Australasian Transport Research Forum 2021 Proceedings
8-10 December, Brisbane, Australia
Publication website: http://www.atrf.info

A GIS-based Walkability Analysis for the Greater Adelaide Metropolitan Area: An Evaluation of the AURIN Walkability Index

Arsham Bassiri Abyaneh[1], Andrew Allan[1], Johannes Pieters[1], Sekhar Somenahalli[2], Ali Soltani[1]

[1]UniSA Creative, University of South Australia, City West Campus, Adelaide SA 5000, Australia

[2]UniSA STEM, University of South Australia, Mawson Lakes Campus, Mawson Lakes SA 5095, Australia

Email for correspondence: arsham.bassiri_abyaneh@mymail.unisa.edu.au

Abstract

Currently, a considerable amount of attention has been given to walking as a human-powered and ecologically friendly mode of transportation that can address the public health and environmental issues faced by contemporary cities. Although a rich body of research has been developed in recent decades aiming to shed light on how the built environment can encourage walking using Geographic Information Systems (GIS), gender and equity issues are evident in the research on walkability. The Australian Urban Research Infrastructure Network (AURIN) has recently developed a GIS-based spatial toolkit to analyse and compare the level of walkability across Australia's metropolitan areas. This study analyses and visualises the level of walkability in each Statistical Area Level 3 (SA3) of the Greater Adelaide metropolitan area using the AURIN walkability index. Furthermore, it adds public transport accessibility to the AURIN toolkit to improve its robustness. Finally, it conducts a gender-based analysis on the relationship between different criteria of the AURIN index including connectivity, land-use mix and population density as well as the modified walkability index against the walk-to-work behaviour of the population. The findings indicate that Adelaide City and Port Adelaide – East are the most walkable and Gawler - Two Wells and Adelaide Hills are the least walkable SA3s of the study area. Developing and maintaining the datasets of other aspects of the built environment such as the effects of terrain, perceptions of crime, perceptions of comfort and the perceived visual interest as well as a more detailed socio-demographic profile of the pedestrians can be suggested for further studies on the available walking data via the AURIN portal.

Key Words: Walkability Index – AURIN – GIS - Greater Adelaide Metropolitan Area

1 Introduction

Contemporary cities are suffering from several public health and environmental issues. Car-dependent lifestyles have resulted in poor quality of life as well as air pollution, compounding the negative impacts of climate change (Speck 2012). Universally, roughly 90% of people breathe polluted air (Tranter & Tolley 2020). On the other hand, physical inactivity and its health consequences including a range of cardiovascular diseases, type-2 diabetes and cancers have not yet been effectively addressed (Tsiompras & Photis 2017). Globally, Inactivity results in 3.2 million deaths annually and more than 50 billion US dollars in healthcare costs (Pratt et al. 2014; Ding et al. 2016).

Generally, Australia's metropolitan areas, and particularly, Greater Adelaide are dominated by low-density suburbs with an extensive road supply which results in car-dependent lifestyles (Soltani & Allan 2006). Based on a study done by Soltani et al. (2006), throughout the Adelaide metropolitan area, active travel modes are marginal. They believe while considering all leisure and work-related trips, only 23% walked and 6% bicycled. More recently, according to the Australian Bureau of Statistics (ABS) (2016), only 2.2% and 1.1% of work trips in the Greater Adelaide metropolitan area are walked and bicycled, respectively.

Because of its direct link with a variety of built environment features, walking is a human-powered and ecologically friendly mode of transportation that may play a significant role in resolving both health and environmental problems (Sallis et al. 2015). According to the London Walking Forum (2000, p. 3), "walking is one of the first things a child wants to do, and one of the last things an adult wants to give up". As a result, in today's world, walking is receiving a lot of attention in the disciplines of transportation and urban planning, as well as health management, because of its critical role in the planning process for a healthy and sustainable city. (Tsiompras & Photis 2017).

'Walkability' has become a popular concept in the fields of city planning, public health and sustainable development. A rich body of research has been developed in recent decades aiming to shed light on how the built environment can be designed in order to encourage more physical activity, particularly walking, using a wide range of Information & Communication Technologies (ICT) including Planning Support Systems (PSS) and Geographic Information Systems (GIS) (Habibian & Hosseinzadeh 2018; Bassiri Abyaneh et al. 2021). In addition to tackling obesogenic environments that have led to the unfortunate level of chronic diseases, the experience of the long-term lockdowns in the COVID-19 era which required the adoption of home-based work and education for millions of people has also highlighted the critical necessity for planning walkable neighbourhoods in which primary medical facilities, community centres, grocery stores and pharmacies are all within walking distance (Kang et al. 2020).

Although there is a rich body of knowledge on how to promote walkable cities, "equity and gender issues were evident in the lack of planning for walking, as the majority of transport planners were middle class men, precisely the group who walked the least and drove the most" (Tranter & Tolley 2020, p. 285). According to Matchett (2018), it can be hypothesised that governments' policies and advice on planning for walking may have differed if suggested by women, especially mothers of young children, or from the perspective of people with disabilities who use a wheelchair. Furthermore, it can be argued that women's safety is a major concern, as several studies have shown that a high incidence of physical and verbal abuse discourages girls and women from choosing walking as a mode of transport (Condon et al. 2007; Tiwari 2018). According to Jensen et al. (2017), the few studies that have conducted gender-based analyses show that females make up less than half of all street users. For instance, only 46% of downtown pedestrians in the small town of Wilkes-Barre Pennsylvania were female (Schasberger et al. 2012). In addition, a walkability study in Australia indicates that being female as well as having a child in the household are negatively associated with the weekly frequency of walking for transport (Owen et al. 2007).

In the Australian context, one of the key applications of the GIS-based spatial toolkits which were recently developed by the Australian Urban Research Infrastructure Network (AURIN) is to analyse and compare the level of walkability across Australia's metropolitan areas. AURIN which is funded by the Commonwealth of Australia is an online platform trying to provide planners, designers and urban researchers with the technical infrastructure to enable evidence-based policymaking in Australian cities with access to a network of analysis tools and datasets (Giles-Corti et al. 2014; AURIN 2021).

However, there is still a lack of comprehensive evaluation studies in terms of the efficiency and comprehensiveness of the AURIN walkability index as well as the practical suggestions for further improvements. Therefore, the main objective of this study is to analyse and visualise the level of walkability in each Statistical Area Level 3 (SA3) of the Greater Adelaide metropolitan area using the AURIN walkability index. In addition, by considering public transportation (PT) stations as key daily walking destinations, this study adds the factor of PT accessibility to the AURIN toolkit to develop a more comprehensive walkability index. Finally, it conducts a gender-based analysis on the relationship between different walkability criteria of the AURIN index as well as the improved walkability index against the walking to work behaviour of the population in each SA3.

2 Literature Review

2.1 Walkability

Although there are several definitions for walkability, it can be considered as a multi-dimensional concept that can be defined as the "extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network" (Southworth 2005, p. 248). In the matter of scale, the walkability criteria can be categorised into two main groups which are micro-level criteria measured at the street level and meso-level criteria calculated at the neighbourhood level (Park et al. 2017).

In a walkability analysis, Lee and Moudon (2006) assert that the quality and context of routes and pathways also known as micro-level criteria may be as significant as meso-level criteria. According to Southworth (2005), a high-quality pedestrian pathway will provide for the safety and comfort of pedestrians of various age groups and physical abilities. It should be seamless, with no gaps, and should have a consistent and smooth surface that could make walking and wheelchair access easy. Moreover, "many aspects of the path context can contribute to a positive walking experience: visual interest of the built environment, design of the street as a whole, transparency of fronting structures, visible activity, street trees and other landscape elements, lighting, and views" (Southworth 2005, p. 251).

However, because this study is carried out at the size of the Greater Adelaide metropolitan area and due to the limited secondary information at the micro-level scale, it only incorporates the meso-level walkability criteria.

2.1.1 Meso-level walkability criteria

Most walkability studies analyse meso-level walkability which can be computed from GIS datasets and calculated using GIS-based software (Cerin et al. 2007; Frank et al. 2010). Meso-level walkability has been assessed by attempting to capture three built environment characteristics: street layouts, population density and land use mix (Park et al. 2017). Ever since Cervero and Kockelman (1997) developed a pioneering concept called 3D (Density, Diversity and Design), these variables have become the most frequently used environmental characteristics in walkability analyses (Bassiri Abyaneh et al. 2021). This is, firstly, because of the absence of rich tract-level data on built environments, and, secondly, the collinearity between factors like neighbourhood densities, mixed use levels and pedestrian amenities (Cervero and Kockelman 1997). The 3D qualities of the built environment were later applied for studying the walking behaviour of the residents of a neighbourhood and are broadly used under the term "neighbourhood walkability" (Park et al. 2017). In this paper, due to the large size of the case study and the limitations of the data availability, four major factors are considered as the meso-level walkability criteria including pathway network connectivity, population density, land-use mix and proximity to public transport (PT) stations as key daily walking destinations.

2.1.1.1 Pathway network connectivity

Streets' network connectivity providing pedestrian access to destinations is central to walking and is considered as one of the most frequently cited indicators of walkability in many studies (Handy et al. 2002; Frank et al. 2010; Wei et al. 2016; Tsiompras & Photis 2017). A high level of connectivity indicates that there are many options for a pedestrian to choose several routes for travelling between two specific points in an urban area which can contribute to shorter walking distances (Southworth 2005). This criterion is calculated by various methods. The most common approach is to calculate the density of intersections in which the number of junctions with more than 3 links is counted in one square kilometre (Tsiompras & Photis 2017). In a study in the US, Frank et al. (2005) claim that areas with more than 30 intersections per square kilometre are more walkable than other spaces. By contrast, many scholars have criticised the usage of street network connectivity in measuring walkability instead of real pedestrian's pathways; since they believe that the street network data represents vehicular accessibility instead of pedestrian mobility (Chin et al. 2008; Ellis et al. 2016).

2.1.1.2 Land-use mix

The diversity of land-use patterns and activities can be regarded as a key component in creating more walkable environments (Southworth 2005; King et al. 2015). According to Saelens et al. (2003), the level of integration among different land-use types in an area can be defined as the land-use mix. Although the land-use mix is a relatively common factor in most walkability studies, Christian et al. (2011) assert that the function of land-use mix relies strongly on the trips' purposes. They point out, for example, walking for transport has the strongest association with the walkability index which incorporates the following land-use categories as a determinant of the land-use mix: residential; office; retail; welfare and community; health; recreation; entertainment; and culture. By contrast, walking with the purpose of recreation is more strongly associated with the walkability index when the land-use mix criterion includes sports facilities, public open space, primary and rural land uses (Christian et al. 2011).

2.1.1.3 Population density

Population density as a key factor in the formulation of the travel demand in cities has been analysed in a vast range of built environment studies (Saelens et al. 2003). High population density can contribute to more liveable and sustainable places with efficient transport systems (Tsiompras & Photis 2017). Ewing and Cervero (2001) argue that the usage of public transportation systems relies primarily on local activity densities (both job and residential densities) and secondarily on the level of the land-use mix. Walking, on the other hand, is dependent on local density as well as the land-use mix. As a result, most walkability studies consider both the level of land-use mix and population density as two key parameters (Ewing & Cervero 2001).

2.1.1.4 Proximity to destinations and public transport accessibility

A walkable place has an accessible pattern of activities in which all daily needs of residents can be supported by a 400-800-metre walk (Southworth 2005). This proximity to major daily destinations can lead to more liveable neighbourhoods and increased social value (Tsiompras & Photis 2017). A rich body of research has demonstrated that there is a strong association between active transport choices (e.g. walking, cycling) and proximity to destinations (Glazier et al. 2014). For instance, Krizek and Johnson (2006) suggest that there is a statistically significant correlation between distances to retail land-uses and choosing walking or cycling as modes of transportation.

Furthermore, public transportation (PT) stations as the primary origins/destinations of everyday walking provide sustainable and alternative mobility choices (Tsiompras & Photis 2021). According to Lai and Kontokosta (2018), the density of PT stations is interlinked with the volume of pedestrian activity. Also, a study done by Xiao et al. (2019) shows that by increasing the public transit choices of a neighbourhood, weekly walking activity grows by about 30 minutes.

2.2 GIS-based walkability indices

Geographic Information Systems (GIS) are widely used computer-based tools in the field of urban and regional planning for data collection, analysis, modelling, and visualisation of spatially referenced data (Leslie et al. 2007). Because walkability is a complex concept intertwined with different characteristics of the built environment, GIS has been vastly used in developing walkability measurement tools in the existing literature. One of the most widely cited GIS-based walkability indices developed by Lawrence Frank and colleagues was published in 2010 in North America. Their proposed walkability index has four main components: net residential density, retail floor area ratio, intersection density and land use mix entropy (Frank et al. 2010).

Another frequently used GIS-based walkability index in the previous literature was Walk Score®. The Walk Score® algorithm grades the walkability of a location by examining walking paths to nearby amenities (Walk Score 2020). According to Knight et al. (2018), by using a distance decay function, this index allocates points to different locations based on the road network distance from a starting address to nearby destinations in various categories such as accessibility to public transit.

One of the main limitations of previous walkability indices is that most of their included factors are treated almost equally, or for instance, the factor of pathway connectivity has higher significance than other factors without clear justification and analysis (Tisompras & Photis 2017).

3 Methodology

3.1 Study Area

The Greater Adelaide Metropolitan Area has been chosen as the study area. According to the Australian Bureau of Statistics (ABS), in 2016, Greater Adelaide had a population of 1,295,714 people and an area of 3,259 square kilometres (ABS 2016). Based on the ABS geographic classification, this metro area consists of 19 Statistical Areas Level 3 (SA3s) which are Adelaide City, Adelaide Hills, Burnside, Campbelltown (SA), Charles Sturt, Gawler - Two Wells, Holdfast Bay, Marion, Mitcham, Norwood - Payneham - St Peters, Onkaparinga, Playford, Port Adelaide - East, Port Adelaide - West, Prospect - Walkerville, Salisbury, Tea Tree Gully, Unley and West Torrens. This study was conducted at the SA3 level because the SA3 borders are quite closely aligned with the borders of Local Government Areas (LGAs). As the LGAs across the Adelaide Greater Adelaide Metropolitan Area tend to have homogenous densities and travel behaviours, the findings can be used as a walkability performance indicator for the Local Governments and as a basis for further research comparing the level of implementation of active travel policies in different jurisdictions.

3.2 AURIN walkability index

The AURIN portal offers several urban and geographic analysis tools among which the “Walkability Index Within Areas” tool has been used in this study. According to AURIN (2021), the “Walkability Index Within Areas” tool is a “sandwich with the lot”, considering the three compound elements of the urban fabric including connectivity, land use mix and gross population density to analyse the walkability of each SA3 as the walking catchments. The AURIN walkability formula, as well as a brief discussion of the components' calculating method, are shown below:

AURIN's Walkability Index = [Z-score Connectivity] + [Z-score Land-use mix] + [Z-score Population density]

Where:

- *Z-score Connectivity = The z-score of the total number of connections per square kilometre in the walking catchments;*
- *Z-score Land-use mix = The z-score of the "Land-use Mix Measure" which measures the extent to which there is an equal distribution of each land use within the catchments;*
- *Z-score Population density = The z-score of the average population per hectare for each of the catchments.*
- *Z-score X =* $\frac{x_i - \bar{x}}{s}$ *Where* X_i *is the non-normalised score of observation i;* $\bar{X}$ *is the sample mean and s is the sample standard deviation.*

3.2.1 AURIN's connectivity calculation

AURIN walkability tool measures connectivity as the count of three (or more) way street intersections over the area of each walking catchment per square kilometre. In terms of the inputs of this tool, the 2020 PSMA Street Network dataset released by PSMA Australia Limited (2020) was used to determine the number of network connections in each SA3 and consequently the connectivity z-score.

3.2.2 AURIN's land-use mix calculation

According to AURIN (2021), this walkability index calculates the land-use mix as "a measure of the heterogeneity/homogeneity of land uses within each walking catchment, by calculating an entropy measure, which uses the areas of the only land uses of interest falling within the catchment polygon by using the following formula:

$$\frac{\sum_{L=1}^{L}(P_{Li}) \cdot ln(1/P_{Li})}{ln(n)}$$

Where:

P_{Li} *is the proportion that each land-use l contributes to each catchment i and where n represents the total number of land-use categories available. Values of the land use mix range from 0 (the lowest mix) to 1 (the highest possible mix).*

In terms of the input of the land-use mix calculations, the dataset of 2016 Usual Residential Population and Dwelling Count (MB) provided by the Australian Bureau of Statistics (2017) considering Commercial, Education, Hospital/Medical, Parkland and Residential land-uses, was used to define a measure for land-use diversity contributing to the land-use mix z-score of each SA3 as the walking catchments.

3.2.3 AURIN's population density calculation

This tool calculates the average population density per hectare within walkability catchments across the study area (AURIN 2021). The Population data obtained from the 2016 MB Mesh Block dataset provided by ABS (2017a) in association with the area of each SA3 generated the average population density Z-score of the SA3s across the study area. It is important to note that this is the gross density, not the net density.

3.3 Incorporating the public transport accessibility factor

Aside from connectivity, land-use mix and population density which are analysed by the AURIN walkability index, this study analyses the access to PT stations as important daily walking destinations and adds this to the AURIN's walkability formula. The count of all PT stops, including bus stops, tram stops, and railway stations, over the area of each SA3 per square kilometre is used to calculate PT accessibility. To calculate this factor, Adelaide Public

Transport Stop Data (2013) by SA's Department for Infrastructure and Transport as well as the Esri ArcGIS 10.8 software were used.

3.4 Association between walking to work (including walked only plus walk to PT station) behaviour and the AURIN walkability index

To understand the association and relationship between the AURIN's walkability criteria and the level of walking to work across the Adelaide metropolitan area, the ABS (2017b) dataset of SA3 Method of Travel to Work by Sex in Census 2016 was used. All one-method PT commutes to work including one-method bus, one-method train and one-method tram include walks to/from transit stations as walking origins/destinations. Therefore, by combining these means of travel to work to walked-only mode, this study has developed a new factor of walking to work behaviour. Due to limitations of the 'SA3 Method of Travel to Work by Sex in Census 2016' dataset, other methods of travel to work were not be analysed in this study.

A bi-variate linear correlation test was conducted between the percentage of the +15-year-old population walking to work and every measured walkability criteria using IBM SPSS ver. 26. Due to the limited sample size (N=18), a non-parametric approach was adopted. It should be mentioned that the SA3 of Adelaide City was excluded from the correlation procedure to ensure consistency because it was considered as an outlier in the sample data due to its considerable differences from other SA3s.

4 Analysis and findings

As shown in Figure 1, three components of the AURIN walkability formula which are connectivity, land-use mix and population density as well as the total z-score of AURIN walkability have been visualised for each SA3 using ArcGIS. The z-score of connectivity were allocated to each SA3 by the AURIN walkability toolkit considering the number of connections per square kilometre on the existing road layout. Adelaide City, Holdfast Bay and Prospect – Walkerville have the highest level of connectivity.

The z-score of land-use mix is generated by the AURIN walkability tool calculating the 'entropy measure' of Land-use mix in each walking catchment. In other words, a walking catchment with a greater range of land uses has a higher z-score. As can be seen in Figure 1, Adelaide City, Port Adelaide – West and Mitcham have the higher level of the land-use mix in comparison with Prospect – Walkerville, Holdfast Bay and Unley.

Another contributing walkability factor is population density. Figure 1 illustrates that the z-scores of population density generated by the AURIN walkability tool were higher in Adelaide City, Holdfast Bay, and West Torrens.

The overall z-score of the AURIN walkability toolkit was then visualised by adding the z-scores of these three criteria, as seen at the bottom right of Figure 1. Adelaide City, Port Adelaide – East, and Port Adelaide – West have the highest and Gawler - Two Wells, Adelaide Hills and Onkaparinga have the lowest walkability.

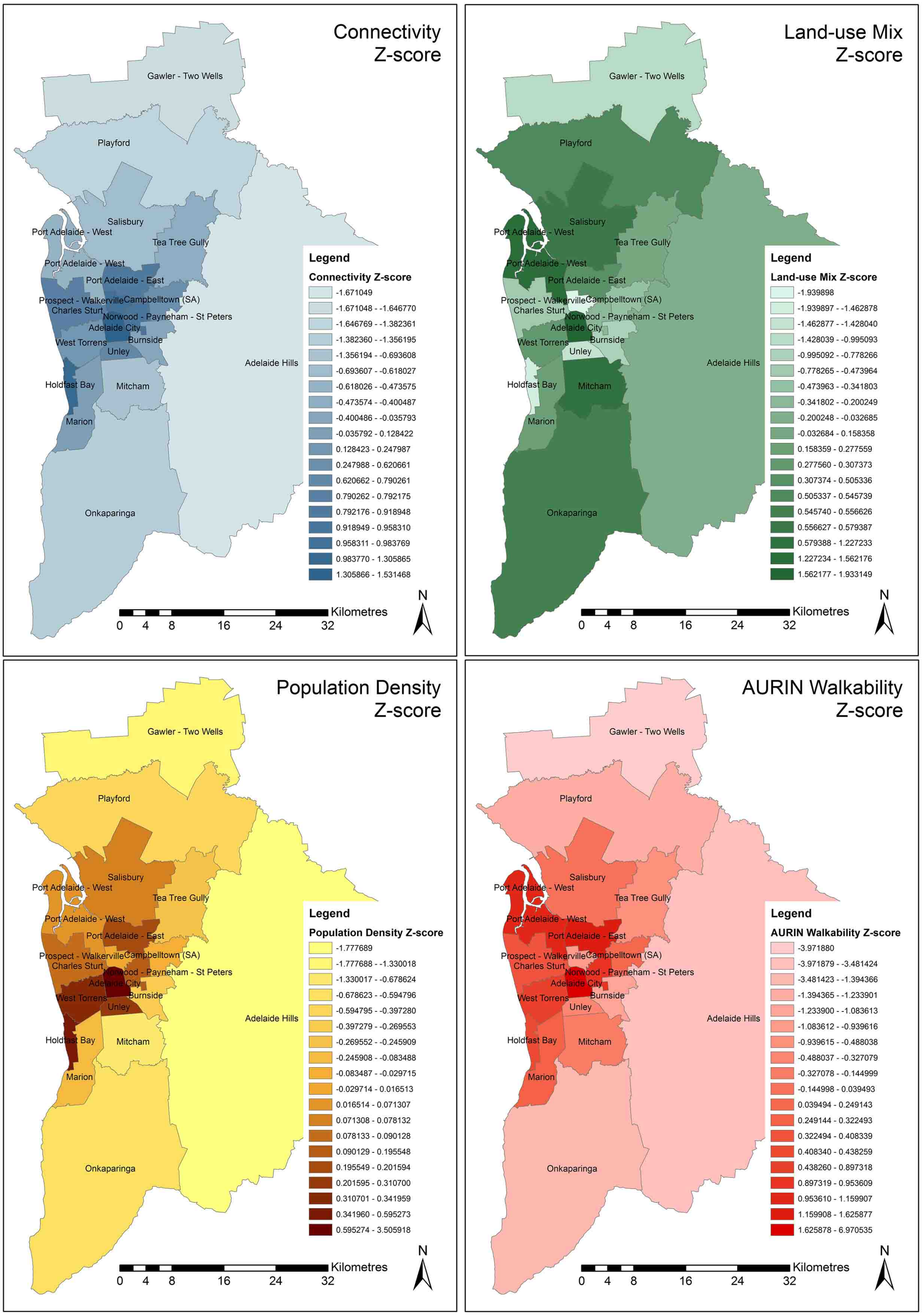


Figure 1: The results of the AURIN walkability index (source: authors)

As can be seen in Figure 2, the PT accessibility factor has been incorporated into the AURIN walkability index and the final sum of all the factors of connectivity, land-use mix, population density and public transport accessibility with equal weightings has been visualised. The top three walkable SA3s of the Adelaide metropolitan area are Adelaide City, Port Adelaide – East and Holdfast Bay. By contrast, the least walkable SA3s are Gawler – Two Wells, Adelaide Hills and Onkaparinga.

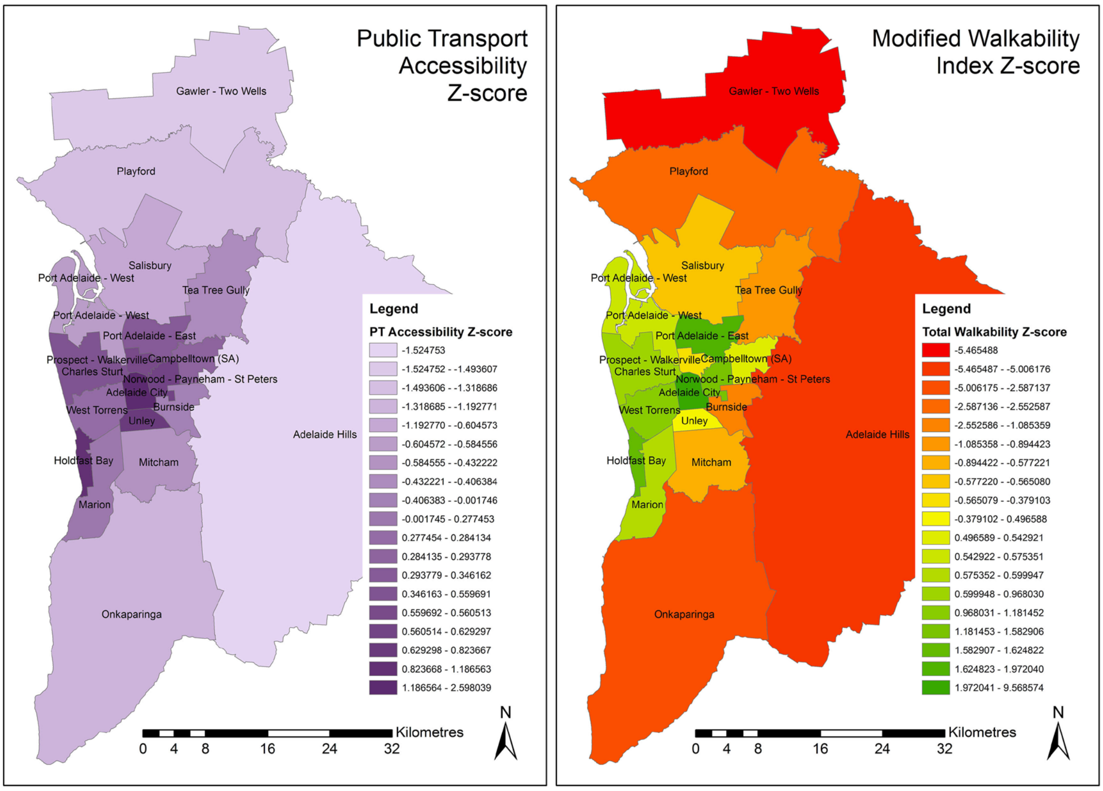
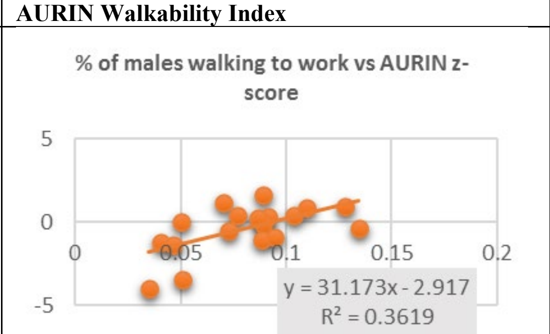
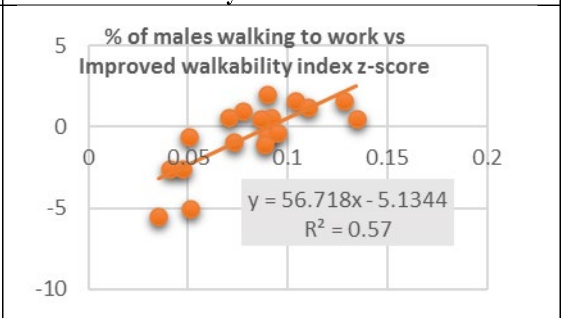
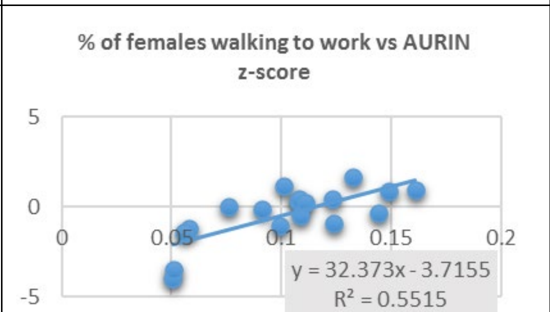
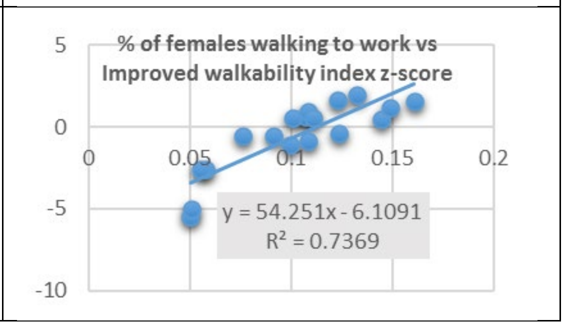


Figure 2: Incorporating the PT accessibility component into the AURIN index and the final results (source: authors)

The relationship between the proportion of employed persons aged 15 years and over walking to work in each SA3 for both genders and the z-scores of AURIN as well as the improved walkability indices can be seen in Figure 3. The results illustrate that the behaviour of walking to work for females is more closely linked to the results of two walkability indices than males.

	AURIN Walkability Index	Modified Walkability Index
M		
F		

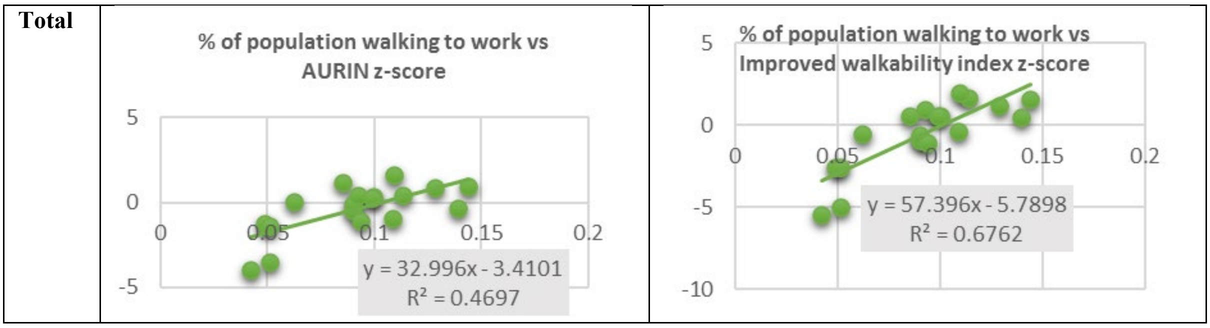


Figure 3: The relationship between the proportion of +15-year-olds walking to work and the z-scores of AURIN as well as the modified walkability indices

The most notable findings of Spearman's correlation test between the proportion of +15-year-old persons walking to work (including walked-only and walked to/from PT stops) in each SA3 and each walkability criterion are as follows:

- The connectivity factor shows a significant correlation with the walking to work (rho = 0.876; p-value < 0.000);
- The land-use mix factor illustrates a significant correlation with the walking to work (rho = 0.412; p-value < 0.090);
- The population density factor is positively correlated with walking to work (rho = 0.794; p-value < 0.000);
- The access to public transport factor indicates a positive correlation with walking to work (rho = 0.911; p-value < 0.000);
- The results of the AURIN walkability index is significantly correlated with walking to work (rho = 0.637; p-value < 0.004); and
- The walkability z-score of the modified walkability index shows a significant correlation with walking to work (rho = 0.796; p-value < 0.000).

However, by comparing the two indices, it can be considered that the modified walkability index (rho = 0.796) performs better than the AURIN walkability index (rho = 0.637). In fact, it shows a 25% increase in the rho value.

Furthermore, the result of the Mean test of Kolmogorov-Smirnov about the walking to work behaviour indicates a significant statistical difference between males and females at the confidence level of 90% (Kolmogorov-Smirnov Z = 1.333; p-value < 0.057).

The detailed results of the gender-based correlation test are presented as follows:

- The connectivity factor is significantly correlated with the walking to work behaviour for both males (rho = 0.800; p-value < 0.000) and females (rho = 0.876; p-value < 0.000); however, females have a stronger correlation (higher rho value);
- Both genders' behaviour of walking to work are positively correlated with the population density, while the correlation for females (rho = 0.831; p-value < 0.000) is stronger than males (rho = 0.697; p-value < 0.001); and
- The associations of the PT accessibility and the walking to work behaviours of males (rho = 0.866; p-value < 0.000) and females (rho = 0.886; p-value < 0.000) are relatively similar.

5 Discussion and conclusion

One of the main planning instruments available via the AURIN portal is its walkability toolkit which has been used in this study to assess the level of walkability in different SA3s of the Greater Adelaide metropolitan area. The results of the analyses of the AURIN walkability toolkit and the modified walkability index suggest that Adelaide City is the most walkable and Gawler - Two Wells is the least walkable SA3.

Another key finding of this study is that the walk-to-work behaviour of females is influenced more by the built environment characteristics of connectivity, population density and PT accessibility than males' behaviour. This aligns with the results of a study done by Adlakha and Parra (2020) in India which indicates a significant correlation between street connectivity and women's active travel. These results show that socio-demographic factors can significantly affect walking behaviour and should be considered in future walkability analyses. The collection of more detailed socio-demographic factors beyond gender when capturing walking data should be considered as an important direction for future studies on the current national walking datasets and the AURIN walkability toolkit. For instance, the collection and visualisation of the walking data based on the age groups, ethnicity, level of fitness, daily destinations and so on can be suggested.

Another limitation is the lack of accurate data on the other aspects of the built environment such as the effects of terrain, perceptions of crime, perceptions of safety from moving vehicles, perceptions of environmental comfort (e.g. availability of shelters, shades, etc), perceptions of physical comfort (e.g. availability of public amenities, etc.) and perceived visual attractiveness which might significantly be associated with the walking behaviour.

By adding the factor of PT accessibility, this study attempted to improve the comprehensiveness of the AURIN walkability index. Although the correlation test shows a stronger association between the modified walkability formula and the walking to work behaviour in comparison with the AURIN index, future studies should incorporate both meso-level and micro-level walkability criteria.

One of the main limitations of this study in terms of methodology is the limited number of data points to conduct correlation studies, as it only considered the SA3s in the Greater Adelaide metro. Conducting state-wide analysis or comparing different SA3s of other Australian metropolitan areas will lead to more data points and more robust results. However, the results of this study at the SA3 scale can be used by the decision-makers in Local Governments (Councils) across the Greater Adelaide metropolitan area to assess and compare the strengths and weaknesses of their respective Local Government Areas (LGA) in terms of walkability. In addition, although conducting analyses at the smaller scales such as SA2 or SA1 significantly increases the complexity of the analysis, it would generally improve the ability to understand the Greater Adelaide's walkability performance.

In conclusion, it is suggested that the AURIN's walkability toolkit can be studied further and developed in terms of its main deficiencies including not assessing the quality of a pedestrian network, using the road system as a proxy for the pedestrian network and ignoring micro-level design attributes of the pedestrian infrastructure of facilities such as shopping centres and schools. Of course, exploring some of these issues may require new datasets that AURIN does not yet have; however, a more comprehensive walkability toolkit can provide better diagnostic information in appraising pedestrian infrastructure in cities.

References

Adlakha, D. and Parra, D., 2020. Mind the gap: Gender differences in walkability, transportation and physical activity in urban India. *Journal of Transport & Health*, 18, p.100875.

AURIN (2018). *Walkability Tools | AURIN. Australian Urban Research Infrastructure Network – Documentation*. [online] Docs.aurin.org.au. Available at: https://docs.aurin.org.au/portal-help/analysing-your-data/walkability-tools/ [Accessed 6 Aug. 2018].

AURIN (2021). *Walkability Index Within Areas - AURIN. Australian Urban Research Infrastructure Network*. [online] AURIN. Australian Urban Research Infrastructure Network. Available at: <https://aurin.org.au/resources/workbench-user-guides/portal-user-guides/analysing-your-data/walkability-tools/walkability-index-within-areas/> [Accessed 15 June 2021].

Australian Bureau of Statistics, 2016. *2016 Census Quickstats: Greater Adelaide*. [online] Quickstats.censusdata.abs.gov.au. Available at: <https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/4GADE?opendocument#:~:text=In%20the%202016%20Census%2C%20there,up%201.4%25%20of%20the%20population.> [Accessed 16 June 2020].

Australian Bureau of Statistics, 2017a. *ABS - Usual Residential Population and Dwelling Count (MB) 2016*. [Dataset] Available at: https://portal.aurin.org.au/ [Accessed 25 Jun. 2021].

Australian Bureau of Statistics, 2017b. *SA3-P44 Method of Travel to Work by Sex-Census 2016*. [Dataset] Available at: https://portal.aurin.org.au/ [Accessed 25 Jun. 2021].

Bassiri Abyaneh, A., Allan, A., Pieters, J. and Davison, G., 2021. Developing a GIS-Based Tourist Walkability Index Based on the AURIN Walkability Toolkit—Case Study: Sydney CBD. In: S. Geertman, C. Pettit, R. Goodspeed and A. Staffans, ed., *Urban Informatics and Future Cities*. Cham: Springer, pp.233-256.

Cerin, E., Leslie, E., Owen, N. and Bauman, A., 2007. Applying GIS in Physical Activity Research: Community 'Walkability' and Walking Behaviors. In: W. Cartwright, G. Gartner, L. Meng, M. Peterson, P. Lai and A. Mak, ed., *GIS for Health and the Environment: Development in the Asia-Pacific Region With 110 Figures*. [online] Berlin Heidelberg: Springer, pp.72-89.

Cervero, R. and Kockelman, K., 1997. Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, [online] 2(3), pp.199-219.

Chin, G., Van Niel, K., Giles-Corti, B. and Knuiman, M., 2008. Accessibility and connectivity in physical activity studies: The impact of missing pedestrian data. *Preventive Medicine*, [online] 46(1), pp.41-45.

Christian, H., Bull, F., Middleton, N., Knuiman, M., Divitini, M., Hooper, P., Amarasinghe, A. and Giles-Corti, B., 2011. How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity*, [online] 8(1), p.55.

Condon, S., Lieber, M. and Maillochon, F., 2007. Feeling Unsafe in Public Places: Understanding Women's Fears. *Revue française de sociologie*, [online] 48(5), p.101.

Ding, C., Wang, Y., Xie, B. and Liu, C., 2014. Understanding the Role of Built Environment in Reducing Vehicle Miles Traveled Accounting for Spatial Heterogeneity. *Sustainability*, [online] 6(2), pp.589-601.

Ellis, G., Hunter, R., Tully, M., Donnelly, M., Kelleher, L. and Kee, F., 2016. Connectivity and physical activity: using footpath networks to measure the walkability of built environments. *Environment and Planning B: Planning and Design*, [online] 43(1), pp.130-151.

Ewing, R. and Cervero, R., 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, [online] 1780, pp.87-114.

Frank, L., Sallis, J., Saelens, B., Leary, L., Cain, K., Conway, T. and Hess, P., 2010. The development of a walkability index: application to the Neighborhood Quality of Life Study. *British Journal of Sports Medicine*, [online] 44(13), pp.924-933.

Frank, L., Schmid, T., Sallis, J., Chapman, J. and Saelens, B., 2005. Linking objectively measured physical activity with objectively measured urban form. *American Journal of Preventive Medicine*, [online] 28(2), pp.117-125.

Geertman, S., Ferreira Jr., J., Goodspeed, R. and Stillwell, J., 2015. *Planning Support Systems And Smart Cities*. Cham: SPRINGER INTERNATIONAL.

Giles-Corti, B., Macaulay, G., Middleton, N., Boruff, B., Bull, F., Butterworth, I., Badland, H., Mavoa, S., Roberts, R. and Christian, H., 2014. Developing a research and practice tool to measure walkability: a demonstration project. *Health Promotion Journal of Australia*, [online] 25(3), pp.160-166.

Glazier, R., Creatore, M., Weyman, J., Fazli, G., Matheson, F., Gozdyra, P., Moineddin, R., Shriqui, V. and Booth, G., 2014. Density, Destinations or Both? A Comparison of Measures of Walkability in Relation to Transportation Behaviors, Obesity and Diabetes in Toronto, Canada. *PLoS ONE*, [online] 9(1), p.e85295.

Government of South Australia, Department for Infrastructure and Transport (2013). *Adelaide Public Transport Stop Data*. [Dataset] Available at: https://data.sa.gov.au/data/dataset/0d2f65f9-4386-4352-b46e-1259ebc06afe [Accessed 25 Jun. 2021].

Habibian, M. and Hosseinzadeh, A., 2018. Walkability index across trip purposes. *Sustainable Cities and Society*, [online] 42, pp.216-225.

Handy, S., Boarnet, M., Ewing, R. and Killingsworth, R., 2002. How the built environment affects physical activity. *American Journal of Preventive Medicine*, [online] 23(2), pp.64-73.

Jensen, W., Stump, T., Brown, B., Werner, C. and Smith, K., 2017. Walkability, complete streets, and gender: Who benefits most?. *Health & Place*, 48, pp.80-89.

Kang, M., Choi, Y., Kim, J., Lee, K., Lee, S., Park, I., et al. (2020). COVID-19 impact on city and region: what's next after lockdown?. *International Journal of Urban Sciences*, 24(3), 297-315. doi:10.1080/12265934.2020.1803107.

King, T., Bentley, R., Thornton, L. and Kavanagh, A., 2015. Does the presence and mix of destinations influence walking and physical activity?. *International Journal of Behavioral Nutrition and Physical Activity*, [online] 12(1).

Knight, J., Weaver, R. and Jones, P., 2018. Walkable and resurgent for whom? The uneven geographies of walkability in Buffalo, NY. *Applied Geography*, [online] 92, pp.1-11.

Krizek, K. and Johnson, P., 2006. Proximity to Trails and Retail: Effects on Urban Cycling and Walking. *Journal of the American Planning Association*, [online] 72(1), pp.33-42.

Lai, Y. and Kontokosta, C., 2018. Quantifying place: Analyzing the drivers of pedestrian activity in dense urban environments. *Landscape and Urban Planning*, 180, pp.166-178.

Lee, C. and Moudon, A., 2006. The 3Ds+R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment*, [online] 11(3), pp.204-215.

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A. and Hugo, G., 2007. Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. *Health & Place*, [online] 13(1), pp.111-122.

London Walking Forum, 2000. *Walking: Making It Happen*. London: London Walking Forum.

Matchett, K., 2018. *Sexism On The Sidewalk: How Poor Street Design Keeps Women From Walking | Americawalks*. [online] Americawalks.org. Available at: <https://americawalks.org/sexism-on-the-sidewalk-how-poor-street-design-keeps-women-from-walking/> [Accessed 22 August 2020].

Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L., Bauman, A., Hugo, G., Saelens, B. and Sallis, J., 2007. Neighborhood Walkability and the Walking Behavior of Australian Adults. *American Journal of Preventive Medicine*, 33(5), pp.387-395.

Park, S., Choi, K. and Lee, J., 2017. Operationalization of path walkability for sustainable transportation. *International Journal of Sustainable Transportation*, [online] 11(7), pp.471-485.

Pratt, M., Norris, J., Lobelo, F., Roux, L. and Wang, G., 2014. The cost of physical inactivity: moving into the 21st century. *British Journal of Sports Medicine*, 48(3), pp.171-173.

PSMA Australia Limited trading as Geoscape Australia (2020). *PSMA - Transport & Topography - Street Network (Line) August 2020*. [Dataset] Available at: https://portal.aurin.org.au/ [Accessed 25 Jun. 2021].

Saelens, B., Sallis, J. and Frank, L., 2003. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, [online] 25(2), pp.80-91.

Sallis, J., Spoon, C., Cavill, N., Engelberg, J., Gebel, K., Parker, M., Thornton, C., Lou, D., Wilson, A., Cutter, C. and Ding, D., 2015. Co-benefits of designing communities for active living: an exploration of literature. *International Journal of Behavioral Nutrition and Physical Activity*, [online] 12(1), p.30.

Schasberger, M., Raczkowski, J., Newman, L. and Polgar, M., 2012. Using a Bicycle–Pedestrian Count to Assess Active Living in Downtown Wilkes-Barre. *American Journal of Preventive Medicine*, 43(5), pp.S399-S402.

Soltani, A. and Allan, A., 2006. Analyzing the Impacts of Microscale Urban Attributes on Travel: Evidence from Suburban Adelaide, Australia. *Journal of Urban Planning and Development*, 132(3), pp.132-137.

Soltani, A., Primerano, F., Allan, A. and Somenahalli, S., 2006. Design for movement: linking non-work travel and activity level to local urban design dimensions. *URBAN DESIGN International*, 11(3-4), pp.173-186.

Southworth, M., 2005. Designing the Walkable City. *Journal of Urban Planning and Development*, [online] 131(4), pp.246-257.

Speck, J. (2012). *Walkable city: how downtown can save America, one step at a time*. 1st ed. New York: Farrar, Straus and Giroux.

Tiwari, R., 2018. *Connecting Places, Connecting People*. New York: Routledge.

Tranter, P. and Tolley, R., 2020. *Slow Cities: Conquering Our Speed Addiction For Health And Sustainability*. 1st ed. Elsevier Inc.

Tsiompras, A. and Photis, Y., 2017. What matters when it comes to “Walk and the city”? Defining a weighted GIS-based walkability index. *Transportation Research Procedia*, [online] 24, pp.523-530.

Tsiompras, A. and Photis, Y., 2021. Microscale Walkability Modelling. The Case of Athens City Centre. *International Journal of Sustainable Development and Planning*, 16(3), pp.413-426.

Walk Score, 2020. *Walk Score Methodology*. [online] Walk Score. Available at: <https://www.walkscore.com/methodology.shtml> [Accessed 12 June 2020].

Wei, Y., Xiao, W., Wen, M. and Wei, R., 2016. Walkability, Land Use and Physical Activity. *Sustainability*, [online] 8(1), p.65.

Xiao, C., Goryakin, Y. and Cecchini, M., 2019. Physical Activity Levels and New Public Transit: A Systematic Review and Meta-analysis. *American Journal of Preventive Medicine*, 56(3), pp.464-473.