walking environment and whose perceptions of the satisfaction of their walking needs are based on a recent experience. However, considering the reasons why some people cannot or choose not to walk remains an important research topic.

5. Conclusion

The findings provide four main take-aways for both research and the practice: (1) users' perceptions of their environments need to be better understood and linked to objective aspects of the walking environment; (2) walking needs to be considered within the transport system – as a complement to public transport or an alternative to other modes; (3) it is crucial to embrace the diversity of users, examining how different constraints (e.g. having difficulties walking, seeing or hearing) might moderate the perceptions of the environment; and (4) assessing walkability should have a lower the emphasis on the pure availability of destinations, giving more room to the quality of the experience. Beyond the surveys of those who were found walking, the study of severance is key to understand what are those characteristics that can act as "deal-breakers" and prevent someone from taking a trip on foot in the first place.

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.

Acknowledgments

Tamara Bozovic is supported by the Auckland University of Technology Doctoral Scholarship, and Melody Smith is supported by a Sir Charles Hercus Health Research Council of New Zealand Research Fellowship (grant number 17/013).

The authors would like to acknowledge Auckland Transport for having made the anonymised survey data available for this research.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2021.01.003.

References

Alfonzo, M. A. (2005). To walk or not to walk? The hierarchy of walking needs. *Environment and Behavior, 37*(6), 808–836. https://doi.org/10.1177/0013916504274016.

Alidoust, S., & Bosman, C. (2015). Planning for an ageing population: Links between social health, neighbourhood environment and the elderly. *Australian Planner, 52*(3), 177–186.

Anable, J. (2005). 'Complacent car addicts' or 'aspiring environmentalists'? Identifying travel behaviour segments using attitude theory. *Transport Policy, 12* (1), 65–78. https://doi.org/10.1016/j.tranpol.2004.11.004.

Annear, M., Keeling, S., Wilkinson, T., Cushman, G., Gidlow, B., & Hopkins, H. (2014). Environmental influences on healthy and active ageing: A systematic review. *Ageing & Society, 34*(4), 590–622. https://doi.org/10.1017/S0144686X1200116X.

Auckland Council. (1999). Auckland regional policy statement. Auckland Council. http://www.aucklandcity.govt.nz/council/documents/regionalplans/aucklandcouncilregionalpolicystatement/ACRPS%20Policy.pdf.

Auckland Council. (2016a). Auckland unitary plan, operative in part, 15 November 2016. Auckland Council. http://unitaryplan.aucklandcouncil.govt.nz/pages/plan/Book.aspx?exhibit=AucklandUnitaryPlan_Print.

Auckland Council. (2016b). Quality of Life Survey 2016: Results for Auckland (Technical Report 2016/043; p. 186). Auckland Council. http://www.knowledgeauckland.org.nz/assets/publications/TR2016-043-Quality-of-Life-Survey-2016-results-for-Auckland.pdf.

Auckland Council. (2018a). Auckland plan 2050 evidence report—Demographic trends for Auckland: Data sources and findings (Auckland Plan 2050, p. 26). Auckland Council.

Auckland Council. (2018b). The Auckland Plan. https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/auckland-plan/Pages/default.aspx.

Auckland council strategic advice unit. (2018). Auckland plan 2050 evidence report developing the auckland plan.

Auckland Disability Research Group. (2009). Step Up Auckland – Decision-makers getting it right for disabled Aucklanders (p. 40). http://www.ipp.aut.ac.nz/__data/assets/pdf_file/0014/110471/step-up-auckland.pdf.

Badland, H. M. (2007). Transport-related physical activity, health outcomes, and urban design: Descriptive evidence [Thesis, Auckland University of Technology]. http://aut.researchgateway.ac.nz/handle/10292/350

Barnett, D. W., Barnett, A., Nathan, A., Cauwenberg, J. V., & Cerin, E. (2017). Built environmental correlates of older adults' total physical activity and walking: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 103. https://doi.org/10.1186/s12966-017-0558-z.

Bean, C. E., Kearns, R., & Collins, D. (2008). Exploring social mobilities: Narratives of walking and driving in Auckland, New Zealand. *Urban Studies, 45*(13), 2829–2848. https://doi.org/10.1177/0042098008098208.

Bigonnesse, C., Mahmood, A., Chaudhury, H., Mortenson, W. B., Miller, W. C., & Ginis, K. A. M. (2018). The role of neighborhood physical environment on mobility and social participation among people using mobility assistive technology. *Disability & Society, 33*(6), 866–893. https://doi.org/10.1080/09687599.2018.1453783.

Bozovic, T., Hinckson, E., & Smith, M. (2020). Why do people walk? Role of the built environment and state of development of a social model of walkability. *Travel Behaviour and Society, 20*, 181–191. https://doi.org/10.1016/j.tbs.2020.03.010.

Brennan, C. (2016). Key issues for disabled people in New Zealand 2016 (No. A8823512). Office for Disability Issues. https://www.odi.govt.nz/guidance-and-resources/improving-information-about-disabled-people/.

Buckley, P., Stangl, P., & Guinn, J. (2016). Why people walk: Modeling foundational and higher order needs based on latent structure. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 10*(2) https://www-tandfonline-com.ezproxy.aut.ac.nz/doi/abs/10.1080/17549175.2016.1223738.

Burdett, B. (2016, September 3). Mind the gap: Views on transport accessibility among transport professionals and the public of New Zealand. https://www.tgconference.co.nz/tuesday-papers-16.

Burdett, B. (2018). Transport, participation and wellbeing: Evidence and recommendations (No. 12513917). https://www.waikatoregion.govt.nz/services/publications/technical-reports/2018-technical-reports/tr201818/.

C40 Cities. (2018). Summary for urban policymakers: What the IPCC special report on global warming of 1.5°C means for cities. C40 Cities. https://www.c40.org/researches/summary-for-urban-policymakers-what-the-ipcc-special-report-on-global-warming-of-1-5-c-means-for-cities.

Ciommo, F. D., & Shiftan, Y. (2017). Transport equity analysis. *Transport Reviews, 37*(2), 139–151. https://doi.org/10.1080/01441647.2017.1278647.

City of Vancouver. (2017). Walking + Cycling in Vancouver- 2016 Report Card. https://vancouver.ca/files/cov/walking-cycling-in-vancouver-2016-report-card.pdf.

City of Vienna. (2015). Thematic concept—urban mobility plan Vienna, together on the move; Step 2025 (Strategy Werkstattbericht 155; p. 124). City of Vienna. https://www.wien.gv.at/stadtentwicklung/studien/pdf/b008443.pdf.

Daniels, R., & Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use, 6*(2), 5–20. https://doi.org/10.5198/jtlu.v6i2.308.

Davis, D., & Golly, T. (2017). The business case for walking—Counting walking to make walking count in Auckland, New Zealand (breakout presentation). *Journal of Transport & Health, 7*, S53–S54. https://doi.org/10.1016/j.jth.2017.11.088.

Day, K. (2016). Built environmental correlates of physical activity in China: A review. *Preventive Medicine Reports, 3*, 303–316. https://doi.org/10.1016/j.pmedr.2016.03.007.

Deng, Y., & Yan, Y. (2019). Propensity score weighting with generalized boosted models to explore the effects of the built environment and residential self-selection on travel behavior. *Scopus*. https://doi.org/10.1177/0361198119837153.

Di, X., Liu, H. X., Zhu, S., & Levinson, D. M. (2017). Indifference bands for boundedly rational route switching. *Transportation, 44*(5), 1169–1194. https://doi.org/10.1007/s11116-016-9699-1.

Ding, C., Chen, P., & Jiao, J. (2018). Non-linear effects of the built environment on automobile-involved pedestrian crash frequency: A machine learning approach. Accident Analysis and Prevention. Scopus. https://doi.org/10.1016/j.aap.2017.12.026

Eisenberg, Y., Vanderbom, K. A., & Vasudevan, V. (2017). Does the built environment moderate the relationship between having a disability and lower levels of physical activity? A systematic review. *Preventive Medicine, 95S*, S75–S84. https://doi.org/10.1016/j.ypmed.2016.07.019.

Farrahi, V., Niemelä, M., Kärmeniemi, M., Puhakka, S., Kangas, M., Korpelainen, R., & Jämsä, T. (2020). Correlates of physical activity behavior in adults: A data mining approach. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 94. https://doi.org/10.1186/s12966-020-00996-7.

Fomiatti, R., Moir, L., Richmond, J., & Millsteed, J. (2014). The experience of being a motorised mobility scooter user. *Disability and Rehabilitation: Assistive Technology, 9*(3), 183–187. https://doi.org/10.3109/17483107.2013.814171.

Forsyth, A. (2015). What is a walkable place? The walkability debate in urban design. *URBAN DESIGN International, 20*(4), 274–292. https://doi.org/10.1057/udi.2015.22.

Franckx, L. (2017, July 28). Status quo bias and travel behaviour – MIND-sets Knowledge Center. MIND-Sets Knowledge Centre. https://mobilitybehaviour.eu/2017/07/28/status-quo-bias-and-travel-behaviour/

Friedman, J. H. (2001). Greedy function approximation: A gradient boosting machine. *The Annals of Statistics, 29*(5), 1189–1232. https://doi.org/10.1214/aos/1013203451.

Fry, T. (2017). *Remaking cities: An introduction to urban Metrofitting*. Bloomsbury Publishing Plc.

Gärling, T., & Axhausen, K. W. (2003). Introduction: Habitual travel choice. *Transportation, 30*(1), 1–11. https://doi.org/10.1023/A:1021230223001.

Gehl Architects. (2010). Auckland Public Life. http://knowledgeauckland.org.nz/assets/publications/Auckland_Public_Life_Survey_2010_Part_1.pdf.

Gehl, J. (2010). Cities for people. Island Press. https://www.goodreads.com/work/best_book/13424577-cities-for-people.

Gehl, J. (2011). Life between buildings. *Island Press*. https://islandpress.org/book/life-between-buildings.

Gibson, B. E., Secker, B., Rolfe, D., Wagner, F., Parke, B., & Mistry, B. (2012). Disability and dignity-enabling home environments. *Social Science & Medicine, 74* (2), 211–219. https://doi.org/10.1016/j.socscimed.2011.10.006.

Giles-Corti, B. (2017, October 12). What makes a city more liveable? Policy Forum. https://www.policyforum.net/makes-city-liveable/.

Glazener, A., & Khreis, H. (2019). Transforming our cities: Best practices towards clean air and active transportation. *Current Environmental Health Reports. cmedm.*. https://doi.org/10.1007/s40572-019-0228-1.

Greenwell, B. (2019). Gbm function | R Documentation (v2.1.5) [R]. https://www.rdocumentation.org/packages/gbm/versions/2.1.5/topics/gbm
Gunn, L. D., Mavoa, S., Boulangé, C., Hooper, P., Kavanagh, A., & Giles-Corti, B. (2017). Designing healthy communities: Creating evidence on metrics for built environment features associated with walkable neighbourhood activity centres. *International Journal of Behavioral Nutrition and Physical Activity, 14*, 164. https://doi.org/10.1186/s12966-017-0621-9.
Haselwandter, E. M., Corcoran, M. P., Folta, S. C., Hyatt, R., Fenton, M., & Nelson, M. E. (2015). The built environment, physical activity, and aging in the United States: A state of the science review. *Journal of Aging and Physical Activity, 23*(2), 323–329. https://doi.org/10.1123/japa.2013-0151.
Healthy Auckland Together. (2017). Monitoring Report 2017. Healthy Auckland Together. http://www.healthyaucklandtogether.org.nz/assets/Summary-Reports/HAT-Monitoring-Report-2017.pdf
Hillnhütter, H. (2016). Pedestrian Access to Public Transport [University of Stavanger, Norway]. https://uis.brage.unit.no/uis-xmlui/handle/11250/2422928
Hoenig, H., Landerman, L. R., Shipp, K. M., & George, L. (2003). Activity restriction among wheelchair users. *Journal of the American Geriatrics Society, 51*(9), 1244–1251. https://doi.org/10.1046/j.1532-5415.2003.51408.x.
Hou, Q., Zhang, X., Li, B., Zhang, X., & Wang, W. (2019). Identification of low-carbon travel block based on GIS hotspot analysis using spatial distribution learning algorithm. Neural Computing and Applications. Scopus. https://doi.org/10.1007/s00521-018-3447-8
Houghton, S., Nettleship, M., & Johnstone, O. (2017). A value of the urban realm toolkit for Auckland? Case study research into applying the Transport for London VURT methodology in Auckland, New Zealand. Boffa Miskell Limited and Auckland Design Office, Auckland Council. http://www.knowledgeauckland.org.nz/publication/?mid=1678
Howard, E. (2018). Auckland transport: Road safety business improvement review, November 2017 to January 2018. (Guidance and Guidelines BIR Report v38 18 04 18). https://at.govt.nz/media/1976967/road-safety-business-improvement-review-executive-summary-finaldocx.pdf
Human Rights Commission. (2005). The accessible journey: Report of the inquiry into accessible public land transport. https://www.hrc.co.nz/your-rights/people-disabilities/our-work/accessible-journey/
Hutabarat Lo, R. (2009). Walkability: What is it? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 2*(2). https://www.tandfonline.com/doi/abs/10.1080/17549170903092867.
Hwang, E. (2017). Impacts of objective neighborhood built environment on older adults' walking: Literature review. *Housing and Society, 44*(1–2), 141–155. https://doi.org/10.1080/08882746.2017.1384993.
Institute for Transportation and Development Policy. (2018). Pedestrians First: Tools for a Walkable City (p. 80) [Guidance and guidelines]. ITDP. https://www.itdp.org/publication/walkability-tool/
Jacobs, J. (1961). *The death and life of great American cities*. Vintage Books.
Kahneman, D. (2012). Thinking, fast and slow. Penguin Press. https://www.penguin.co.nz/books/thinking-fast-and-slow-9780141033570
Kerr, J., Emond, J. A., Badland, H., Reis, R., Sarmiento, O., Carlson, J., ... Natarajan, L. (2016). Perceived neighborhood environmental attributes associated with walking and cycling for transport among adult residents of 17 cities in 12 countries: The IPEN study. *Environmental Health Perspectives, 124*(3), 290–298. https://doi.org/10.1289/ehp.1409466.
Kirchner, C. E., Gerber, E. G., & Smith, B. C. (2008). Designed to deter. Community barriers to physical activity for people with visual or motor impairments. American Journal of Preventive Medicine, 34(4), 349–352. Scopus. https://doi.org/10.1016/j.amepre.2008.01.005
Klöckner, C. A., & Friedrichsmeier, T. (2011). A multi-level approach to travel mode choice – How person characteristics and situation specific aspects determine car use in a student sample. *Transportation Research Part F: Traffic Psychology and Behaviour, 14*(4), 261–277. https://doi.org/10.1016/j.trf.2011.01.006.
Koschinsky, J., Talen, E., Alfonzo, M., & Lee, S. (2017). How walkable is Walker's paradise?. *Environment and Planning B: Urban Analytics and City Science, 44*(2), 343–363. https://doi.org/10.1177/0265813515625641.
Lowe, M., Whitzman, C., Badland, H., Davern, M., Aye, L., Hes, D., Butterworth, I., & Giles-Corti, B. (2015). Planning healthy, liveable and sustainable cities: How can indicators inform policy?. *Urban Policy and Research, 33*(2), 131–144. https://doi.org/10.1080/08111146.2014.1002606.
Ma, L., & Cao, J. (2019). How perceptions mediate the effects of the built environment on travel behavior?. *Transportation, 46*(1), 175–197. https://doi.org/10.1007/s11116-017-9800-4.
Macmillan, A., Smith, M., Witten, K., Woodward, A., Hosking, J., Wild, K., & Field, A. (2020). Suburb-level changes for active transport to meet the SDGs: Causal theory and a New Zealand case study 136678. *Science of The Total Environment, 714*. https://doi.org/10.1016/j.scitotenv.2020.136678.
Mattingly, K., & Morrissey, J. (2014). Housing and transport expenditure: Socio-spatial indicators of affordability in Auckland. *Cities, 38*, 69–83.
Mayor of London, & Transport for London. (2019). Travel in London (No. 12; p. 279). Transport for London. http://content.tfl.gov.uk/travel-in-london-report-12.pdf
McCann, B., Garland, M., Tracey-Mooney, R., Bernstein, S., Kienitz, R., Ewing, R., & Dittmar, H. (2000). Driven to spend: The impact of sprawl on household transportation expenses. http://transact.org/wp-content/uploads/2014/04/DriventoSpend.pdf.
McCann, P. (2009). Economic geography, globalisation and New Zealand's productivity paradox. *New Zealand Economic Papers, 43*, 279–314. https://doi.org/10.1080/00779950903308794.
McCormack, G. R., & Shiell, A. (2011). In search of causality: A systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity, 8*(1), 125. https://doi.org/10.1186/1479-5868-8-125.
Mehta, V. (2008). Walkable streets: Pedestrian behavior, perceptions and attitudes. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 1*(3), 217–245.
Miller, C., Clay, G., McHarg, I. L., Hammond, C. R., Patton, G. E., & Simonds, J. O. (1966). A declaration of concern. *Landscape Architecture Foundation*.
Mindell, J. S. (2017). Street mobility project toolkit: Measuring the effects of busy roads on local people (p. 53). UCL. http://discovery.ucl.ac.uk/1542993/1/Mindell_Street_Mobility_Project_Toolkit_updated.pdf
Mindell, J. S., & Karlsen, S. (2012). Community severance and health: What do we actually know?. *Journal of Urban Health, 89*(2), 232–246. https://doi.org/10.1007/s11524-011-9637-7.
Ministry of Transport. (2017). New Zealand Household Travel Survey: Regional results 2015–2017 (2-year moving average). https://www.transport.govt.nz/resources/household-travel-survey/new-results/
Ministry of Transport, & Auckland Council. (2018). Auckland transport alignment project 2018. Ministry of Transport. https://www.transport.govt.nz/land/auckland/atap/
Ministry of Transport, Transport Knowledge Hub. (n.d.). Access to the transport system: Travel perceptions. Retrieved November 2, 2018, from https://www.transport.govt.nz/resources/tmif/accesstothetransportsystem/am010/
Naderi, J. R., & Raman, B. (2005). Capturing impressions of pedestrian landscapes used for healing purposes with decision tree learning. *Landscape and Urban Planning. Scopus.*. https://doi.org/10.1016/j.landurbplan.2004.11.012.
National Institute for Health and Care Excellence (NICE). (2018). Physical activity and the environment (Guidance and Guidelines No. NG90). https://www.nice.org.uk/guidance/ng90
NZ Ministry of Transport. (2015). Walking New Zealand Household Travel Survey 2011—2014.
NZ Transport Agency. (2018). Journeys that didn't happen. NZ Transport Agency.
NZIER. (2014). Big city life? Challenges and trade-offs for Auckland city. https://nzier.org.nz/publication/big-city-life-challenges-and-trade-offs-for-auckland-city-nzier-public-discussion-paper-201402.
Oliver, M. (2013). The social model of disability: Thirty years on. *Disability & Society, 28*(7), 1024–1026. https://doi.org/10.1080/09687599.2013.818773.
Peter Nunns. (2014). Population-weighted density in New Zealand and Australian Cities: A new comparative dataset. MRCagney Working Paper. https://www.greaterauckland.org.nz/wp-content/uploads/2014/09/Nunns-2014-NZ-Aus-population-weighted-density-small.pdf.

Procter, D. S., Page, A. S., Cooper, A. R., Nightingale, C. M., Ram, B., Rudnicka, A. R., ... Owen, C. G. (2018). An open-source tool to identify active travel from hip-worn accelerometer, GPS and GIS data. *International Journal of Behavioral Nutrition and Physical Activity. Scopus*. https://doi.org/10.1186/s12966-018-0724-y.

R Core Team. (2019). R: A language and environment for statistical computing (3.6.0) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/.

Rafferty, L. A., Stanton, N. A., & Walker, G. H. (2013). Great expectations: A thematic analysis of situation awareness in fratricide. Safety Science, 56, 63–71. ega.

Rose, E., Witten, K., & McCreanor, T. (2009). Transport related social exclusion in New Zealand: Evidence and challenges. *Kotuitui: New Zealand Journal of Social Sciences Online, 4*(3), 191–203. https://doi.org/10.1080/1177083X.2009.9522454.

Rosenberg, D. E., Huang, D. L., Simonovich, S. D., & Belza, B. (2013). Outdoor built environment barriers and facilitators to activity among midlife and older adults with mobility disabilities. *The Gerontologist, 53*(2), 268–279. https://doi.org/10.1093/geront/gns119.

Sallis, J. F. (2009). Measuring physical activity environments: A brief history. American Journal of Preventive Medicine, 36(4, Supplement), S86–S92. https://doi.org/10.1016/j.amepre.2009.01.002

Sallis, J. F., Bull, F., Burdett, R., Frank, L. D., Griffiths, P., Giles-Corti, B., & Stevenson, M. (2016). Use of science to guide city planning policy and practice: How to achieve healthy and sustainable future cities. *The Lancet, 388*(10062), 2936–2947. https://doi.org/10.1016/S0140-6736(16)30068-X.

Samuelson, W., & Zeckhauser, R. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty, 1*(1), 7–59. https://doi.org/10.1007/BF00055564.

Sen, K., & Kenyon, G. (2012). A model for assessing consumer perceptions of quality. *International Journal of Quality and Service Sciences, 4*(2), 175–188. https://doi.org/10.1108/17566691211232909.

Singh, H. (2018, November 4). Understanding gradient boosting machines. Medium. https://towardsdatascience.com/understanding-gradient-boosting-machines-9be756fe76ab.

Smith, C., & Dixon, S. (2018). Independent. Confident. Connected. Achieving equality for disabled people. Disability charity Scope UK. /campaigns/independent-confident-connected/

Smith, M., Cedar-Dawe, O., Carroll, P., Kayes, M. N., Lin, E.-Y., Kearns, R. A., & Witten, K. (n.d.). A cross-sectional examination and new socio-technical-ecological-cultural model for understanding mobility and disability. S-TEC. Environmental Health Perspectives, (in review).

Speck, J. (2012). *Walkable city: How downtown can save America*. One Step at a Time (Reprint): North Point Press.

Stafford, L., & Baldwin, C. (2017). Planning walkable neighborhoods: Are we overlooking diversity in abilities and ages?. *Journal of Planning Literature*. https://doi.org/10.1177/0885412217704649.

Statistics New Zealand. (2014). Disability survey: 2013. Statistics New Zealand. http://archive.stats.govt.nz/browse_for_stats/health/disabilities/DisabilitySurvey_HOTP2013.aspx.

Stradling, S., Anable, J., & Carreno, M. (2007). Performance, importance and user disgruntlement: A six-step method for measuring satisfaction with travel modes. *Transportation Research. Part A, Policy and Practice, 41*(1), 98–106. https://doi.org/10.1016/j.tra.2006.05.013.

Tao, T., Wang, J., & Cao, X. (2020). Exploring the non-linear associations between spatial attributes and walking distance to transit. *Journal of Transport Geography. Scopus.*. https://doi.org/10.1016/j.jtrangeo.2019.102560.

The Landscape Architecture Foundation (LAF). (2016). The New Landscape Declaration. Landscape Architecture Foundation. https://lafoundation.org/news-events/2016-summit/new-landscape-declaration/

TRA. (2016). Measuring and growing active modes of transport in Auckland. Auckland Transport. https://at.govt.nz/media/1957535/at_active-modes-2016.pdf.

TRA. (2017). Measuring and growing active modes of transport in Auckland, Wave 3. Auckland Transport. https://at.govt.nz/media/1973977/at-active-modes-2017.pdf.

TRA. (2018). Measuring and growing active modes of transport in Auckland. Auckland Transport. https://at.govt.nz/media/1977266/tra_at_activemodes_publicrelease-1.pdf.

UN DESA. (2016). Good practices of accessible urban development. https://www.un.org/development/desa/dspd/2016/10/good-practices-of-accessible-urban-development/.

UN-HABITAT. (2014). 7th World Urban Forum Medellín Declaration. https://unhabitat.org/7th-world-urban-forum-medellin-declaration/.

UN-HABITAT. (2016). Cities 2030, Cities for all: Implementing the New Urban Agenda. United Nations. http://wuf9.org/theme/.

United Nations. (2015, September 25). Cities—United Nations sustainable development action 2015. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/cities/

Van Cauwenberg, J., Nathan, A., Barnett, A., Barnett, D. W., Cerin, E., & the Council on Environment and Physical Activity (CEPA)-Older Adults Working Group. (2018). Relationships between neighbourhood physical environmental attributes and older adults' leisure-time physical activity: A systematic review and meta-analysis. Sports Medicine, 48(7), 1635–1660. Scopus. https://doi.org/10.1007/s40279-018-0917-1

Walk Score. (n.d.). WalkScore TM. Walk score. Retrieved August 29, 2018, from https://www.walkscore.com/

Walton, D., & Sunseri, S. (2007). Impediments to walking as a mode choice (Research Report No. 329; p. 48). Land Transport New Zealand. https://www.nzta.govt.nz/resources/research/reports/329/index.html

Webber, S. C., Ripat, J. D., Pachu, N. S., & Strachan, S. M. (2019). Exploring physical activity and sedentary behaviour: Perspectives of individuals with osteoarthritis and knee arthroplasty. *Disability And Rehabilitation, 1–8*, cmedm. https://doi.org/10.1080/09638288.2018.1543463.

World Health Organization. (n.d.). Let's be active, the global action plan on physical activity 2018—2030. Retrieved September 27, 2018, from http://www.who.int/ncds/prevention/physical-activity/gappa.

Yang, Y., He, D., Gou, Z., Wang, R., Liu, Y., & Lu, Y. (2019). Association between street greenery and walking behavior in older adults in Hong Kong. *Sustainable Cities and Society. Scopus*. https://doi.org/10.1016/j.scs.2019.101747.

Transportation Research Part F: Psychology and Behaviour 81 (2021) 490–507

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

How to improve the walking realm in a car-oriented city? (Dis) agreements between professionals

T. Bozovic [a,*], E. Hinckson [a,1], T. Stewart [a,1], M. Smith [b,1]

[a] Auckland University of Technology, New Zealand
[b] The University of Auckland, New Zealand

ARTICLE INFO

Keywords:
Walkability
Retrofit
Multidisciplinary
User experience
Urban design
Public health

ABSTRACT

Purpose: Urban environments and transport systems can enable and encourage walking, and therefore play a key role in climate action, public health, equity of access, and population wellbeing. The question, especially in cities that have been dominated by car traffic, is *how*? The challenge is heightened by the multidisciplinary involvements in the design, operation, and maintenance of urban infrastructure.

This study examines the views of professionals from different disciplines involved in delivering walking environments in Auckland, New Zealand. The study examines agreements and disagreements regarding users' needs, priorities, challenges, and evidence gaps for delivering quality walking environments in a car-dominated city.

Methods: Primary data were collected through an online survey (N = 28) and a focus group, both involving professionals active in urban design, road safety, transport planning, public health, urban development and strategy. Analysis involved content coding and comparing the frequency of responses across professional groups.

Results: The results indicated a consensus on the complexity associated with providing walking environments, as well as the importance of the quality of street environments. The lack of priority given to walking, car-dominated environments, and the inability to deliver change were seen as challenges. The inputs suggested a negative chain reaction linking the low priority of walking and the lack of consensus relative to users' experience. There appeared to be a lack of common understanding of users' needs and experiences and a paucity of evidence on this topic.

Conclusion: The findings suggest the need for urban retrofit rooted in a sound understanding of users' needs and experiences, and walkability as a sub-system of the urban environment. Recommendations include higher interdisciplinary collaboration at the policy and practice level, reviewed delivery processes, and better-quality data.

1. Introduction

The United Nation's recent "Making Peace with Nature" presents a pathway for addressing climate change, biodiversity loss, and pollution (United Nations Environment Programme., 2021). The report calls for an "urgent and clear break with current trends of environmental decline" (United Nations Environment Programme., 2021) and large-scale transformations, in which cities play an

* Corresponding author at: Auckland University of Technology, Faculty of Health and Environmental Sciences, Auckland 92006, New Zealand.
E-mail address: tamara.bozovic@aut.ac.nz (T. Bozovic).
1 Postal address: School of Nursing, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand.

https://doi.org/10.1016/j.trf.2021.06.011
Received 10 March 2021; Received in revised form 25 May 2021; Accepted 24 June 2021
1369-8478/

Nomenclature

Complex socio-technical system (CSTS) Refers to systems that are evolving, dynamic, and open to external forces (Davis et al., 2014). CSTS approaches were developed in an effort to understand and manage relationships between people, technologies, infrastructure, processes and goals (Davis et al., 2014).
Social Model of Walkability Theoretical model linking the environment and transport systems to walking as a behaviour, with the mediating effects of people's perceptions and the individual, social, and trip-related characteristics (Bozovic et al., 2020).
User Experience (UX) Refers to experiential qualities – in this case, relative to walking.

important role (UN-HABITAT., 2014; OECD/ITF., 2021; United Nations, 2015). Land use, infrastructure, and services should be retrofit and integrated to encourage low-carbon mobility (United Nations Environment Programme., 2021; Sallis et al., 2015). A modal shift towards walking in urban areas would contribute to this vision and the Sustainable Development Goals (United Nations, 2015).

The socio-ecological framework helps conceptualise the diverse correlates of walking behaviour (Sallis et al., 2015; Sallis, 2009; Forsyth, 2015; Alfonzo, 2005), and aspects that might need to be altered to realise this modal shift. The framework points towards the built environment, individual characteristics, and availability of travel options. A previous umbrella review conceptualised this range of associations within the Social Model of Walkability (Bozovic et al., 2020). The review outlined the complexity of walkability and suggested a lack of consensus on the relative importance of different dimensions of the walking environment. As such, different professional disciplines may have different perspectives on the challenges and priorities for creating walkable environments. It is agreed, in principle, that a modal shift towards walking requires more supportive environments (Sallis et al., 2015; Giles-Corti, 2017; Giles-Corti et al., 2016). Achieving a modal shift poses the challenge of retrofitting car-oriented urban environments, which can cause systemic barriers to, or risks for, walking (OECD/ITF., 2021; America and Coalition, 2019; Mindell and Karlsen, 2012). There is a growing understanding of the need to prioritise the removal of barriers experienced by people of greatest need (Burdett, 2018; Transport for London, 2019). However, it is not clear if professionals in charge of street design share views regarding what these barriers are and who suffers from them (Burdett, 2016; Middleton, 2010; Park et al., 2020).

1.1. Assumptions

This study builds on two assumptions: firstly, that the delivery of walkable environments is a complex socio-technical system; second, that the delivery of walkable environments is hindered by a lack of quality data regarding users' experience, and therefore a lack of consensus among professionals relative to needs and priorities. These two assumptions are explored briefly below, with a focus on the city used as a case study: Tāmaki Makaurau Auckland, Aotearoa New Zealand (hereafter: Auckland).

1.2. Walking as a complex socio-technical system

In this study, the planning and delivery of walkable environments are understood as part of a complex socio-technical system (CSTS). The concept refers to systems that are evolving, dynamic, and open to external forces (Davis et al., 2014). CSTS approaches were developed in an effort to understand and manage relationships between people, technologies, infrastructure, processes and goals (Davis et al., 2014). Cities had previously been characterised as CSTS, with Davis and colleagues (Davis et al., 2014), and Adelt and colleagues using systems approaches to analyse modal choice (Adelt et al., 2018).

Complexity is framed and described by Righi and Saurin's research (Righi and Saurin, 2015): complexity is real and measurable, but cannot be described objectively (i.e., the description is limited by the biases of those trying to describe it). The authors showed that complexity can be examined through an assessment of four dimensions (Saurin and Gonzalez, 2013): a multitude of components interacting dynamically with each other; an important diversity of those components; unexpected variability; and resilience, including redundancies and the possibility for outcomes to be generated in different ways. The key aspects of each dimension and an application to the walking environment are presented in supplementary file A.

The complexity of delivering more walking environments is amplified given that diverse components of walking environments are managed and/or altered by professionals from different disciplines. A focus on professionals is crucial because they can help deliver better environments for walking but might disagree regarding what needs to be delivered. Different disciplines might assess the quality of the same built environments differently (Sallis, 2009), or understand the causes of negative outcomes such as pedestrian causalities, differently (Ralph and Girardeau, 2020). Achieving more streamlined multidisciplinary collaboration is urgent as major integrated urban transformations are required to achieve carbon neutrality (C40 Cities., 2018). Given the dispersion of professionals' views and the fact that these views don't necessarily align with users' needs and behaviours (Park et al., 2020; Ralph and Girardeau, 2020; Read et al., 2018), users' insights and experience should be brought into the picture, as a form of "reality check". Citizen Science (King et al., 2016; Hinckson et al., 2017) is a methodology involving the civil society in research projects, from data gathering to recommendations. Citizen Science can improve the understanding and consideration of people's experiences in decision-making (King et al., 2019). This methodology has been applied by the authors in a previous study that aimed to better understand the barriers to walking, as experienced by diverse people (Bozovic et al., submitted for publication). The present study builds on this information and uses the inputs of previously involved Citizen Scientists.

1.3. Lack of consensus between professionals

Previous research has suggested that professionals who deliver urban environments (e.g., planners, policy-makers) and those who deal with their outcomes (e.g., health researchers) do not necessarily share a common vision regarding needs and priorities (Mackie et al., 2018; lge-Elegbede, J., Pilkington, P., Bird, E. L., Gray, S., Mindell, J. S., Chang, M., … Petrokofsky, C., 2020; Burdett, 2017). It is suggested that transport planning and public health have been disconnected from each other, resulting in transport systems being associated with adverse health outcomes (Sallis et al., 2015; Giles-Corti et al., 2016). Further, a lack of integration between land use and transport planning appears to be a barrier to modal shift away from personal vehicles towards active modes (Sallis et al., 2015; Giles-Corti et al., 2016). A disconnect between disciplines can be observed at different decision-making levels. In New Zealand, Ministerial portfolios delivering infrastructure, or portfolios impacted by it, can lack coordination and operate within legislation that can be conflicting (Waihanga and New Zealand Infrastructure, 2020). This situation can result in negative interactions between domains, namely transport, housing, economy, and productivity (Waihanga and New Zealand Infrastructure, 2020). Further, investment decision-making is based on benefit-cost ratios that overlook pedestrian accessibility (Burdett et al., 2017), suggesting a difficulty in delivering optimal walkable environments. At the local level, past evidence indicates a certain misalignment between stated policy objectives and the infrastructure delivery (Chapman et al., 2017). An example of this situation is special housing areas that can be car-dependent and therefore not meet the objective of reducing greenhouse gas emissions (Chapman et al., 2017).

Professionals' views also appear to align poorly with the diverse needs of diverse users. For instance, Park and colleagues also recently showed gaps between priorities seen by professionals involved in the design of transport systems, and users (Park et al., 2020). In New Zealand, <20% of 238 interviewed transport professionals considered that walking realm retrofit was prioritised according to the needs of people who use it (Burdett, 2016). Paucity of data regarding users' needs appears to be an important element. Only 6.7% of the interviewed transport professionals thought that good data was available about people using the footpaths (Burdett, 2016). While access to jobs, leisure and recreation, green spaces, and social networks is instrumental to people's well-being, the ease of access remains poorly captured in New Zealand (Smith, 2018). Previous research has linked neglect from policy and practice to difficulties of access and decreased wellbeing (Burdett et al., 2017; Meher et al., 2021; Smith et al., 2021). The New Zealand Transport Agency is currently (April 2021) investigating barriers to participation experienced by disabled people (Waka Kotahi and Agency, 2021).

1.4. Aims and questions

This study has two aims. Firstly, gain the views of professionals from five different disciplines, with a focus on priorities, challenges, and evidence gaps for delivering quality walking environments in a car-oriented city. The targeted disciplines are urban design, road safety, transport planning, public health, urban development, and urban strategy. The reference to "the practitioners" relates to participating professionals active in one or more of the five disciplines identified. The second aim is to examine, from the professionals' perspective, the assumption that walking for transport is a CSTS.

The study is located in Auckland, New Zealand's biggest city (1.5 million residents) and main economic centre. The city is characterised by low residential density (Nunns, 2014), a transport system dominated by traffic infrastructure (Architects, 2010), and a reliance on cars for everyday travel (Ministry of Transport, 2017). The study seeks to move beyond the observation of disagreements and provide insights regarding how professional practices could evolve towards a more integrated approach.

The research questions are:

1. **How is "walkability" understood?** What are elements of consensus and divergence regarding the nature of a "walkable" city? How are users' walking needs understood, and what data do professionals use to justify their understanding of walking needs?
2. **How do professionals perceive facilitators of and barriers to walking in Auckland**? What are aspects of consensus or disagreement, and how do the ideas compare with the insights gained from users? What elements of consensus or divergence can be outlined?
3. **How is pedestrian accessibility implemented?** How do professionals perceive the priorities for retrofit in Auckland and the challenges relative to the improvement of the walking environment, and how is "improvement" understood? What elements of consensus or divergence can be outlined?
4. **How do practitioners rate the four dimensions of systemic complexity of the walking environment considered as a complex socio-technical system?** To what extent to the ratings support the claim of the walking environment being a complex socio-technical system?

The paper is structured as follows: the methods are described, covering participants characteristics and recruitment, data gathering (online survey and focus group), and data analysis. The results section presents an overview of the survey responses, the survey findings relative to the four research questions and more in-depth insights gathered from the focus group. The discussion is structured around the four research questions; an overview of the mentions of walking environments and transport system, across the questions; and the strengths and limitations. A brief section concludes the paper.

2. Methods

Data were collected via an online survey completed over September and October 2020 and a focus group (November 2020). While this study targets professionals, users were included in the process in two ways: Citizen Scientists previously involved (Bozovic et al., submitted for publication) were invited to prepare the questions to be submitted to the professionals in the focus group, and to delegate up to three representatives who would participate in the focus group. The methods are presented in Fig. 1 and below.

2.1. Participants

The survey participants were professionals from fields relative to design and delivery of walking environments and public health, working in New Zealand. Professionals were identified by the research team through their networks and online searching of organisation websites. The participants were selected based on three criteria: **(1) Primary activity in one of the designated areas**; **(2) Expertise**: senior role and over 5 years of experience in that field; and **(3) Focus on walking**: primary employment activity has a focus on walking - through planning and design of the urban environment, urban strategy, or public health interventions and strategies to promote walking as contributor to physical and mental health.

All survey participants were invited to participate in an online survey via email. At the end of the survey, participants could opt in for being re-contacted for the focus group. The focus group included professionals, by order of expression of interest, ensuring that each area of expertise was represented; and one of the users who had previously participated in the project as a Citizen Scientist (King et al., 2016).

Measures were taken to minimise the risk of associating specific survey responses to individual participants. Namely: only one wave of invites was sent; the participants opted in by accessing the provided link and did not need to contact the research team; and expressions of interest for the focus group were gathered in a way that did not allow association to the responses provided (the last ("thank you") screen is de facto a separate survey with a sign in option for the focus group). The focus group was transcribed without participants' identity but only a letter (unrelated to their name) and an indication of their profession.

2.2. Online survey

The survey questions are presented in supplementary file B. Briefly, the survey covered five topics, presented in Table 1.

2.3. Focus group

The purpose of the focus group was to discuss and further explore the results of the survey. The topics to discuss with the professionals were first discussed and reworked with the group of Citizen Scientists. The Citizen Scientists received a summary of the survey findings ahead of the meeting, with a focus on questions for which the professionals' responses showed either a lack of consensus or an agreed evidence gap. The purpose of the meeting with the Citizen Scientists was to collect their views regarding what topics should be further explored, in the focus group.

The Citizen Scientist group prioritised two topics: (1) the lack of consensus regarding users' needs and (2) the lack of prioritisation of walking. Prior to the focus group, the professionals received an information pack (supplementary file C) presenting the two topics to be discussed and potential questions to help the discussion. The focus group was facilitated by TB, with the presence and support of MC. The discussions were audio-taped and transcribed verbatim.

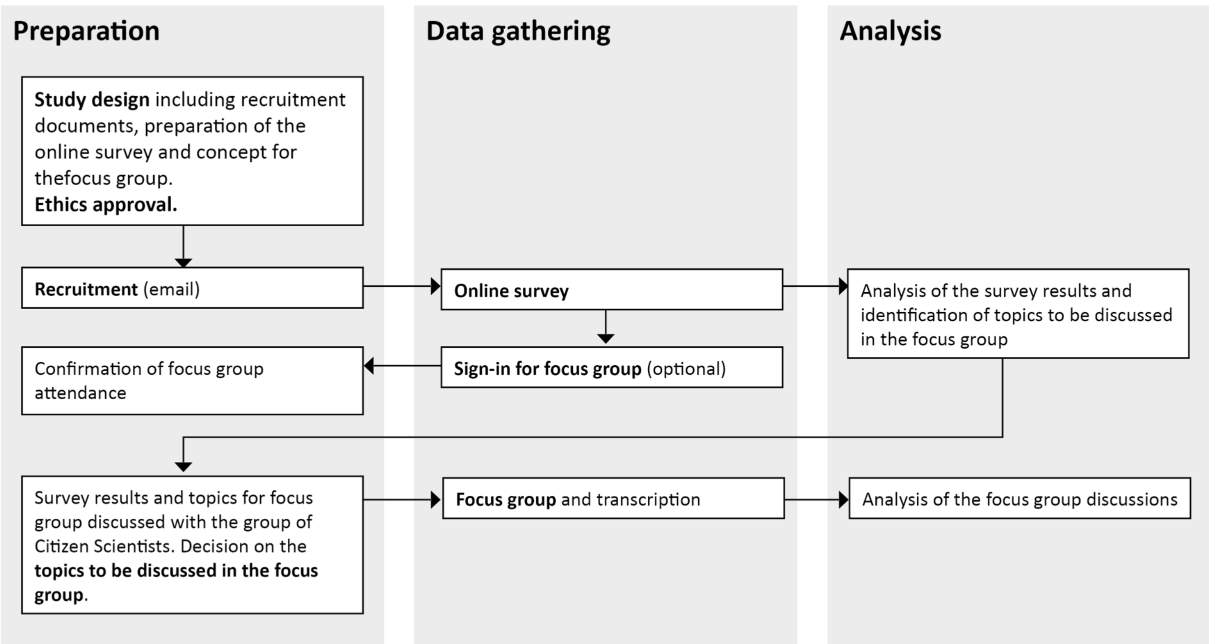


Fig. 1. Methods overview.

Table 1
Survey topics, inputs given to participants and response types (see supplementary file B for the full survey).

	Survey topic	Further framing/indications	Response type
1	An accessible city: signs of success	Cite three aspects	Open
2	Priorities of intervention regarding accessibility on foot/ by wheelchair	For the next 3 and 10 years.	Open
3	How well the users' needs are understood	n/a	4-point Likert scale, from "not at all" to "extremely well"
4	The single biggest challenge regarding retrofit of built environments	n/a	Open
5	Levels of complexity, within the activity of planning and delivering walkable environments	Agreement with four statements (brief version below): 1. *There are many dynamically interacting elements* 2. *There is a wide diversity of elements* 3. *There is unexpected variability* 4. *There is resilience*	Sliding scale from 0 ("disagree entirely") to 100 ("entirely agree"), for each statement

2.4. Data analysis

Survey data were both qualitative (open-ended questions regarding the priorities and challenges relative to the improvement of the walking realm, and open-ended focus group questions) and quantitative (scoring of aspects of complexity relative to different dimensions of the professional practices dealing with the walking environments). Two forms of data analysis were used: (1) inductive and deductive content analysis (Elo and Kyngäs, 2008), for the inputs to open-ended survey questions and focus group questions; and (2) descriptive statistics and quantitative analysis of the associations between the scores.

Content analysis is a flexible approach to exploring qualitative content (Elo and Kyngäs, 2008). The content analysis examined individual responses to different questions as units of meaning (Elo and Kyngäs, 2008). Topics were examined separately for different types of questions (perceived motivations and deterrents to walking, perceived priorities, sources of data, data gaps, and challenges relative to implementing walkable environments). For each type of question, the process followed the three steps described by Elo and Kyngäs: open coding, creating categories, and abstraction (Elo and Kyngäs, 2008).

Content analysis can be inductive or deductive. **Deductive content analysis** was used for testing a previously established model (Elo and Kyngäs, 2008), the social model of walkability (Bozovic et al., 2020). Responses regarding incentives and deterrents were associated to pre-established categories and sub-categories, covering (1) the availability of destinations and the higher-level walking network; (2) the qualities of the walking environment; (3) the broader transport system; and (4) personal characteristics and preferences. The categories are presented in Supplementary file D. The codes relative to the walking environment previously used to test the theoretical model through users' interviews (Bozovic et al., submitted for publication) were re-applied here. Further, the frequency of mentions of environmental characteristics was compared between the professionals (primary data of this paper) and the users previously interviewed (Bozovic et al., submitted for publication), using a chi-square test. **Inductive content analysis** was used to code survey questions relative to priorities, challenges and data used, as well as the focus group transcriptions. The technique was chosen due to the explorative nature of those questions, and allowed categories to be extracted from the data (Elo and Kyngäs, 2008). For the responses relative to the characteristics of a walkable city, the priorities and the challenges, the open coding stage (annotating text with draft categories) led to defining categories under four types, presented in Table 2. Each response could be coded in several categories. For instance, a characteristic relative to pedestrian connectedness due to intentional implementation of pedestrian priority was coded across all four categories (environment: holistic design; perceptions: accessibility; practice: pedestrian priority through design; policy: prioritisation of walking).

The ratings of the levels of complexity were analysed in a descriptive way, reporting means, interquartile range (IQR), minimum, maximum, and number of ratings above 70, retained as an arbitrary "high" threshold, roughly corresponding to the highest tertile. Distributions were generated for the four dimensions of complexity, and a composite index was created and used to compare responses from professionals associated to different disciplines. The composite index is the average, by participant, of the ratings provided. For each dimension, the number of ratings above 70 was determined, and compared using chi-square tests.

Table 2
Types of categories for the content coding analysis of the characteristics of the "walkable city"

Type of category	Explanation
Built environment and transport system	every time an environmental aspect is mentioned, e.g. footpaths or crossings
Perceptions	implicit or explicit mention of perceptions, e.g. "safe"
Practice	implicit or explicit mention of design or management, e.g. Healthy Streets approach embedded in design
Policy	implicit or explicit mention of policy, e.g. reference to parking management or speed management

3. Results

3.1. Overview of the survey responses

Twenty-eight practitioners responded (37% response rate). Half of the respondents self-associated with several disciplines, for instance, seven mentioned urban design, urban development, and transport planning together. A clustering was performed, grouping together professionals working in similar fields. The frequency of mentions of disciplines and the suggested clustering are presented in Table 3.

Most participants self-defined as technical specialists (19 mentions), but the cohort also included nine decision-makers and three researchers. Five participants self-associated with roles not listed (e.g., advocacy). The following paragraphs examine the results relative to specific questions, after which the focus group inputs are reported.

3.2. The understanding of walkability

The notion of walkability was examined through the attributes of a walkable city, the level of understanding of the barriers to walking, and the evidence used regarding barriers and motivations to walking, in Auckland. The results for each dimension are presented below.

3.2.1. The attributes of a walkable city

Participants were asked to name three characteristics of *a city supportive of walking*. The 84 inputs related mostly to the built environment and the transport system but also included references to implementation and experiential qualities. Three major topics were identified: **quality street environments; implementation of pedestrian amenity; and walking being perceived as a positive experience by the users**.

Quality street environments were described as a range of features of the walking environment detailed in Table 4. The biggest cluster of responses related to holistic environments. A few participants provided some detail about the environmental characteristics of those holistic walkable environments (e.g., “human scaled infrastructure and architecture”, “people scale”, or “high-quality public spaces”). The majority mentioned the broad outcomes that these environments deliver (e.g., “the ability to permeate the city on foot”, “attractive”, or “designed to genuinely put pedestrian at the top of the modal hierarchy”). Participants took a user-centric approach, stressing that the environment needs to be adapted to the users’ needs as a minimum, some indicating that beyond being accessible, the environment needs to be perceived as inviting or “delightful”. Universal design was mentioned and could be understood as a specific dimension of holistic design quality, participants stressing the need for streets to consistently provide for all, regardless of their age and ability.

Implementation of pedestrian amenity (33 mentions, 39%) related mostly to a higher focus on walking in the delivery of streets and spaces. Twenty of the responses (61%) spoke about design of walking environments, fourteen focusing on the streets design, six mentioning land use (compact, connected to public transport). Features relative to the pedestrian amenity were either explicit (e.g., “Priority at intersections for people” or “intersection designed around ped delay and not vehicle delay” delivering “the ability to permeate the city on foot”) or implicit (e.g., “A city that values streets and connectivity, space to walk” or “Designed to genuinely put pedestrian at the top of the modal hierarchy”). Nine of the comments specified that best practice should be embedded in the design process (e.g., “A commitment to a healthy streets approach at mayoral level and embedded throughout planning policy and urban design https://healthystreets.com/home/about/“).

The perceptual quality of walking as a positive experience (22 mentions, 26%) related to comments describing the kind of feelings that a walkable city would foster. The comments referred to dimensions of safety (nine mentions), pleasant walking experience (eight) and accessibility (five). Safety was not always explicitly related to traffic and/or stranger danger, some participants noting just “safe”. Traffic was however explicitly mentioned four times. The perceived pleasantness was described through characteristics such as “Attractive”, “Interesting - things to look at, things to do” or “Designed not just to make walking accessible, but to make it delightful”.

Table 3
Disciplines selected by respondents and clustering.

Cluster	N	Self-selected disciplines	N
UD_PH	**8**	Urban design	5
Urban design with a public health perspective		Urban design, Public health	2
		Urban design, Public health, Urban development	1
UD_TP	**7**	Urban design, Road safety, Transport planning, Urban development	4
Urban design and transport planning		Urban design, Transport planning, Urban development	2
		Transport planning, Public health, Urban development	1
TP_RS	**8**	Transport planning	3
Transport and safety		Road safety	3
		Road safety, Transport planning	2
PH_RS	**4**	Public health	3
Public health		Road safety, Public health	1
NA	**1**	Urban design, Road safety, Transport planning, Public health, Urban development	1
	28	**Total**	**28**

Table 4
Characteristics of a walkable city – aspects relative to the built environment and the transport system.

Dimension	Category		Mentions		% participants
Street environment - quality	Holistic design quality	16	**52**	70%	57%
	Universal design	8			29%
	Footpaths design	7			25%
	Crossings and traffic conditions	6			21%
	Traffic intensity	5			18%
	Footpaths maintenance	2			7%
	Presence of other people	2			7%
	Signalised crossings - waiting time	2			7%
	Greenery	3			11%
	Lighting (presence, quality)	1			4%
Destinations	Distance to destinations	10	**10**	14%	36%
Walking network	Pedestrian connectedness	5	**6**	8%	18%
	Connectivity	1			4%
Broader transport system	Efficiency of public transport	3	**4**	5%	11%
	Parking management	1			4%
Pedestrian priority when crossing side streets		2	**2**	3%	7%
Total built environment and transport system		**74**	**74**	**100%**	
Total general, including perceptions and delivery		**84**			

Accessibility was framed through the ideas of ability to easily cross the streets or "permeate the city on foot". One participant specified that accessibility involved an environment that is "inclusive, culturally safe, disability friendly", but overall, the answers did not provide much detail on what accessibility implied in terms of environmental features, design, or traffic. In most comments, it was not necessarily clear if the participant was speaking of their own experience or imagining themselves in users' shoes (e.g., "Easy to cross the street […]"). Three inputs related perceptions to features of the walking environment (well-maintained footpaths, safe crossings and walkways separate from traffic) and eighteen did not.

The clusters of professional disciplines were compared regarding the frequencies of mentions of quality of street environments, broader transport system, and perceptions of safety, accessibility or pleasant walking experience. The differences of frequencies were not significant at Chi2 $p < 0.10$, and the only difference being in the range 0.1–0.2 related to the frequencies of mention of quality (lower for public health and road safety specialists, higher for urban designers).

3.2.2. Understanding of barriers and motivations to walking

The professionals were asked: *How well do we understand what might cause people not to choose to walk/wheel, or to struggle by doing so?* The views were diverse: 10 respondents considered that the barriers are well/extremely well understood, while 18 thought that they were not well understood. The answers were also mixed when examining the professional clusters, with some interesting differences: a majority of public health professionals (3/4) considered that barriers and motivations were very well understood, while this was the case for a minority of transport planners and urban designers (2/8 and 5/15, respectively). The differences of frequencies were not significant at $p < 0.1$.

3.2.3. Evidence used

The practitioners were asked: *If you had to present evidence about motivations or barriers to walking, for Aucklanders, what source(s) of data would you use?* Twenty-six of the 28 participants responded to this question, providing 63 inputs (2.4 per participant who answered). Most of the inputs (51, 81%) provided some detail about what type of evidence they would use. Overall, the noted sources were quite disparate: no consensus was observed about "go to" evidence base, and variety of types of documents was noted.

Eleven participants noted using specific documents or data sets and the participants collectively mentioned 13 documents: three international publications and ten local documents or data sets (WalkScore™ scores were considered as local data, in this study). Four documents had two mentions each (National Census (NZ Statistics. (n.d.). Home - Census | Census Online | Census NZ, 2018) and Disability Survey (Statistics New Zealand., 2014), the Healthy Streets guideline (Mayor of London, T. for L., 2017) and WalkScore ™ (Score, 2018), while the other documents were mentioned only once.

Empiric evidence was predominantly noted (23 mentions to qualitative insights and 16 to quantitative findings), but the participants also noted a variety of other sources such as guidelines, expert advice, or even own experience. Three participants spoke about the difficulty to source appropriate evidence (e.g., "I would probably struggle to find data to support claims about motivations or barriers to walking or I wouldn't know where to turn to first. [..] I'd probably turn to international research and try to apply it to the Auckland context.").

Differences were noted between the professional clusters: **transport and safety professionals** were more likely to indicate quantitative evidence and statistics (11 mentions, $p < 0.05$), and less likely to refer to research documents (1 mention, $p < 0.05$). **Urban designers** contributed most of the mentions to guidelines (5 out of 6, 83%) while transport planners did not report using guidelines. **Urban designers with a transport planning perspective** were more likely to cite research documents (6 mentions, $p = 0.05$). There were however no significant differences in the frequencies of use of qualitative data, expert advice or audits ($p > 0.1$).

3.3. Incentives and deterrents to walking

Responses suggested five main types of incentives and deterrents to walking: **the quality of the street environments** (major potential deterrent and a potential incentive); **the broader transport system** (incentive to walking and to a lesser extent as deterrent); **the availability of destinations** (potential incentive or deterrent); **users' perceptions of their environments** (potential deterrent); and **health and fitness** (incentive). The frequencies of mentions are presented in Table 5 and detail (including subcategories and professional disciplines of respondents) is reported in supplementary file E.

Public health experts spoke only of deterrents relative to the street environment, objective or perceived, while other disciplines mentioned other aspects, such as weather. Health and fitness were mentioned 16 times as incentives for walking, 14 of which from practitioners who associated with urban design and/or transport planning. The topic was not noted as a deterrent and was mostly noted without further indications. The other topics referred to a range of aspects, examined below.

The quality of the street environments was noted as incentive or deterrent and was the biggest cluster of mentions. When noted as incentive, the quality mostly related to holistic design (e.g., "Urban amenity" or "Nice environments"). Other characteristics were noted each by one participant only (footpaths design, presence of other people, greenery, shelter, traffic intensity or priority at crossings). Quality of street environments was also seen as potential deterrent. In this case, quality related to the holistic design quality (e.g., "Barriers to walking including car focused infrastructure and deficient pedestrian infrastructure" or "hostile road environment"); the crossing facilities, relating to availability, layout, waiting time or interactions with traffic; and the motorised traffic, referring to traffic volumes, speeds, noise and fumes.

When examining the aspects cited within the broader umbrella of quality, the answers were diverse. Holistic design was noted both as a possible incentive and deterrent (eight and ten mentions, respectively). **Quality when noted as an incentive** related to six other aspects, noted one time each (oversight of the street, waiting time at signalised crossings, footpaths design, greenery, shelter, and traffic along the path). **Quality when noted as a deterrent** also related to the crossing facilities (availability, layout, appropriateness regarding traffic conditions, waiting times; 7 mentions), and the traffic and the associated noise and pollution (6 mentions).

Some polarisation was observed across professional clusters: those associating with urban design/strategy and/or transport planning contributed the bulk of the mentions to qualities of street environments (11 out of the 14 noted incentives, 79%; and 19 out of the 23 deterrents, 83%), and transport planners were the only ones who spoke of the crossings (7 mentions as deterrents).

The broader transport system was a label applied to answers comparing walking to other modes or speaking of walking as the companion mode of public transport. Professionals considered that walking was chosen when more convenient, faster, cheaper, or more sustainable than other modes or convenient when combined with public transport. The transport system was also noted as a potential deterrent, mainly in relation to the ease of driving (e.g., "why walk or PT/walk when you can drive", or "Driving is too easy"). The different professional disciplines mentioned the topic at similar rates ($p > 0.1$).

The availability of destinations was either explicit (e.g., "A mix of land uses meaning key things to walk to are in walking distance", "Distance to useful destinations is not walkable") or implicit, participants mentioning for instance "distance" or "(in)convenience", without further indications. There were no significant differences in the frequencies of mentions of destinations across professional groups ($p > 0.1$).

Users' perceptions of their environments noted as incentives related to pleasantness, comfort and safety. While some responses were loosely associated to the environment (e.g., "Traffic danger from motor vehicles"), the responses did not provide much detail overall on the environmental aspects that could incentivise or deter from walking. Perceptions noted as deterrents related mostly to a lack of safety (12 out of 15 mentions, 80%). Public health professionals mentioned perceived safety more often than other disciplines ($p < 0.05$).

When comparing the mentions to the environmental dimensions (broader transport system, availability of destinations, quality of street environment and walking network) given by the professionals and those previously collected from users (Bozovic et al., submitted for publication), some significant differences were found. The professionals were less likely to mention the broader transport system as incentive ($p < 0.05$) but more likely to mention it as a deterrent ($p < 0.01$). Professionals were also more likely to indicate the availability of destinations as an incentive ($p < 0.1$) but less likely to mention the walking network (connectivity, topography) as a deterrent ($p < 0.1$). The frequency of mentions of street environment quality as incentives or deterrents were not significantly different

Table 5
Incentives and deterrents to walking - professionals' inputs coded against dimensions and ordered by highest percentage of mentions, either as incentive or as deterrent.

Dimension	Incentives N	Incentives % mentions	Deterrents N	Deterrents % mentions
Street environment - quality	15	24%	23	44%
Broader transport system	17	27%	7	13%
Destinations	15	24%	15	29%
Perceptions	8	13%	14	27%
Internal motivations/deterrents	17	27%	2	4%
External motivations/deterrents	4	6%	12	23%
Walking network	1	2%	2	4%
Other	0	0%	0	0%
Total mentions	**62**	**100%**	**52**	**100%**

at $p < 0.1$. The comparison is displayed in supplementary file E. The professionals' views on the incentives and deterrents to walking appeared both dispersed and different from the users' views. This observation prompted the research team and the Citizen Scientists involved to further discuss this topic in the focus group (results reported below).

3.4. Priorities

Each participant indicated their main priorities relative to improving accessibility on foot/by wheelchair (three-year and ten-year horizons). Three main topics were identified from the 56 responses: the quality of the walking environment, design and delivery, and the systemic nature of the walking realm. An overview of the topics is presented below, and detail findings are in supplementary file E.

The quality of the walking environment was noted 42 times (75% of the mentions), without significant differences in frequencies across professional groups ($p > 0.1$). The participants most often associated quality with a holistic vision of design: eleven spoke of better streetscapes in general (e.g., "Improved walking infrastructure, wider streets, sep[a]ration from traffic, improved crossings. Walking is given greater priority"), while five specified that this design needs to provide a good walking experience to users regardless their age or ability. Nine of the 42 mentions (21%) related specifically to traffic, participants noting the importance of streets with low traffic, low speeds, or no traffic at all. The idea of quality was mostly associated to design and delivery (36 of the mentions, 86%), however some participants also mentioned the importance of policy (e.g., "Change design standards and road rules so that pedestrians have genuine priority in a fully accessible way."); footpath maintenance; planning (requiring accessibility considerations early on, in projects development) and data (one participant noting the need to access current levels of accessibility). Professionals who associated with both urban design and transport planning spoke less often in proportion of the quality of the walking environment than the other groups ($p < 0.01$). The priorities mentioned by group covered a wide range of aspects, such as maintenance, better planning, or policy.

Design and delivery were noted 44 times (78% of all the mentions). Inputs related to the "how" (e.g., "universal [design] approach mandatory for new and existing streets and spaces", "LQC [light, quick, cheap] opportunities - where small moves could add up to a bigger whole") or the "what" (e.g., safer crossings, or low traffic neighbourhoods). Four mentions (10%) did not relate directly to the quality of the walking environment but mentioned urban density (three references) or good quality public transport services (one reference). Again, this topic was less mentioned by those who associated with both urban design and transport planning ($p < 0.05$).

The systemic nature of the walking realm was sometimes noted directly, referring to holistic pedestrian-friendly environments and their multiple facets (11 mentions, 20%), but mainly suggested by the diversity of types of actions noted: the priorities noted by the professionals included design and delivery (new build, retrofit, or both), policy and regulation, maintenance, data collection, education, and planning. The responsesincluded diverse features of the walking environments: a range of elements of the built environment, but also traffic, urban density, activation, pedestrian network connectedness and public transport service. Among the clusters of professional disciplines, those participants who associated with both urban design and transport planning seemed to have the broadest view in terms of system-related priorities.

3.5. Challenges

The professionals were asked to name *the single biggest challenge regarding the improvement of street environments*. Three main topics were identified: **the lack of prioritisation of walking** (15 mentions, 54%); **an inherited car-dominated environment** (14 mentions, 40%); and **the inability to implement change** (11 mentions, 39%). Eleven responses referred to two or three topics each.

The lack of priority given to walking was described as both technical and political (e.g., "Aside from budget, I think there is an underlying car-centric mindset amongst designers and policy makers which reflects on the streetscape. […] The language is still car centric; for example, highway and intersection design levels of service are centred around vehicle delay and travel time. Even though pedestrians use the same intersection, their time is valueless and is not captured in the design."). The participants' emphasis on this theme as well as its importance for delivering more walkable environments prompted to further discuss it in the focus group (below).

The mentions to car-dominated environments suggested a need for re-allocating space and/or priority, or were simply stated as the challenge, implying the extent of the inherited inadequate infrastructure. One participant described the issues as "[…] roadside parking, long crossing times and intimidating signalised crossings, vehicle priority at minor roads, roads maintained whilst footpaths are not etc." The car-oriented environment was implicitly associated to a lower pedestrian amenity and often mentioned together with the challenge of delivering change and retrofitting the urban environment. One participant noted that the challenge was the "reallocation of priority from other uses, esp. space from traffic/parking lanes, time/delay at crossings".

The inability to deliver change was associated to design and delivery, policy, and a combination of both. The challenge regarding design and delivery related to understanding users' needs, having the appropriate tools and knowledge, bureaucracy, and inadequate everyday practices, as illustrated by the quote below:

> *Traffic modelling (belief in). There are many people in senior roles New Zealand who believe that the traffic model, with all its simplifications, assumptions and parameters, must be 'solved' for streets to be successful. Erroneous assumptions (e.g. that traffic is "a liquid that always flows somewhere") are stated by people who should know better. This attitude, when it excludes user-centred design, rarely leads to improvements in street environments. Actually, it never leads to improvements in street environments.*

References to policy mentioned investment allocation, political courage and inertia, as illustrated in the quote below:

Political/social inertia which continues the dominance of car-oriented thinking above all else. Reluctance to implement any real change for fear of inconveniencing/upsetting drivers (voting public). Design and planning for walking is not technically difficult, but implementing it appears to be almost beyond us.

One participant noted that "this is a system challenge, there is no biggest challenge". The idea of system was very present through this section, either explicitly as before, or through the references to the way the city has been designed, the professional practice, the policies and the governance. All the dimensions noted need to change, and this change either involves large scale retrofit, or a reconsideration of everyday practices.

The three topics have been mentioned by participants of all four professional groups, without differences significant at $p < 0.1$. It is however interesting to note that urban designers contributed nine of the 14 mentions to car-dominated environments (64%).

3.6. Assessment of walking as a complex socio-technical system

The participants were asked to indicate their level of agreement with four statements, in relation to the planning and delivery of the walking environments. The ratings for the four aspects had median values higher than 60/100, the highest being the dimensions of dynamic interactions and diversity of elements (see Table 6).

The four professional groups were compared based on the aggregate rating of complexity (average of the ratings provided for the four dimensions considered) and the frequency of high ratings (≥70/100). The median values were between 60/100 (public health) and 90/100 (transport planning with a road safety perspective). Results were more consistent amongst public health specialists and urban designers with a public health perspective (IQR 13 for both). Across participants, 63% of all ratings were ≥ 70/100. This ratio was lower for public health specialists (31%, $p < 0.01$) and higher for transport planners (78%, $p < 0.1$). The distributions and the complete results are presented in Table 6 and Supplementary file E.

3.10. Focus group inputs

The focus group took place on 17.11.2020, from 5 to 6 pm. The participants included four professionals (one of each discipline, by order of expressions of interest; none of the public health experts who had participated to the survey volunteered also for the focus group, therefore the discipline was not represented) and one Citizen Scientist. One of the professionals had not been able to participate in the focus group due to an emergency having occurred immediately prior. They were however keen to be involved in the process and this was achieved through a separate face-to-face interview. At this extra meeting, the professional gave their thoughts on the two topics and reacted to other participants' views, as reported by the facilitator.

The two sessions examined two prioritised topics: (1) **the lack of consensus regarding users' experiences and needs**, and the reasons why this lack of consensus does not appear as a challenge to implementation; and (2) **the lack of prioritisation for walking in the policy and the practice**, discussing the reasons for it and the apparent disconnect with the vision for Auckland as a liveable, accessible and carbon–neutral city (Council, 2018; Council, 2019).

A content analysis of the focus group's inputs helped understand the components of the two topics and their relationships, illustrated in Fig. 2. Links between the two topics were identified, in the form of a vicious circle: the lack of prioritisation of walking can explain why walking levels and experience are neither monitored nor used as indicators in decision-making; as user experience (UX) is not an indicator of success nor a decision-making input, it is not routinely considered in design and planning; transport planning either doesn't consider walking or uses proxies that assimilate pedestrians to "little cars", through models that consider their numbers, speeds and delay, but not the experience; there is therefore no overview of the difficulties faced by those who walk, participation (ability of diverse people to access their destinations on foot, and therefore presence of people of all ages and abilities in the streets) or suppressed walking trips; this lack of overview can explain the lack of consensus regarding UX, but also perpetuate a system where walking is not given much political priority.

The lack of UX, both in decision-making and project development, was a recurrent idea and also a key aspect of the noted vicious cycle. The participants provided rich insights relative to its reasons and consequences, explored below.

The lack of UX was often associated by the participants to a traffic-oriented "business-as-usual" practice. Two key ideas were discussed. Firstly, participants noted traffic-oriented decision-making metrics, stressing that if some projects examine UX, it is not a metric required for decision-making.

Table 6
Levels of agreement with the four dimensions of complexity characterising the planning and delivery of walking environment.

	Level of agreement with the dimension of complexity (0 to 100, n = 28)				% scores >= 70
Dimension of complexity	**median**	**IQR**	**min**	**max**	
Dynamic interactions	82.5	29.3	39	100	79%
Diversity	91.0	32.3	50	100	75%
Variability	71.0	41.5	30	100	61%
Resilience	60.5	34.0	19	100	39%
Total	**73.8**	**25.3**	**50**	**99**	**63%**

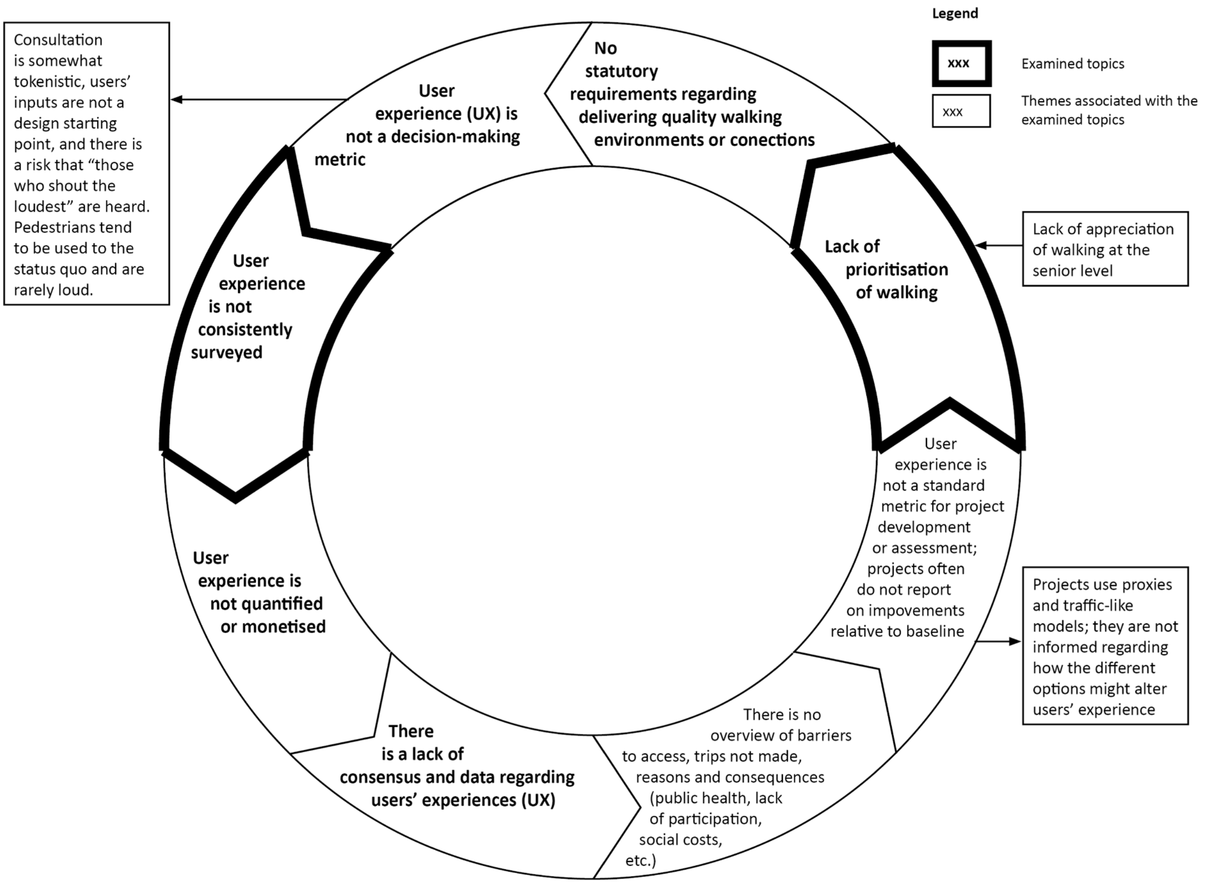


Fig. 2. Topics identified from the focus group and relationships.

The decision-making that we mostly deal with is about numbers and volumes and speeds and time, and safety risk. Nowhere in there is experience captured and so if your decision-making metrics exclude it, it's excluded from the process. […] we are dealing with people like we are dealing with vehicles – so we are counting them, looking at direction of travel maybe, A was talking about mass and force, regarding collisions and then you have visibility issues and he gave a kind of engineering solution of a potential risk between a pedestrian and a car, and it was very much not a human-focused solution. […] I've never been asked "did you include diverse groups of people in your project planning?". It's always "what's the benefit-cost ratio", in the end. "Oh, it's a good value project – we will do it". So all these things about policy and having more people included are fantastic, but if you can't include it in a value judgment, in the end it will just get excluded. And I experience that every day, so I know! - B, transport planner

If you cut AT [Auckland Transport] open it's not a cake, it's a traffic model – Q, urban designer

Professionals also described commonly used monetary indicators (benefit-cost ratio) that are less appropriate for assessing projects related to walkability or liveability because dimensions such as inclusion, accessibility or severance are difficult to monetise and routinely not monetised. One participant spoke with conviction about the needed monetisation of those benefits (quote above). Another, however, noted that the monetisation is both difficult and potentially unnecessary, arguing that if decision-making metrics included participation or accessibility, those aspects could be considered without the need of transforming them into dollar values.

Participants noted a lack of focus on walkability, liveability and carbon emissions at the governance level of local authorities. One of the participants explained this lack of focus by a certain lack of awareness of the members of transport authorities' Boards:

No one there knows much about transport. They know lots about governance – they are lawyers, or accountants. I mean, the main thing with governance is that you are doing everything you are meant to do legally and that you are financially competent. So you need good accountants and good lawyers for that. It means that decision-making doesn't have anything to do with transport. It is about good governance. Which leads to a real reversion to conservatism and path dependency and you don't rock the boat or the tanker – you stick with what you know and it's very difficult to bring meaningful change […]. If in your twelve Board members you had someone from Living Streets, someone who has had a 20-year career in transport analysis, a land use planner, and so on – you would have very different questions, and very different outcomes. – Q, urban designer

Given that UX is not required for project evaluation, the experience is not routinely monitored and planning does not consider how it might be altered. When walking is assessed traffic-like models are used. In those models, pedestrians are not more than moving units, and results assess a form of hydraulic feasibility of footpaths, as explained by one participant:

I think that our processes are very much set up in an engineering sense to deal with metal boxes moving around, and that people are treated as a small metal box. So there is nothing about experience and how they might feel, and what might make them walk, not walk, or feel more comfortable walking – none of that is there. It's simply how many were there, where were they going, is there enough room for them, and maybe is it safe? – B, transport planner

The participants abundantly spoke about the issues caused by both the absence of a shared view of users' needs and the lack of prioritisation. They noted the need to better understand why certain trips are not walked and to capture the diverse needs:

I think also that when we talk about "the user", we need to further break it down. We need to gather more information – whether it's just talking to people with different life experiences or conditions, or research and bring it all together. People find urban spaces hostile for different reasons. – O, urban development strategy expert

The issue of the lack of prioritisation was both related to its influence on practice but also to the idea that a systemic change was needed:

I think that you need a statutory change because – the point is, you can't do it one piece at a time because it requires too much effort. It needs to be something fundamental. I think that a legal requirement to use every opportunity to enhance pedestrian amenity would be fundamental. – Q, urban design specialist

4. Discussion

This study engaged with 28 professionals involved in the design of street environments and public health, in Auckland, New Zealand. Through an anonymous online survey, professionals provided insights regarding what matters (what is a walkable city, what incites or deters from walking, and how well we understand users' needs) and how walkability is delivered (evidence used, priorities and challenges). They also indicated their level of agreement with four statements framing the delivery of walkable environments as a complex socio-technical system.

Answers about incentives and deterrents were analysed through deductive content analysis (Elo and Kyngäs, 2008) and associated with topics drawn from the previously outlined Social Model of Walkability (Bozovic et al., 2020). As a reminder, the model's *inputs* are the walking environment and the transport system. The inputs are linked to walking behaviour through the moderating effects of people's perceptions of walkability (hierarchy of walking needs) and their personal characteristics (Bozovic et al., 2020). The open answers regarding what makes a walkable city, priorities, challenges, and evidence available were coded using deductive content analysis (Elo and Kyngäs, 2008), the codes being developed from the data. A focus group further aimed to clarify the reasons why users' experience (UX) is not agreed upon and the reasons for the observed lack of priority given to walking.

The findings are discussed below. First, we examine the findings to each research question separately. Second, we discuss the case of dimensions of the walking environment and transport system for which inconsistencies in feedback were noted across the questions.

4.1. Question 1: How is "walkability" understood?

Participants' responses regarding how a city could support walking were overall consistent with the Social Model of Walkability (Bozovic et al., 2020) (further referred to as the model). The participants predominantly noted the importance of holistic quality of street environments but also people's perceptions: feeling safe, having enjoyable walking experiences, and perceiving the environment as accessible.

This emphasis on quality and people's perceptions can seem surprising given that transport engineers have historically had a more functional approach to walking, modelling pedestrian flows as they model vehicles' movements (Hutabarat Lo, 2009). For instance, D'Arcy analysed in depth the understanding of walkability across professional disciplines, finding some consensus around functional aspects and safety, but a lack of agreement relative to aesthetics and comfort (Fitzsimons D'Arcy, 2013). Further, D'Arcy's analysis also indicated engineers' tendency to value functional aspects (Fitzsimons D'Arcy, 2013), in line with the historical trend noted by Lo (Hutabarat Lo, 2009). In the focus group, the participants had spoken of habitual transport planning processes treating pedestrians like "little cars" and ignoring experience. The fact that participants valued the quality of walking realms and people's perceptions could be explained by the recruitment method, through researchers' networks: the principal researcher is a transport planner focusing on walkability and with a history of collaborations with urban designers and landscape architects. Therefore, the professionals recruited could represent a more progressive fringe of transport planning. Another possible explanation could be that the transport planning field has progressed towards a more humanist approach. The quality of the street environments had also been a major topic gathered from the interviews of 56 Auckland adults, who predominantly mentioned

The three types of perceptions noted (safety, accessibility, pleasure) are part of the hierarchy of pedestrian needs, a key moderator between the environment and the walking behaviour, in the model. The professionals' views align therefore with the posited model. Interestingly, the dimension of feasibility, or: having destinations in a reachable distance, was not directly noted, despite being the core component of most commonly used walkability indices such as WalkScore ™ (Score, 2018). Implicitly, professionals saw walkability from the angle of the walking *experience*, rather than the mere physical possibility of reaching destinations.

The broader transport system, including the provision for transport alternatives, was mentioned, although much less than the physical walking environment. This aspect is examined below (Overview: walking environment and transport system across dimensions).

Interestingly, the responses to the question how well the barriers to walking are understood were very diverse, ranging from "not well at all" to "extremely well". While knowledge gaps have often been identified in the literature (e.g. (Forsyth, 2015; Mindell and

Karlsen, 2012; Hutabarat Lo, 2009), it can be surprising that a good understanding would be noted for Auckland, especially in the absence of shared evidence regarding the barriers (nature, location) and the numbers of people affected by them. A previous survey of 238 New Zealand transport planners had shown that a small percentage (6.7%) thought that good data was available about pedestrians (Burdett, 2016).

The participants quoted a variety of sources of evidence, when asked what would help them make a case for barriers experienced by Aucklanders. There was no clear consensus or “go to” source of information, and no document was cited more than two times. Gathering of evidence appeared to be mostly ad hoc. When mentioning specific data sources, two thirds of the mentions referred to data other than users’ insights (for instance street quality audits or even international guidelines), which could be related to Andrews’ view that much is assumed, regarding what matters (Andrews et al., 2012), and then potentially measured.

Interestingly, no one mentioned the users’ insights on walking commissioned annually by Auckland Transport (TRA., 2018), although some respondents noted “Auckland Transport resources” without more detail. This ongoing research, now replicated at the national level, questions users about walking (agreement/disagreement with statements such as “I don’t feel safe”). The published overview reports present adult Aucklanders’ views of their environments (e.g., barriers and motivations to walking) but with two major caveats: these data are collected only from people who declare not having difficulties walking, and the perceived barriers are not further related to objective environmental characteristics. These gaps might contribute to a lower usability, especially from the part of professionals focusing on infrastructure and its features. To the authors’ knowledge, Auckland does not have a form of inventory of barriers to walking, that could be a start for a prioritised action plan.

Data gaps had also recently been noted by lge-Elegbede and colleagues, examining professionals’ views on the barriers to integrating public health evidence in spatial planning, in the UK (lge-Elegbede et al., 2020). The 162 respondents were asked to rate their agreement with potential challenges. A majority agreed with a lack local evidence ready to be translated into practice (91% agreement) and lack of monitoring and evaluation of the planning decisions, implying missing data that could be used in future decisions (81%) (lge-Elegbede et al., 2020). Surprisingly however, the absence of data was not one of the important topics in the present survey, when talking about challenges to retrofit. However, this aspect was largely discussed in the focus group and linked to a lack of interest in pedestrian experiences. The participants stressed the need to transform a car-oriented environment. Both aspects suggest the need for data that could be used as practical and pragmatic decision-support. Differences noted between professional disciplines indicate a need for building a common understanding of urban complexity and its critical links, for instance transport – public health, or land use – urban design – travel patterns. This need has been stressed by previous research (e.g., (Giles-Corti et al., 2016; lge-Elegbede et al., 2020; Sallis et al., 2016).

4.2. Question 2: How are facilitators of and barriers to walking described?

The disparity of the responses and the inputs from the focus group revealed an important gap in the understanding of users’ experiences and attributes that could be perceived as incentives or barriers. This finding aligns with previous results gathered in New Zealand: Burdett had identified that only a small minority of transport planners considers that pedestrians’ needs are well understood (Burdett, 2016), while Park and colleagues found differences between barriers to access to transit as perceived by professionals (transport planners, urban designers, and policy-makers) and users (Park et al., 2020). The finding is however at odds with a piece of work commissioned by the New Zealand Transport Agency, stating that “The overall drivers and barriers to walking and cycling are well understood; they remain constant over time.” (TRA., 2019) The commissioned research captured general perceptions of walkability (e.g., safety or convenience), not examining however what features of the built environment might influence them and how these associations might vary across demographics (e.g., availability of other options, habits, or disability).

Under the New Zealand Transport Outcomes Framework, having inclusive access as one of its five pillars (Ministry of Transport, 2018), the Ministry of Transport is leading an initiative aiming to inform people’s perceptions of transport and experienced barriers (Ministry of Transport, 2020). The existence of this initiative seems to support the need to better understand people’s perceptions and how they relate to their environments. However, the way this topic has been addressed indicates a rather shallow approach, not addressing the “what” causes difficulties to whom.

The barriers and incentives stated by the professionals were based on disparate elements of evidence but also often on personal experience and assumptions. This observation seems to support the idea of a lack of quality data on users’ experiences, shared across professional disciplines. The participants’ emphasis on convenience/availability of destinations and perceived safety both reflect declared barriers to walking from the Auckland Transport active modes survey (TRA., 2018). Interestingly, the ease of driving did not come up as a major deterrent to walking, in contradiction with evidence suggesting the importance of both ease of driving and public transport services respectively as barriers to or facilitators of walking (Bozovic et al., 2021; Rafferty et al., 2004; Stevenson et al., 2016). This point is examined below (Overview: walking environment and transport system across dimensions).

Future research should examine what environmental characteristics are associated to users’ perceptions, namely those relative to the experienced difficulties, targeting in priority populations most likely to be excluded. An example of such an approach is given by Transport for London: at risk users group are defined (including disabled people or people with a low income), the barriers they face are analysed in detail, and an effort is made to address those barriers and incorporate inclusive design in all processes (Transport for London, 2019). While Transport for London stresses that understanding and addressing barriers is “integral to success” (Transport for London, 2019), it was found here that the improvement of users’ experience is not considered as an indicator of success and is not part of decision-making metrics. A change is required at policy level: projects should be assessed not only on a benefit-cost scale but also in terms of their contributions to the visions regarding ease of walking or modal shift – a recommendation already made globally (Giles-Corti et al., 2016; Sallis et al., 2016) or for instance specifically for the UK (lge-Elegbede et al., 2020).

4.3. Question 3: How is pedestrian accessibility implemented?

For the professionals, the priority relative to improvements to pedestrian accessibility related mostly to the quality of street environments, which participants associated to both traffic (especially reduction of vehicle flows and/or speeds and safer crossings) and physical infrastructure providing for all ages and abilities (design and maintenance). Availability of destinations and improved public transport were mentioned only by a small minority of responses (3/56 and 1/56, respectively). In a sprawling, low density city like Auckland (Nunns, 2014), it could be quite surprising not to see a greater role given to intensification.

The challenges relative to improving street environments related to retrofitting a whole inherited car-oriented infrastructure, but also to transport planning practice geared towards delivering more of the same. One participant noted that "this is a system challenge, there is no biggest challenge", and the focus group stressed the lack of political priority, further linked to inadequate data and processes. Governance of transport agencies was described as broadly lacking awareness of the issues and potentials associated to walkability, liveability or public health. This aspect is a major challenge in delivering future visions and aligns with the findings of Carron Blom's thesis, having noted a disconnect between strategies and infrastructure, and "inability to fully deliver appropriate and relevant infrastructure outcomes over the long term" (Blom, 2017). Sectorial differences in priorities had also been noted even by New Zealand's Infrastructure Commission, warning the new Minister of the array of negative outcomes they can have (Waihanga and New Zealand Infrastructure, 2020).

Participants stressed that the improvement of quality of the walking environments or improvements of users' experiences (UX) are not captured in the metrics used to assess projects and take investment decisions. The lack of UX in the evidence available and the processes reflects recent findings from the UK (Middleton, 2010; lge-Elegbede et al., 2020). Middleton and colleagues posited that examining walkers' experiences could even seem unnecessary, noting that "much of this policy-commissioned research assumes walking is a homogeneous and largely self-evident means of getting from one place to another. As such, the very practice of walking is positioned as a functional, easily understandable mode of transport people 'just do' and to this end the ways in which walking is understood and engaged with is essentialised as a self-evident activity." (Middleton, 2010). This lack of interest in UX appears at odds with the widespread use of this approach in other sectors, such as product development: a quick search for "ux" yields almost 550 million entries from Google, and 6,302 results from Scopus (Elsevier, 2020), three quarters of them published in 2017 and later. In a paper from 2006, cited by over 1,300 publications, Hassenzahl and Traktinsky noted that the term had become a buzzword in the area of human–computer interaction design and offered a proposal for future research (Hassenzahl and Tractinsky, 2006).

Improvement of the walking environment would require a strategic shift, including a progressive retrofit of current environments, with appropriate budgets and focus; the requirement to deliver benefits regarding access, inclusion, participation, and climate change; adequate monitoring of users' perceptions (user experience), behaviours, and the infrastructure; and expertise at the governance level (Boards of the national and local transport agencies).

4.4. Question 4: How do professionals perceive the complexity of delivering walkable environments?

The rapid assessment of four dimensions of complexity suggests that professionals consider the delivery of walkable environments as a complex socio-technical system (CSTS): an evolving, multi-dimensional entity (Davis et al., 2014). UCL's Lancet Commission had grounded its analysis of the delivery of healthier cities in the notion of complexity (Rydin et al., 2012).The potentials of CSTS had previously been outlined: Adelt and colleagues outlined for instance the appropriateness of the approach to governance and took the urban transport system as a practical example for implementation (Adelt et al., 2018). The team also noted being surprised by the lack of discussion on how to apply system approaches to governance, in an era where multitude of complex systems need to be influenced or re-directed (Adelt et al., 2018). Importantly, complexity implies that incremental improvements need to be tested and monitored, within an iterative learning process (Rydin et al., 2012).

An example of application of socio-technical systems approach was shown by Hoffmann and colleagues, examining how existing European "automobility regimes" could be shifted towards sustainable mobility (Hoffmann et al., 2017). They outlined structural issues relative to the large number of actors and dimensions (e.g. behaviours, technology, infrastructure, funding, regulation), their interactions, as well as established social norms and models, and suggested that a shift to a sustainable mobility cannot be achieved simply through the offer of new alternatives (Hoffmann et al., 2017). The systemic challenges relative to delivering more walkable environments encourage further research aiming to identify levers of intervention.

Our results suggest however different perceptions of complexity across disciplines: higher complexity for transport planners (based on ratings) and urban designers (based on the higher variety of aspects mentioned by this group as potential deterrents to walking) and lower complexity for public health specialists. This finding could be due to the differences in understanding of walkability noted above. Authors have also noted past tendencies to segmented approaches, failing to fully acknowledge and address the repercussions they might have on other sectors (Burdett, 2017; Sallis et al., 2016). Our findings support previous calls for a greater awareness of sectorial interdependencies, at the policy and implementation levels (Burdett, 2018; lge-Elegbede et al., 2020; Rydin et al., 2012).

4.5. Overview: walking environment and transport system across dimensions

The quality of street environments was generally agreed upon as key characteristic of a walkable city, a potential incentive and deterrent to walking, but also a priority for retrofit and a challenge (delivering change in a car-centric environment). The responses did not provide however a clear picture of the "what" should be addressed: firstly, numerous features of the walking environment were indicated (e.g., destinations, crossings, quality of street environments noted in general). Second, the participants also took the users' perspective, talking about perceptual qualities of the environment (e.g., "that INVITES you to walk"), raising the question what it is, that prompts the desired perceptions of pleasantness, convenience, comfort, or safety? Thirdly, the challenges cited had a strong focus on transforming a car-oriented environment, which again calls for an agreement regarding what should be done and how the expected long "to-do list" should be prioritised. While all the professional groups considered mentioned quality, as incentive or deterrent to walking, or characteristic of the walkable city, it is possible that quality can be conceptualised differently: for instance, public health specialists' mentions of feeling safe and transport planners' references to crossings could both to relate to environments where a pedestrian does not feel threatened by traffic.

The broader transport system, including the provision for driving and public transport, was seen in diverse ways by the professionals thinking of related topics (walkability, incentives, and deterrents to walking, priorities and challenges). The comparative quality of walking as compared to the alternatives available was suggested as incentive to walking, and both potentials and challenges spoke about a system geared towards the comfort of driving. However, although some participants noting that driving is "too easy" in Auckland and that the city is "car-centric", the ease of driving and the poor quality of public transport were not major topics within the potential deterrents to walking. Previous research had however suggested the importance of considering walking within the broader transport system: namely, perceived ease of driving was cited as a major deterrent to walking, by interview participants (Bozovic et al., 2021; Rafferty et al., 2004; Walton and Sunseri, 2007; Badland, 2007); conversely, the perceived difficulties of driving were associated with increased walking (Bozovic et al., 2021); and the case was made for an efficient public transport as the natural enabler of walking (Hillnhütter, 2016; Institute for Transportation and Development Policy., 2018; Speck, 2012). The importance of the broader transport system supports the idea of cities as systems (or CSTS), where outcomes such as the modal share of walking cannot be understood by examining the walking realm in a vacuum (Forsyth, 2015). It could also help explain the high ratings given by the participants to the dimensions of complexity, possibly influenced by chain reactions linking different modes (e.g., it is easy to drive, therefore people drive which can incite them to choose neighbourhoods accessible primarily by car, meaning in turn low density, low potentials for public transport and low attractiveness to walking, further inciting to drive).

Park and colleagues had noticed that policy-makers in the transport field tended to focus more on built, tangible characteristics, rather than on perceptions or "soft" characteristics (Park et al., 2020). This explanation could help understand the apparent disconnect between on the one hand the car-oriented *environment* identified by the participants of this study as a priority for improvement, a challenge and a barrier, and on the other hand a lesser consideration of the *ease of* driving.

The idea of the walkable city as a CSTS coupled with the indication that this systemic characteristic is inconsistently considered have important implications. For both the practice and the research, they suggest the need to examine conditions of walking *within the broader system* and communicate the importance of the qualities of walking *as compared to* other options available. The trap to be avoided would be to speak about physical features of the walking realm, without much consideration of the experience of accessing destinations on foot, as compared to using other modes of transport.

5. Significance and contributions

Following the numerous previous calls for more walkable cities, this work examined the *how* and the potential hurdles in retrofitting an inherited car-dominated environment. The results outlined that while complexity and the need of reversing the car dominance are generally acknowledged, the professionals of different disciplines can have different understandings of walkability. The findings suggest actions regarding both policy and delivery.

5.1. Policy level suggestions

- **Vision to action.** Ensure linkages between high level objectives (e.g., accessibility for all) and practical implementation – namely: delivery of walkable environments and prioritised retrofit of barriers. This requires revisiting the funding decision mechanisms, including data and indicators; ensuring coordination between different sectors delivering infrastructure or dealing with its outcomes (transport, urban design, health, road safety, economy); and providing appropriate funding.
- **Addressing the needs of those who need it most.** Identify populations of greatest need, regarding accessibility on foot/wheelchair as a primary mode or as access to public transport, investigate their needs and current barriers, and confirm budgets and time frames for addressing those barriers.
- **Prioritised retrofit.** Ensure the tools and processes do consider users' experience and deliver against it. It is for instance known that benefit-cost ratios as applied currently in New Zealand are not well adapted to pedestrian improvements (Burdett, 2018; Burdett et al., 2017). Instead, projects should be prioritised against the value they deliver against policy objectives, namely accessibility, safety, health, well-being, or climate change mitigation.
- **Awareness and education.** A sound understanding of the systemic complexity of cities is necessary. Decision-makers need to be aware of the important interactions between land use, transport planning, health, well-being, participation, and local economies, namely. This understanding should be strengthened through training, inter-sectorial collaboration (for instance, health and urban design experts on the Boards of transport authorities), and resource allocation towards shared evidence bases.

5.2. Suggestions for planning and delivery

- **Vision-based action plans.** The action plans should be crafted towards delivering on the vision and specific enough about targets and interventions. This will require data currently not available – for instance, barriers to walking, their magnitude and the populations they affect.
- **Addressing the needs of those who need it most.** Data on barriers to walking should be improved so to better understand who has barriers to walking and what the specific barriers are. This should include substantial user engagement and collaboration with academia. Data gathered should be used to prioritise interventions.
- **Prioritised retrofit.** Practice to take ownership on delivering higher visions such as access, climate change mitigation, public health or participation. This will mean changing some planning standards – instead of a predominant reliance on traffic models and benefit-cost ratios, retrofit should be prioritised acknowledging user experience and broader benefits against policy objectives. Sound monitoring and evaluation should be in place so to learn from the improvements made and the projects underway (for instance: implementations under the Innovating Streets (Waka Kotahi and Agency, 2020) initiative, in New Zealand).
- **Awareness and education.** Professionals need to be aware of the important interactions between land use, transport planning, health, well-being, participation, and local economies. This understanding should be strengthened through training (both at graduate levels and throughout the career) and more integrated approaches (for instance, collaborations between transport planners, urban designers and public health experts should become more common).

6. Strengths and limitations

This work has four major strengths. First for the first time in New Zealand, it targeted a range of disciplines involved in the design of streets and public health, to better understand the breadth of views regarding needs, priorities and challenges associated to walkability. Second, after having analysed survey data through content analysis, questions requiring more detail were examined in a focus group. Thirdly, insights were triangulated, examining the roles of the quality of the walking environment and the broader transport system from different perspectives (attributes of walkability, incentives, and deterrents to walking, priorities and challenges). Fourth, practical recommendations based on findings were made for both policy and practice.

Several limitations are to be noted. Firstly, the sample size of practitioners ($n = 28$, nine to fifteen associating with each of the five targeted disciplines) and the clustering into groups that might have some heterogeneity. Second, recruitment through researchers' networks includes a risk of "echo chamber". Third, while all the professionals are active in New Zealand and therefore provide useful insights regarding the local practice, the results might not be directly transposable to environments presenting strong differences in comparison to New Zealand (namely: cities with higher densities and transport systems that hadn't been predominantly influenced by traffic). Future research should investigate perspectives between professionals involved in the design and retrofit of walkable environments elsewhere, identify patterns (for instance: are there commonalities across car-dominated cities?), and inform best practice (what is done differently in cities where professionals' views are consistent and aligned with users' needs – for instance, is there a culture of UX and interdisciplinary exchange?).

7. Conclusion

Improving urban environments to support walking aligns with the current urgency of providing urban environments that deliver drastically better outcomes in terms of greenhouse gas emissions, public health and inclusion. Considering Auckland, New Zealand, this study examined how professionals of different disciplines understood the needs, challenges and priorities relative to delivering walkable environments. The findings indicate (a) a general agreement on the priorities and challenges (car-dominated realm and practices, and the need of transforming them in a consistent and systemic way), and on the complexity associated with delivering good walking environments; (b) a lack of consensus and shared evidence on user experience (UX), namely regarding features of the walking environments that might now cause barriers; and (c) a tendency of not considering the comparative convenience of driving as a barrier to walking. Underlying issues included a lack of prioritisation of walking linked to the lack of UX evidence through a negative chain reaction and possible communication gaps between professional disciplines. Through the in-depth analysis realised, this study identified complexities of and barriers to improving walkability. Findings were further used for crafting recommendations to policy and practice. Further research should investigate other cities, identify common patterns, develop the recommendations suggested here, and inform best practice in terms of multidisciplinary collaboration based on UX.

Acknowledgements

Tamara Bozovic is supported by the Auckland University of Technology Doctoral Scholarship, and Melody Smith is supported by a Sir Charles Hercus Health Research Council of New Zealand Research Fellowship (grant number 17/013).

No direct funding was received for this project. The authors do not declare any conflict of interest.

The authors would like to acknowledge Auckland Transport for having made the anonymised survey data available for this research, and Dr Moushumi Chaudhury for her inestimable help with the focus group and the workshop with Citizen Scientists.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2021.06.011.

References

Adelt, F., Weyer, J., Hoffmann, S., & Ihrig, A. (2018). Simulation of the governance of complex systems (SimCo): Basic concepts and experiments on urban transportation. *JASSS, 21*(2). https://doi.org/10.18564/jasss.3654.

Alfonzo, M. (2005). To Walk or Not to Walk? The Hierarchy of Walking Needs. *Environment and Behavior, 37*(6), 808–836. https://doi.org/10.1177/0013916504274016.

Smart Growth America, & National Complete Streets Coalition. (2019). Dangerous by Design 2019. Retrieved from https://smartgrowthamerica.org/resources/dangerous-by-design-2019/.

Andrews, G. J., Hall, E., Evans, B., & Colls, R. (2012). Moving beyond walkability: On the potential of health geography. *Social Science & Medicine, 75*(11), 1925–1932. https://doi.org/10.1016/j.socscimed.2012.08.013.

Gehl Architects. (2010). Auckland Public Life (p. 53). Copenhagen: Gehl Architects · Urban Quality Consultants. Retrieved from http://knowledgeauckland.org.nz/assets/publications/Auckland_Public_Life_Survey_2010_Part_1.pdf.

Badland, H. M. (2007, September 9). Transport-related physical activity, health outcomes, and urban design: descriptive evidence (Thesis). Auckland University of Technology. Retrieved from http://aut.researchgateway.ac.nz/handle/10292/350.

Blom, C. M. (2017, November 1). Strategic intent and the management of infrastructure systems (Thesis). University of Cambridge. Retrieved from https://www.repository.cam.ac.uk/handle/1810/268224.

Bozovic, T., Hinckson, E., Stewart, T., & Smith, M. (Submitted for publication). How street quality influences the walking experience: a naturalistic inquiry into the perceptions of adults with diverse ages and disabilities.

Bozovic, T., Hinckson, E., & Smith, M. (2020). Why do people walk? role of the built environment and state of development of a social model of walkability. *Travel Behaviour and Society, 20*, 181–191. https://doi.org/10.1016/j.tbs.2020.03.010.

Bozovic, T., Stewart, T., Hinckson, E., & Smith, M. (2021). Clearing the path to transcend barriers to walking: Analysis of associations between perceptions and walking behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour, 77*, 197–208. https://doi.org/10.1016/j.trf.2021.01.003.

Burdett, B. (2016). Mind the gap: Views on transport accessibility among transport professionals and the public of New Zealand. Retrieved from https://www.tgconference.co.nz/tuesday-papers-16.

Burdett, B. R. D., Locke, S. M., & Scrimgeour, F. (2017). The Economics of Enhancing Accessibility. *International Transport Forum Discussion Papers, 21*. https://doi.org/10.1787/84eb3253-en.

Burdett, B. (2017). Understanding Pedestrian Safety in New Zealand. In PENZ Transportation Group Conference, Hamilton 29 – 31 March 2017 (p. 14). Retrieved from https://static1.squarespace.com/static/5591f57ee4b07952c1a4d8bd/t/58b4c7dd725e25bf6113074e/1488242659802/Burdett%2C+Bridget+-+Paper+26+-+Understanding+pedestrian+safety+in+New+Zealand.pdf.

Burdett, B. (2018). Transport, participation and wellbeing: Evidence and recommendations (No. 12513917) (p. 70). Hamilton, New Zealand: Waikato Regional Council. Retrieved from https://www.waikatoregion.govt.nz/services/publications/tr201818/.

C40 Cities. (2018). Summary for Urban Policymakers: What the IPCC Special Report on Global Warming of 1.5°C means for Cities. C40 Cities. Retrieved from https://www.c40.org/researches/summary-for-urban-policymakers-what-the-ipcc-special-report-on-global-warming-of-1-5-c-means-for-cities.

Chapman, R., Dodge, N., Whitwell, K., Reid, P., Holmes, F., Severinsen, C., … Sobiecki, L. (2017). Why and how New Zealand cities could become more compact and sustainable. In Cities in New Zealand : preferences, patterns and possibilities (New Zealand Centre for Sustaiable Cities by Steele Roberts Aotearoa., pp. 51–65). Wellington, Aotearoa New Zealand. Retrieved from https://catalogue.nla.gov.au/Record/7505952.

Auckland Council. (2018, June). The Auckland Plan. Retrieved from https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/auckland-plan/Pages/default.aspx.

Council, A. (2019, July). Draft Te Tāruke-ā-Tāwhiri: Auckland's Climate Action Framework. Auckland Council. Retrieved from https://www.aucklandcouncil.govt.nz/have-your-say/topics-you-can-have-your-say-on/auckland-climate-action-framework/Pages/consultation-documents.aspx#panelLinks.

Davis, M. C., Challenger, R., Jayewardene, D., & Clegg, C. W. (2014). Advancing socio-technical systems thinking: A call for bravery. *Applied Ergonomics: Human factors in technology and society, 45*, 171–180. https://doi.org/10.1016/j.apergo.2013.02.009.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing, 62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x.

Elsevier B.V. (n.d.). Scopus. Database. Retrieved November 7, 2020, from https://www.scopus.com/home.uri.

Fitzsimons D'Arcy, L. (2013, November). A multidisciplinary examination of walkability: Its concept, measurement and applicability (doctoral). Dublin City University. Retrieved from http://doras.dcu.ie/19387/.

Forsyth, A. (2015). What is a walkable place? The walkability debate in urban design. *URBAN DESIGN International, 20*(4), 274–292. https://doi.org/10.1057/udi.2015.22.

Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., … Owen, N. (2016). City planning and population health: A global challenge. *The Lancet, 388*(10062), 2912–2924. https://doi.org/10.1016/S0140-6736(16)30066-6.

Giles-Corti, B. (2017, October 12). What makes a city more liveable? Policy Forum. Retrieved from https://www.policyforum.net/makes-city-liveable/.

Hassenzahl, M., & Tractinsky, N. (2006). User experience - a research agenda. *Behaviour & Information Technology, 25*(2), 91–97. https://doi.org/10.1080/01449290500330331.

Hillnhütter, H. (2016, October 25). Pedestrian Access to Public Transport. University of Stavanger, Norway. Retrieved from https://uis.brage.unit.no/uis-xmlui/handle/11250/2422928.

Hinckson, E., Schneider, M., Winter, S. J., Stone, E., Puhan, M., Stathi, A., … King, A. C. (2017). Citizen science applied to building healthier community environments: Advancing the field through shared construct and measurement development. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 133. https://doi.org/10.1186/s12966-017-0588-6.

Hoffmann, S., Weyer, J., & Longen, J. (2017). Discontinuation of the automobility regime? An integrated approach to multi-level governance. *Transportation Research Part A: Policy and Practice, 103*, 391–408. https://doi.org/10.1016/j.tra.2017.06.016.

Hutabarat Lo, R. (2009). Walkability: what is it? Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 2(2). Retrieved from https://www.tandfonline.com/doi/abs/10.1080/17549170903092867.

Institute for Transportation and Development Policy. (2018). Pedestrians First: Tools for a Walkable City (Guidance and guidelines) (p. 80). New York: ITDP. Retrieved from https://www.itdp.org/publication/walkability-tool/.

King, A. C., Winter, S. J., Chrisinger, B. W., Hua, J., & Banchoff, A. W. (2019). Maximizing the promise of citizen science to advance health and prevent disease. *Preventive Medicine, 119*, 44–47. https://doi.org/10.1016/j.ypmed.2018.12.016.

King, A. C., Winter, S. J., Sheats, J. L., Rosas, L. G., Buman, M. P., Salvo, D., … Dommarco, J. R. (2016). Leveraging Citizen Science and Information Technology for Population Physical Activity Promotion. *Translational Journal of the American College of Sports Medicine, 1*(4), 30. https://doi.org/10.1249/TJX.0000000000000003.

lge-Elegbede, J., Pilkington, P., Bird, E. L., Gray, S., Mindell, J. S., Chang, M., … Petrokofsky, C. (2020). Exploring the views of planners and public health practitioners on integrating health evidence into spatial planning in England: a mixed-methods study. Oxford University Press, 1–9. https://doi.org/10.1093/pubmed/fdaa055.

Mackie, H., Macmillan, A., Witten, K., Baas, P., Field, A., Smith, M., … Woodward, A. (2018). Te Ara Mua - Future Streets suburban street retrofit: A researcher-community-government co-design process and intervention outcomes. *Journal of Transport & Health*. https://doi.org/10.1016/j.jth.2018.08.014.

Mayor of London, T. for L. (2017). Healthy Streets for London, Prioritising walking, cycling and public transport to create a healthy city. Transport for London. Retrieved from https://www.tfl.gov.uk/corporate/about-tfl/how-we-work/planning-for-the-future/healthy-streets.

Meher, M., Spray, J., Wiles, J., Anderson, A., Willing, E., Witten, K., … Ameratunga, S. (2021). Locating transport sector responsibilities for the wellbeing of mobility-challenged people in Aotearoa New Zealand. *Wellbeing, Space and Society, 2*, Article 100034. https://doi.org/10.1016/j.wss.2021.100034.

Middleton, J. (2010). Sense and the city: Exploring the embodied geographies of urban walking. *Social & Cultural Geography, 11*(6), 575–596. https://doi.org/10.1080/14649365.2010.497913.

Mindell, J. S., & Karlsen, S. (2012). Community Severance and Health: What Do We Actually Know? *Journal of Urban Health, 89*(2), 232–246. https://doi.org/10.1007/s11524-011-9637-7.

Ministry of Transport. (2020). Transport Evidence Base Strategy - Progress report. Retrieved from https://www.transport.govt.nz/assets/Uploads/Report/TEBSProgressReport2020.pdf.

Ministry of Transport. (2017). New Zealand Household Travel Survey 2015-2017. Retrieved from https://www.transport.govt.nz/mot-resources/household-travel-survey/results-from-household-travel-survey-2015-2017/.

Ministry of Transport. (2018). Transport Outcomes Framework (Policy) (p. 8). Wellington, Aotearoa New Zealand: Ministry of Transport. Retrieved from https://www.transport.govt.nz/multi-modal/keystrategiesandplans/transport-outcomes-framework/.

Peter Nunns. (2014). Population-weighted density in New Zealand and Australian Cities: A new comparative dataset. MRCagney Working Paper. Retrieved from https://www.greaterauckland.org.nz/wp-content/uploads/2014/09/Nunns-2014-NZ-Aus-population-weighted-density-small.pdf.

NZ Statistics. (n.d.). Home - Census | Census Online | Census NZ 2018. Retrieved March 3, 2018, from https://www.census.govt.nz/.

OECD/ITF. (2021). Reversing Car Dependency - Summary and Recommendations (Guidance and guidelines) (p. 41). Paris: OECD/ITF. Retrieved from https://doi.org/10.1787/bebe3b6e-en.

Park, J., Chowdhury, S., & Wilson, D. (2020). Gap between Policymakers' Priorities and Users' Needs in Planning for Accessible Public Transit System. *Journal of Transportation Engineering, Part A: Systems, 146*(4), 04020020.

Rafferty, A. P., McGee, H. B., Petersmarck, K. A., & Miller, C. E. (2004). Proportion of Trips Made by Walking: Estimating a State-Level Baseline for Healthy People 2010 Objective 22–14. *American Journal of Health Promotion, 18*(5), 387–391. https://doi.org/10.4278/0890-1171-18.5.387.

Ralph, K., & Girardeau, I. (2020). Distracted by "distracted pedestrians"? *Transportation Research Interdisciplinary Perspectives, 5*, Article 100118. https://doi.org/10.1016/j.trip.2020.100118.

Read, G. J. M., Stevens, E. L., Lenné, M. G., Stanton, N. A., Walker, G. H., & Salmon, P. M. (2018). Walking the talk: Comparing pedestrian "activity as imagined" with "activity as done". *Accident; Analysis and Prevention, 113*, 74–84. https://doi.org/10.1016/j.aap.2018.01.016.

Righi, A. W., & Saurin, T. A. (2015). Complex socio-technical systems: Characterization and management guidelines. *Applied Ergonomics, 50*, 19–30. https://doi.org/10.1016/j.apergo.2015.02.003.

Rydin, Y., Bleahu, A., Davies, M., Dávila, J. D., Friel, S., De Grandis, G., … Wilson, J. (2012). Shaping cities for health: Complexity and the planning of urban environments in the 21st century. *Lancet, 379*(9831), 2079–2108. https://doi.org/10.1016/S0140-6736(12)60435-8.

Sallis, J. F., Bull, F., Burdett, R., Frank, L. D., Griffiths, P., Giles-Corti, B., & Stevenson, M. (2016). Use of science to guide city planning policy and practice: How to achieve healthy and sustainable future cities. *The Lancet, 388*(10062), 2936–2947. https://doi.org/10.1016/S0140-6736(16)30068-X.

Sallis, J. F., Spoon, C., Cavill, N., Engelberg, J. K., Gebel, K., Parker, M., … Ding, D. (2015). Making the Case for Active Cities: The Co-Benefits of Designing for Active Living. *International Journal of Behavioral Nutrition and Physical Activity, 12*(30). https://doi.org/10.1186/s12966-015-0188-2.

Sallis, J. F. (2009). Measuring Physical Activity Environments: A Brief History. American Journal of Preventive Medicine, 36(4, Supplement), S86–S92. https://doi.org/10.1016/j.amepre.2009.01.002.

Saurin, T. A., & Gonzalez, S. S. (2013). Assessing the compatibility of the management of standardized procedures with the complexity of a sociotechnical system: Case study of a control room in an oil refinery. *Applied Ergonomics, 44*(5), 811–823. https://doi.org/10.1016/j.apergo.2013.02.003.

Walk Score. (n.d.). WalkScore TM. Walk Score. Retrieved August 29, 2018, from https://www.walkscore.com/.

Smith, M., Calder-Dawe, O., Carroll, P., Kayes, N., Kearns, R., (Judy) Lin, E.-Y., & Witten, K. (2021). Mobility barriers and enablers and their implications for the wellbeing of disabled children and young people in Aotearoa New Zealand: A cross-sectional qualitative study. Wellbeing, Space and Society, 2, 100028. https://doi.org/10.1016/j.wss.2021.100028.

Smith, C. (2018). Treasury Living Standards Dashboard: Monitoring Intergenerational Wellbeing, 81.

Speck, J. (2012). Walkable City : How Downtown Can Save America, One Step at a Time (Reprint.). Berkeley, California, United States: North Point Press.

Statistics New Zealand. (2014, June 17). Disability Survey: 2013. Statistics New Zealand. Retrieved from http://archive.stats.govt.nz/browse_for_stats/health/disabilities/DisabilitySurvey_HOTP2013.aspx.

Stevenson, M., Thompson, J., de Sá, T. H., Ewing, R., Mohan, D., McClure, R., … Woodcock, J. (2016). Land use, transport, and population health: Estimating the health benefits of compact cities. *The Lancet, 388*(10062), 2925–2935. https://doi.org/10.1016/S0140-6736(16)30067-8.

TRA. (2018, May). Measuring and growing active modes of transport in Auckland. Auckland Transport. Retrieved from https://at.govt.nz/media/1977266/tra_at_activemodes_publicrelease-1.pdf.

TRA. (2019). Understanding attitudes and perceptions of cycling and walking (p. 75). Wellington: Waka Kotahi NZ Transport Agency. Retrieved from https://www.nzta.govt.nz/assets/resources/understanding-attitudes-and-perceptions-of-cycling-and-walking/NZTA-Attitudes-to-cycling-and-walking-final-report-2019.pdf.

Transport for London. (2019). Travel in London: Understanding our diverse communities 2019 - A summary of existing research (p. 315). London: Transport for London. Retrieved from http://content.tfl.gov.uk/travel-in-london-understanding-our-diverse-communities-2019.pdf.

UN-HABITAT. (2014, April 15). 7th World Urban Forum Medellín Declaration. Retrieved from https://unhabitat.org/7th-world-urban-forum-medellin-declaration/.

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. United Nations: Retrieved from. https://doi.org/10.18356/e5a72957-en.

United Nations Environment Programme. (2021). Making Peace with Nature (No. DEW/2335/NA) (p. 168). Nairobi, Kenya. https://doi.org/10.18356/9789280738377.

Te Waihanga - New Zealand Infrastructure Commission. (2020). Briefing to the Incoming Minister for Infrastructure (p. 19). Te Waihanga - New Zealand Infrastructure Commission. Retrieved from https://www.beehive.govt.nz/sites/default/files/2020-12/Infrastructure%20Commission.pdf.

Waka Kotahi NZ Transport Agency. (n.d.). Innovating Streets COVID-19 guidance. Retrieved June 10, 2020, from https://www.nzta.govt.nz/roads-and-rail/innovating-streets/covid-19-guidance/.

Waka Kotahi NZ Transport Agency. (n.d.). Active research projects. Retrieved April 19, 2021, from https://www.nzta.govt.nz/planning-and-investment/learning-and-resources/research-programme/active-research-projects/.

Walton, D., & Sunseri, S. (2007). Impediments to walking as a mode choice (Research Report No. 329) (p. 48). Land Transport New Zealand. Retrieved from https://www.nzta.govt.nz/resources/research/reports/329/index.html.