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Measuring Neighbourhood Walking Access for Older Adults

Kaniz Fatima [1,*], Sara Moridpour [1] and Tayebeh Saghapour [2]

1 Civil and Infrastructure Engineering Discipline, School of Engineering, Royal Melbourne Institue and Technology, Melbourne, VIC 3000, Australia
2 School of Global, Urban and Social Studies, Royal Melbourne Institute of Technology, Melbourne, VIC 3000, Australia
* Correspondence: kaniz.fatima.shawon@gmail.com

Abstract: Older adults are an important part of the world's population. Many researchers have worked on walking as a mode of transport and measuring walking access. However, considering older adults (aged 65 and over) walk time, older population, and older pedestrians' safety to measure walking accessibility has not been widely discussed. This study proposes two Walking Accessibility Index (OWAI1 and OWAI2) to measure walking access levels for older adults around the neighbourhoods. The index considers the older travelers' walk time to reach various destinations (e.g., shopping, healthcare, education, and recreation services), land use mix, pedestrian crash datasets, street connectivity and the older population. Among these two proposed indices, OWAI1 statistically performs better. The transport and urban planners can use the newly developed OWAI1 for future planning and policy implementations. The index may be applied to measure disabled commuters' walking access levels as considerable walking speed is lower. Besides, the proposed index is also appropriate for other adults by using the corresponding variables for that particular age group. Metropolitan Melbourne is used in this paper as the case study to measure older adults' walking accessibility. This paper outlines that the older adults' walking access level is very low for most Melbourne areas, negatively impacting their travel behavior.

Keywords: older adult; walking; accessibility; active transport; sustainable mobility; walk time

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1. Introduction

The number of older adults increased worldwide [1]. This aging society faces many challenges, including social isolation, physical/mental health issues, limitations in mobility, and transport access. Walking is essential to improve health, independence, personal mobility, and social connectivity among older adults [2–5]. Walking is one of the most recognised types of exercise [4,6], which positively influences physical and mental health, specifically for older travelers [7–9]. For an older adult, the risks of developing major cardiovascular, and metabolic diseases, muscular weakness and dementia can be reduced through regular walking [9].

Increasing the walking accessibility of a neighbourhood/city promotes sustainable transportation as well as increased physical activities [10,11]. Specifically, when it comes to walking facilities for older adults, defining the neighbourhood walkability access measurement is essential [12]. Older adults' travel behavior is different from other age groups [13,14]. For instance, they (older travelers) make fewer travels per day; they have limited walking speed and limited mobility. Additionally, the elderly may need assistance due to fear of falling, which potentially discourages them from walking [15–17]. The older adults may feel more independent if their neighbourhood is well planned (in terms of availability of different facilities), accessible through walking, and green and pedestrian safe [18,19]. For older travelers, the necessity of independent travel may be higher than for the working-age group, specifically for attending more social and health services [20]. Furthermore, built-environment factors are one of the main influences on improving older people's walkability levels, frequency, and physical activity duration. Some of the common examples of built-environment factors are housing density, sidewalk conditions, better road intersection density, public transport accessibility, and land-use mix. Better walking access promotes more walking/running. This may increase social activity and reduce different issues, including depression, obesity, and alcohol/drug consumption [15–19].

Therefore, promoting walking as a transport mode attracted many researchers, transport planners and health practitioners [17,21–29]. Measuring walkability generally involves analyzing the access levels and individuals' willingness and ability to walk to various local destinations [30]. However, there is still very limited study on older people's walking (as a transport mode) accessibility. The older population is rapidly increasing, but their percentage is among the least in physical activity [31]. Therefore, enhancing older adults' life quality, and better walking accessibility levels to different destinations is essential [32].

Most previous older adult walkability studies have focused on health-related issues, older adults' travel behavior, mode choice analysis, distance-based access measures or the theoretical method [28,33–58]. Travel time and distance are the two most popular variables used to measure accessibility levels. Walk time is a critical component that directly impacts travel behavior and travel mode choice. When the total walk travel time is higher, the walking access level is more likely lower. Although time-based approaches have been considered on several occasions, it has been rarely discussed for older pedestrians. Measuring the neighbourhood walking access considering older travelers' walk time and the population for a small geographic level has not been widely discussed [49,54]. Besides, the safety of older pedestrians has not been included in measuring walkable neighbourhood levels. The lack of proper travel data for older commuters is one of the critical reasons for limited research on transport accessibility. This paper contributes to fulfilling the gap of limited time-based walking accessibility measure studies for older adults. This study intends to develop an Older people Walking Accessibility Index (OWAI) using time-based components within the smallest statistical area (as per census data availability). In this study, two time-based OWAIs (OWAI1 and OWAI2) are introduced to identify the levels of older adult walking accessibility; these two proposed indices include (1) A time-based OWAI1 considering the walk time and older population and (2) A time-based OWAI2 based on older adults' walk time, population, pedestrian safety, street connectivity and land use mix. The time-based OWAIs include different trip purposes, including shopping trips (trips to shopping centers), medical trips (travel to healthcare centers), education trips (travel to education centers) and recreation trips (e.g., restaurants, parks, and cafes); these developed indices are validated using statistical validation methods, including Pearson Chi-square, Likelihood Ratio, Cramer's V, Contingency Coefficient, and Phi. Several different variable combinations of index structures are tested and analyzed. Among those, OWAI1 and OWAI2 show the best results in terms of statistical tests. In addition, the performance of the developed index is compared with household survey data and a popular existing walking index (WI) [37] in replicating the observed walking behavior of older adults. This paper evaluates metropolitan Melbourne SA1s as a case study area for the analysis of more detailed walking access levels considering older peoples' travel. The indices represent the correlation between walk time and better accessibility within the urban area. Future transport policy and urban planners may use these indices to plan better walkable neighbourhoods. Urban planners can plan better allocations of the key destinations visited by older people frequently. The walking route and intersection density can be increased to poor-level access areas; these will reduce the walk time, which leads to better access levels. This index applies to other city/statistical areas to measure walking access levels. The proposed OWAI1 and OWAI2 can be applicable to identify detailed walking access levels for older adults; these proposed indices can also be applied to measure walking access levels for disabled/sick/physically not fit people. Besides, the proposed index is also appropriate for other adults by using the corresponding variables for that particular age group. In this study, adults aged 65 and over are considered older commuters [50]. From this age, most senior adults stop engaging as employees.

This paper is structured as follows. Section 2 reviews the previous literature related to walking as a travel mode. Section 3 describes the study area and datasets. Section 4 introduces the methodology of the index calculation. Section 5 presents the results and statistical validation, followed by presenting the discussions in Section 6. Section 7 highlights the Spatial transferability and implementation of OWAI. Finally, Section 8 points out the conclusions with directions for future research.

2. Literature Review

The ability of an older adult to walk depends on a range of factors, such as physical strength and cognitive-motor skills, which generally result in older adults walking slower than other adults [33]. The walking accessibility index study is one of the effective methods to evaluate neighbourhood access levels. Transport researchers worldwide are working to improve walkable neighbourhoods, positive built-in environmental effects, and walkability studies [13,29,34–36,59–62]. A study by Leung et al. [51] discussed the relationship between the physical environment, social environment, and walking among older adults in Hong Kong. This study identified that a better land use mix influences older adults to increase walking. A similar study by Koohsari et al. [52] mentioned the positive influence of a high level of land use mix and active transport. Similarly, Alves et al. [17] indicated easy access to various public places might increase the health benefit for older people. This study also [17] developed an index to measure the correlation between public space availability level and the physical exercise benefit of older people. A research study by Wu and Tseng [32] used older peoples' walkability distance-decay factor, population, and supplier loading to evaluate geographic accessibility for elderly community care resource distribution. Gaglione et al. [53] proposed a methodology to identify accessible pedestrian paths and related urban areas for older people. Yang [63] discussed various mobility mode choice models which focused on walking behavior. Duncan et al. [37] examined the correlation between neighbourhood walkability, transportation mode choice and walking among older adults in Paris, France. Böcker et al. [64] analyzed binomial and multinomial logit regression models to evaluate the older adult's trip and mobility mode choices. Hatamzadeh and Hosseinzadeh [48] also analyzed the travel mode choice behavior of older people in Iran. Zhou et al. [45] introduced a mixed logit model to identify older adults' recreation-shopping-oriented patterns.

Likewise, Guida et al. [54] implemented a time-based measure for identifying urban accessibility to healthcare centers for older people considering walkable streets and local public transport lines (bus and metro) in France. Cheng et al. [43] investigated walking accessibility to recreational amenities for elderly people using the distance-based measure in China. A national transport-specific walkability index [38,39] analyzes Australian capital cities relevant to transport-related walking behaviors. Nathan et al. [13] measured walking access for older Australian adults toward specific commercial destinations. This study [13] mentioned that older adults' walking habits are decisive when walking, mainly for social purposes such as religious places, restaurants, pharmacies, and hairdressers. A study by Yu et al. [40] examines the effect of built environment elements on older people's leisure-time physical activity and walking level. One of the most common walkability measures, "Walk Score" [41,65], was introduced in 2007. Since then, it has been used as a macro-level walkability measuring tool. The Walk Score considers the distance to the closest destination in each land use category. Frank et al. [24] presented a Walkability Index (WI) using land mix-use, street connectivity, and residential population density, which has been extensively used in the literature [36,66–72]. Several researchers have used WI to measure and evaluate older adult walking accessibility [72,73]. Table 1 provides a synthesis of previous studies related to walking accessibility indices. Walking accessibility indices are classified into distance-based, time-based, gravity-based, topological/infrastructure-based, and walkability/walk score-type measures [36].

Table 1. Walking accessibility studies.

Index and References	Definition and Highlights
Distance-based accessibility [29,43,55]	This method considers the distance between two specific points. (1) distance to the closest destination, (2) the number of destinations within specific meters or minutes, (3) the mean distance to all distances, and (4) the mean distance to the closest distance.
Time-based accessibility [54]	The method considers the actual availability of mobility for older people and their travel choices within different timeslots.
Gravity-based accessibility [29]	Newton's theory of gravity was followed by Gravity-based measures. This method considers that the trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the origin and the total attractions at the destination. This measure is based on the spatial distribution of residence and travel time/cost between zones. The basic gravity model used by Hanson is: $A_i = \frac{\sum_j a_j * f(d_{ij})}{A}$ Where aj is the attraction in zone j, dij is the travel time, distance or cost from zone i to zone j, f(dij) is the impedance function, and A is a standardizing factor.
Topological or Infrastructure based [29]	This method does not focus on the origin and destination of the neighbourhood. It considers an analysis of network connectivity and/or the characteristics of the walking infrastructures.
Walkability/walk score-type measures [21,27]	This measure considers build-in-environment and accessibility from an origin to a destination
Walk Score [41]	One of the most common approaches for walkability is Walk Score. The Walk Score considers the distance to the closest destination in each land use category. It is based on the gravity-based model
Walkability Index (WI) [38,56–58,67,74]	The WI considered dwelling density, street connectivity, land use mix (LUMIX) and net retail areas. The WI is calculated from the sum of the z-scores of the four mentioned urban form measures. The typical form of the WI is as follows: $WI = (Z\text{-}_{scoreLUMIX}) + (Z\text{-}_{ScoreResidential\ Density}) + (Z\text{-}_{ScoreStreet\ Connectivity})$

As discussed previously, very few studies identified accessibility using time-based methods toward specific travel destinations for older adults. This study intends to develop time-based measures to identify walking access levels for older people.

3. Study Area and Dataset

As stated previously in the abstract, Metropolitan Melbourne Statistical Area, Level One (SA1s) datasets are evaluated for this study. Melbourne, the state capital of Victoria, Australia, has various active transport modes of access, including walking, bicycling, and public transport modes (trains, trams, and buses). SA1s are the second smallest statistical units and the smallest units released in census data in the Australian Statistical Geography Standard (ASGS) main structure. SA1s are the closest conformity to walking catchments. Metropolitan Melbourne is divided into 10,290 SA1s. SA1s conform closest to walking catchments. Metropolitan Melbourne is divided into around 10,290 SA1s, the area of which is not uniform, ranging from 0.0023 km^2 to 275.61 km^2. The population of SA1s varies from 200 to 800, with an average of approximately 400 people. In this study, the older adult walking accessibility index development and analysis dataset comprises seven different data components [75]. The dataset used to develop and analyze the older adult walking index is as follows.

3.1. Victorian Integrated Survey of Travel and Activity (VISTA)

Victorian Integrated Survey of Travel and Activity (VISTA) [76] is a detailed database presenting an ongoing survey of Victorian household travel activity. The VISTA datasets help government make better transport and land-use planning decisions. A dataset [61] contains detailed information on all statistical areas, travel modes, travel time, trip change and trip destination. The survey is conducted throughout the year across metropolitan Melbourne. This allows average daily travel behavior to be understood. Around 46,563 travel responses for weekdays and weekends were documented for metropolitan Melbourne. Of these responses, 7029 responses were from the elderly. The living area details (Such as SA1 and home sub-region location), travel mode (public/private/walk), travel time (when is trip happening), trip change (to reach a destination, what are the trip changes methods) and trip destination (traveled destinations) were extracted and analyzed for older people using the statistical software IBM SPSS 26 [75]. Around 1012 older travelers walking information to reach different destinations are mentioned within this travel dataset. The survey datasets are used for index validation purposes.

3.2. Point of Interest (POIs)

Figure 1 presents the distribution of POIs within metropolitan Melbourne SA1.

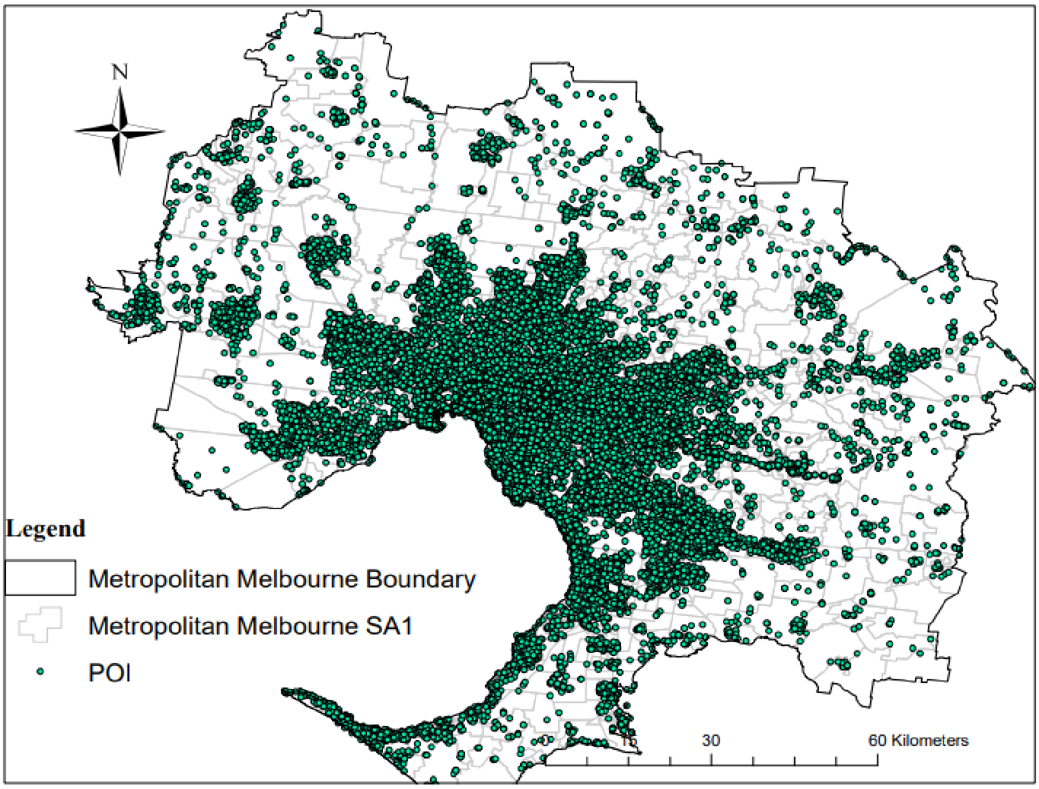

Figure 1. Distribution of POIs within metropolitan Melbourne SA1s (https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77].

A detailed "Features of Interest" database is collected from the Victorian Government open data source (https://discover.data.vic.gov.au/ (accessed on 12 October 2022). Figure 1 is created using the geographic software ArcMap, version: 1071 (https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77] and is used to plot different POIs within metropolitan Melbourne; these features include information on various trip destinations and trip purposes. According to VISTA (2016), older adults mostly travel toward four main POIs categories, including (1) shopping centers, (2) healthcare centers, (3) education centers, and (4) recreational centers [78]. Hence, this study considers these four popular categories of POIs traveled by older commuters for index development. The locations for these four targeted POIs are extracted from the main dataset (Features of Interest). As shown in Figure 1, the number of POIs is higher within inner Melbourne SA1s. However, outer Melbourne SA1s have less coverage of these four category destinations.

3.3. Population Density

The total older adult population in metropolitan Melbourne was 629,485 in 2016. Population datasets for older adults are extracted from census data. The census datasets are extracted from the Australian Urban Research Infrastructure Network (AURIN) [79]. Table 2 represents the summary of population statistics in metropolitan Melbourne SA1s.

Table 2. Population Summary of metropolitan Melbourne SA1s.

Population in SA1	Minimum *	Maximum	Standard Deviation	Mean
Older adults	0	778	48.578	82.260
Total Population	0	4354	208.076	435.843

* Minimum population is zero because the Melbourne Airport SA1 does not have any population.

According to previous studies, the population and population density are significant indicators of walking accessibility measure calculation [24,32,66,80]. The distribution of the older adult population is not consistent within all SA1s. For instance, some inner Melbourne SA1s have a lower older adult population density. Similarly, some outer Melbourne SA1s include higher older adult population density. Therefore, considering the older adult population or population density is necessary to calculate the OWAI. Depending on the population density, transport planners can prioritize the development areas.

3.4. Walk Time

Walking speed varies from person to person. For older adults, the average walking speeds are generally less than for other adults [55]. Walking speed for older adult is considered as 0.70 m/s (2.5 km/h) for developing the OWAI, [53,66,75,81–83]. The travel speed varies from person to person. Even with the same age group walking speeds can be different [80]. Therefore, lower walking speed is considered to cover all groups of older travelers.

3.5. Land Use Mix (LUMIX)

Mixed land use involves a range of complementary land uses located together in a balanced mix, including residential development, shops, employment community, recreation facilities, parks, and open space. This study uses an entropy land-use mix method which is based on Shannon's Diversity Index [39,67,68,74]. This index is popular to quantify the diversity (rarity or commonness) in a community or neighbourhood. The entropy score for LUMIX indicates the extent of different types of destinations' spatial distributions.

3.6. Safety (Crash Rates)

Neighbourhood traffic/pedestrian safety is another major factor for older adults walking. If the footpaths/walkways are safe for pedestrians, older people will be more attracted to walking. Pedestrians are at a higher risk of traffic-related injuries than motor vehicle users. Older adults experience a higher severity of pedestrian injuries than younger adults. Around 1149 older pedestrian crashes are recorded in Victoria between 2008 and 2013 [84]. Crash rate datasets are extracted and analyzed from the VicRoads crash database (2016). The crash rates database is considered the safety measure for OWAI calculation.

3.7. Street Connectivity

A spatial structure of a city can be defined as networks of streets, related routes, open spaces, clusters of land parcels, and buildings. Many walkability studies have considered street connectivity as an influencing variable to measure walking access [85,86]. Street connectivity indicates the directness of links and density of intersection connections within street networks. A neighbourhood with a highly connected street network is combined with many short links, numerous intersections, and dead ends. Street connectivity is measured as the count of three (or more) street intersections over a specific neighbourhood area. AURIN walkability tools consist of several various options to analyze the datasets. To calculate the street connectivity, different attributes such as road network, street map, POIs, walking distance, and LUMIX polygons are connected through AURIN walkability tools [79]. To achieve the result, the older peoples' travel datasets, including street network, POIs, population and statical area datasets, were analyzed using the tool. The street connectivity result was generated as a form of a Z-score index based on a selected statistical area (for this research SA1).

4. Methodology

As mentioned before, two separate OWAIs are developed in this paper. The reason for developing two indexes is to evaluate the impact of considering different variables on the accuracy of the developed OWAIs. Figure 2 presents the OWAI development framework.

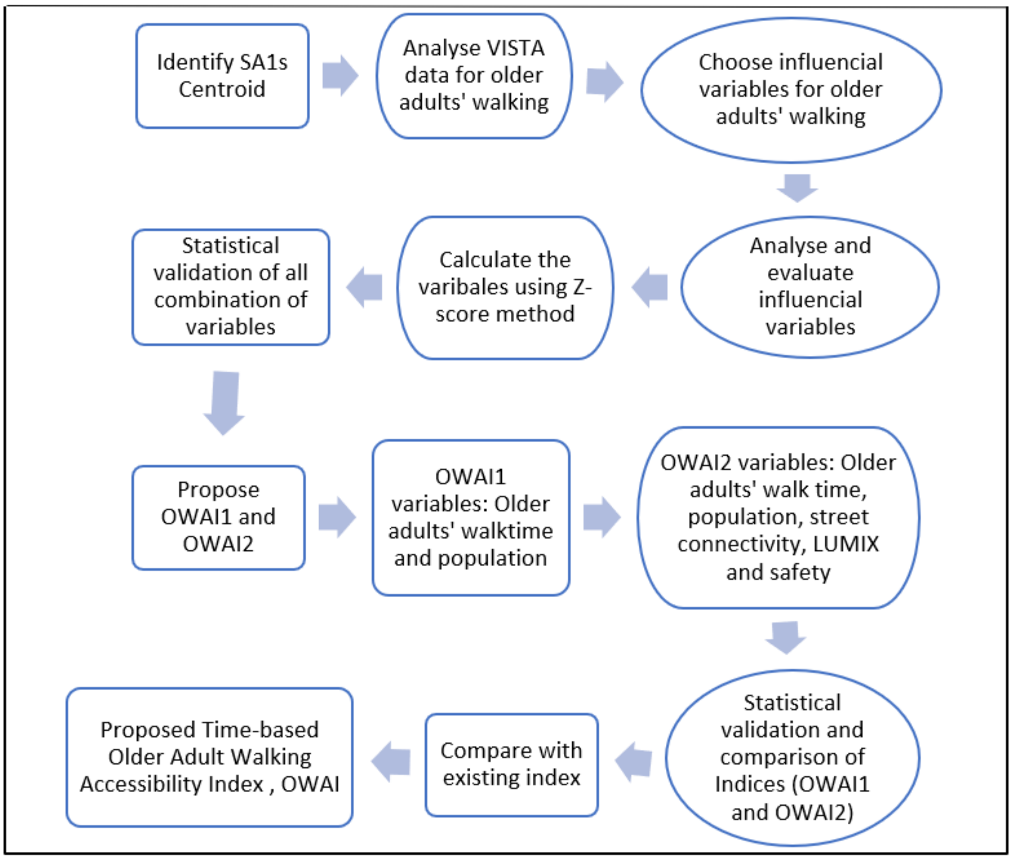

Figure 2. The framework for developing time-based OWAI.

From Figure 2, to develop the indices, this study identifies the centroid of each SA1s (total of 10,289) within metropolitan Melbourne. Using the household survey datasets (VISTA datasets) total number of older people walking, including the population, residence area information, and walking destinations, are analyzed. Afterward, the influential variables, including walk time, LUMIX, population, safety, and street connectivity datasets, are collected from various sources, and analyzed using the Z-score method. The statistical Z-score calculation method is used for all variables, including older adults' walk time, older adult population, land-mix use for four destination types, street connectivity and older adults' pedestrian safety. Z-score (also called the standard score) is a numerical measurement that describes a value's relationship to the mean of a group of values. The z-score value indicates the difference between standard deviations and the mean. If a z-score is equal to 0, it is on the mean. A positive z-score indicates that the raw score is higher than the mean average. Similarly, a negative z-score reveals that the raw score is below the mean average [69–72]. In this paper, the variables are calculated for all 10,289 SA1s. All the variables were analyzed with a different combination of index structures. Each of these variable combination index structures was checked using statistical test methods. Among those indices, OWAI1 and OWAI2 are statistically significant with the best results. Finally, the proposed time-based older adult walking accessibility index is compared with existing WI.

The Quantile, Natural Breaks (Jenks) and Geometrical Interval classification method is used in ArcMap 1071 for index grouping. In this study, data values are classified into six classes ((1) very low, (2) low, (3) moderate, (4) good, (5) very good and (6) excellent). The classification methods used for addressing OWAI1 groups are based on the destinations' index values. The Quantile classification method assigns the same number of data values to each class. There are no empty classes or classes with too few/too many values in the Quantile method. The Quantile method is one of the accurate techniques for index comparison and map reading [73,87,88]. The Quantile classification method examines the result precision. The Quantile classification method assigns the same number of data values to each class. In other words, quantile maps arrange the groups in a way that each group have the same number of datasets. Using this classification method, map color shading look equally distributed. The Natural breaks classification (Jenks) creates the best group's similar values together and maximizes the differences between classes. The geometrical interval classification scheme is based on class intervals that have a geometric series. The geometric coefficient can change once (to its inverse) to optimize the class ranges. The older adult walking accessibility index classification procedure simplifies the access level comparison between different SA1s.

4.1. OWAI1

According to Senior Final Report [2,46], the mean value for older adult walking trip time is 13.7 min, compared with 12.5 min for younger adults. This slower speed results in extended walk time for older pedestrians. For each POI, two thresholds, including the desirable and maximum walking travel times, are defined for older travelers based on their travel speed (older people). To calculate OWAI1 (Equation (1)), older adults' total walking time and population are considered for a specific POI. The total weighted walking time is calculated using Equation (2) [89]. The total time is calculated considering the number of POIs (four types of POIs) accessible within the acceptable walking range of older people. Besides, the maximum and desirable time is considered to calculate the time component for the older adult walking accessibility index (Equation (2)).

$$OWAI1_{SA1} = (Z_{\text{-}scoreWalkTime}) + (Z_{\text{-}scorePratio}) \quad (1)$$

$$WT_{SA1i} = \sum_{j=1}^{n} Ni\left(\frac{WT_j^M - WT_{ij}^A}{WT_j^D}\right) \quad (2)$$

where:

WT_{SA1i} = total walking time for older adults from SA1 centroid;
WT_j^M = maximum walking time to destination *j*;
WTj^A = average walking time from an SA1-weighted centroid *i* to destination *j*;
WT_{ij}^D = desirable walking time to destination *j*;

Ni = number of POIs within the walking range for older people.

$$P_{ratio} = \frac{\sum_1^n Older\ Population\ for\ a\ specific\ SA1}{\sum_1^n All\ group\ Population\ for\ a\ specific\ SA1} \tag{3}$$

Pratio = Population ratio,
n = types of POIs (Four types of POIs are considered in this study).

The desirable walk time is the time when around 50% of pedestrians feel comfortable [89]. A maximum travel time is where a greater percentage of adults (Depending on survey sample size and study area) would find it within the comfortable walking limit. As the walking speed is different for the older adult, the standard travel time also varies compared to the other adults. Table 3 shows the standard walk time comparison for older adults and other adults.

Table 3. Walk time comparison.

Commuters	Desirable * Walk Time (Mean)	Maximum ** Walk Time (Mean)
Older travelers	5.83	11.6
Other travelers ***	<10	<20

* A desirable travel time that satisfies half of the road users. ** A maximum travel time is when a greater percentage of adults find it a comfortable walking limit. *** Other travelers: adults aged between 18 and 64 [90].

4.2. OWAI2

To calculate OWAI2, the older adult's total walk time, land use mix, street connectivity, older adult population and older adult pedestrians' safety are considered. Equation (5) is used to calculate OWAI2. *Walk time* (WTS_{A1i}), $P_{ratio,}$ and *LUMIX* are calculated using Equations (2)–(4), respectively.

$$OWAI2_{SA1} = (Z_{\text{-scoreWalk Time}}) + (Z_{\text{-scoreLUMIX}}) + (Z\text{-}_{\text{scoreStreet Connectivity}}) + (Z\text{-}_{\text{scorePratio}}) + (Z\text{-}_{\text{score Safety}}) \tag{4}$$

For each component, the Z score is calculated considering each SA1.

$$LUMIX = -1\sum_{j=1}^{n}(Pi * \ln(Pi)/\ln(n)) \tag{5}$$

where:

LUMIX = land use mix score;
Pi = the proportion of the area covered by land use j;
n = the total number of land-use types.

5. Results

Statistical tests are conducted using IBM SPSS 26 to measure the correlation between the observed VISTA trip data (older people only) and the walking accessibility measures from the developed indices. Cross-tabulation analysis, along with Chi-square, Likelihood, Phi, Cramer's V and Contingency Coefficient test, is applied to evaluate the index using IBM SPSS 26; these tests can identify the existence and the level of correlation between the components used to develop OWAI1 and OWAI2. If the *p-value* is less than 0.005, then it can be assumed that the variables are correlated with each other. The expected frequency for each variable cell (row/column) should be greater than 5 to fit into the statistical model goodness criteria. The Chi-square test is one of the standard statistical tests, and it is used to check the significant difference between the expected frequencies and the observed frequencies. The index is valid if the observed Chi-square statistics is greater than the minimum expected Chi-square statistics value. The likelihood-ratio test is among the oldest classical approaches for hypothesis testing. The likelihood-ratio test can evaluate the goodness of fit of two competing statistical models based on their ratio.

The symmetric measures test (nominal-by-nominal tests) describes the correlation between more than two variables. In this study, the nominal-by-nominal test defines the association between the older adult walking accessibility index and observed walking travels made by the older adult. Phi, Cramer's V and Contingency Coefficient tests are known as the most common nominal-by-nominal test. The statistical values between −1 to +1 indicate the limit for measuring the relationship between influencing variables. The values that are closer to +1 show more accurate results. The availability of older pedestrian walking trip data is minimal compared to non-walking datasets. All these statistical tests have been applied to OWAI1 and OWAI 2. Table 4 presents the cross-tabulations validation result summary for OWAI1 and OWAI2.

Table 4. Cross-tabulation validation summary * for OWAI1 and OWAI2.

Statistics Test		OWAI1 Statistics Value (Observed)	*p*-Value	OWAI2 Statistics Value (Observed)	*p*-Value
Chi-Square Tests	Pearson Chi-Square, χ^2	32.38	0.000	21.62	0.000
	Likelihood Ratio	24.89	0.000	18.00	0.000
Symmetric Measures					
Nominal by Nominal	Phi	0.63	0.000	0.52	0.000
	Cramer's V	0.45	0.000	0.37	0.000
	Contingency Coefficient	0.54	0.000	0.46	0.000

* Number of valid cases = 10,289; 0 cells have expected count less than 5. The minimum expected count is 18.92.

In Table 4, all *p-values* < 0.005 indicate both indexes are statistically significant and the index variables are correlated. Here "number of valid cases" are the total analyzed SA1 numbers. From the IBM SPSS 26 analysis results, all cells have an expected count greater than 5. In addition, according to the result of the Chi-Square test (from IBM SPSS 26 analysis results), the minimum expected count is 18.92, which is less than OWAI1 and OWAI2 observed statistic values (32.38 and 21.62, respectively).

As stated previously, no elderly time-based walking accessibility index has been reported to date, which measures access levels in statistical areas. Therefore, the accuracy of the developed OWAIs is compared with an existing index WI. WI considered the LUMIX, residential density, and street connectivity. The WI does not consider the older adult's pedestrian walk time which is one of the significant elements in identifying the accessibility level. However, the two indexes introduced in this paper, OWAI1 and OWAI2, consider the older adult's walk time in their structure. To evaluate the accuracy of the newly developed accessibility indices, OWAI1 and OWAI2 are compared with WI. The accuracy of the OWAI1, OWAI2, and WI in terms of predicting the older adult walking accessibility in metropolitan Melbourne SA1s are compared with the observed walking trips [76]. The WI is calculated for each SA1 (10,289 SA1) of metropolitan Melbourne. The comparison summary of OWAI1, OWAI2 and WI in terms of accuracy is presented in Table 5.

Table 5. Comparison of the accuracy of OWAI1, OWAI2 and WI *.

Statistics Test		OWAI1 Statistics	OWAI2 Statistics	WI Statistics
Chi-Square Tests	Pearson Chi-Square, χ^2	32.38	21.62	16.58
	Likelihood Ratio	24.89	18.00	16.65
Symmetric Measures				
Nominal by nominal	Phi	0.63	0.52	0.45
	Cramer's V	0.45	0.37	0.32
	Contingency Coefficient	0.54	0.46	0.41

* Number of valid cases = 10,289.

Table 5 shows the OWAI1 accurate performance in estimating older adult walking accessibility. All statistical test comparisons represent similar results. The calculated statistics value is higher for OWAI1 compared to OWAI2 and WI. OWAI1 considers fewer variables that can be easily measured, and the index can be calculated easier. However, OWAI2 considers variables that may create a conflicting impact on walk time despite being statistically significant. Therefore, OWAI1 is a better measure to identify older adults' walking access levels. Moreover, this study suggests OWAI1 as a new time-based older adult walking accessibility index. The higher index values indicate a lower walking access level for older adults. As mentioned previously, the OWAI1 values are grouped into six main classes, including (1) very low, (2) low, (3) moderate, (4) good, (5) very good and (6) excellent to measure the walking access level for a specific SA1 [73,87,88]. Table 6 presents the comparison of the three classification methods results of OWAI1.

Table 6. Summary results of the classification method results (OWAI1).

Index Range	OWAI1 Accessibility SA1s (%)		
Accessibility Group	**Quantile Method**	**Natural Breaks (Jenks)**	**Geometrical Interval**
Very poor	27.21	15.77	26.16
Poor	17.52	12.07	20.71
Moderate	13.37	14.76	13.66
Good	11.21	5.32	13.15
Very Good	16.39	25.12	9.76
Excellent	14.30	26.96	16.60

From Table 6, Quantile and Geometrical interval methods show similar accessibility results. Around 60% of total SA1s are categorised as very poor, poor, and moderate walking access for older adults. More than half of the total SA1s contain lower older adult walking accessibility levels compared to expected standards. Around 30% of total SA1s are identified as very good or excellent categories.

Furthermore, Figures 3–8 illustrate the spatial distribution of three different classification methods using OWAI1 within Metropolitan Melbourne SA1s. Geographic accessibility analysis is a convenient method to identify and visualize the access levels in different spatial areas. Figures 3–8 are developed using geographic software ArcMap version: 1071 (https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77] for representing access levels. The index value OWAI1 is plotted within metropolitan Melbourne, specifying the higher walking access level for older adults. In these Figures 3–8 different colors indicate older adult walking access levels. SA1s with lower index values specify the higher walking access level for older adults.

To have a more detailed analysis, the older adult walking access to each main POI can be evaluated separately. Table 7 presents the older adult walking access to different POIs using OWAI1.

Table 7. Evaluating walking access to different POIs using OWAI1.

	SA1s Accessibility (%)					
POIs	**Very Poor**	**Poor**	**Moderate**	**Good**	**Very Good**	**Excellent**
Shopping Center	43.7	23.0	10.5	11.5	5.7	5.8
Health Care Center	33.7	25.7	14.3	9.4	15. 7	11.3
Education Center	9.9	7.8	4.8	18.0	23.7	35.9
Recreation Center	3.3	4.7	10.9	8.2	23. 5	49.0

The results are discussed in the next section (Section 6).

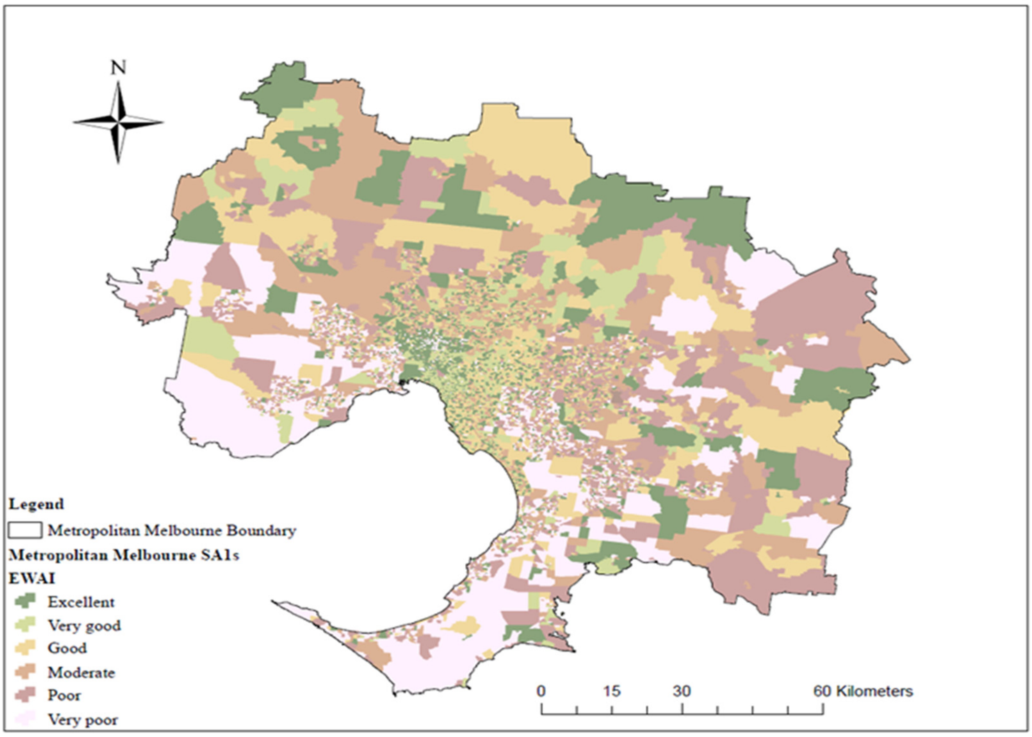

Figure 3. Distribution of walking access levels in different SA1s in metropolitan Melbourne using OWAI1 (Quantile method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

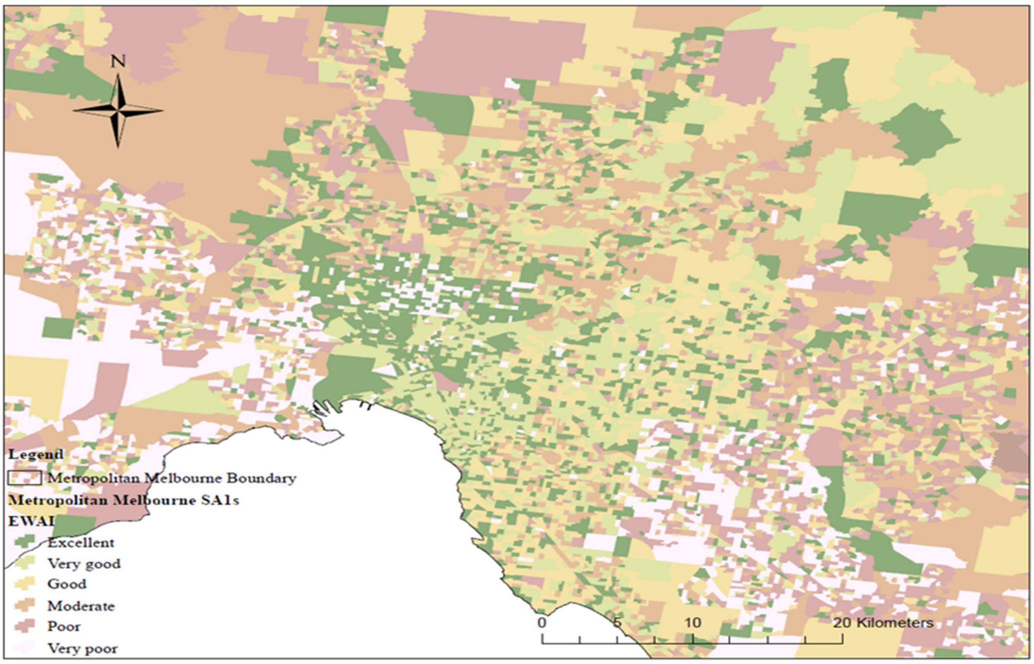

Figure 4. Elderly walking access level, zoom in visualisation, OWAI1 (Quantile method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

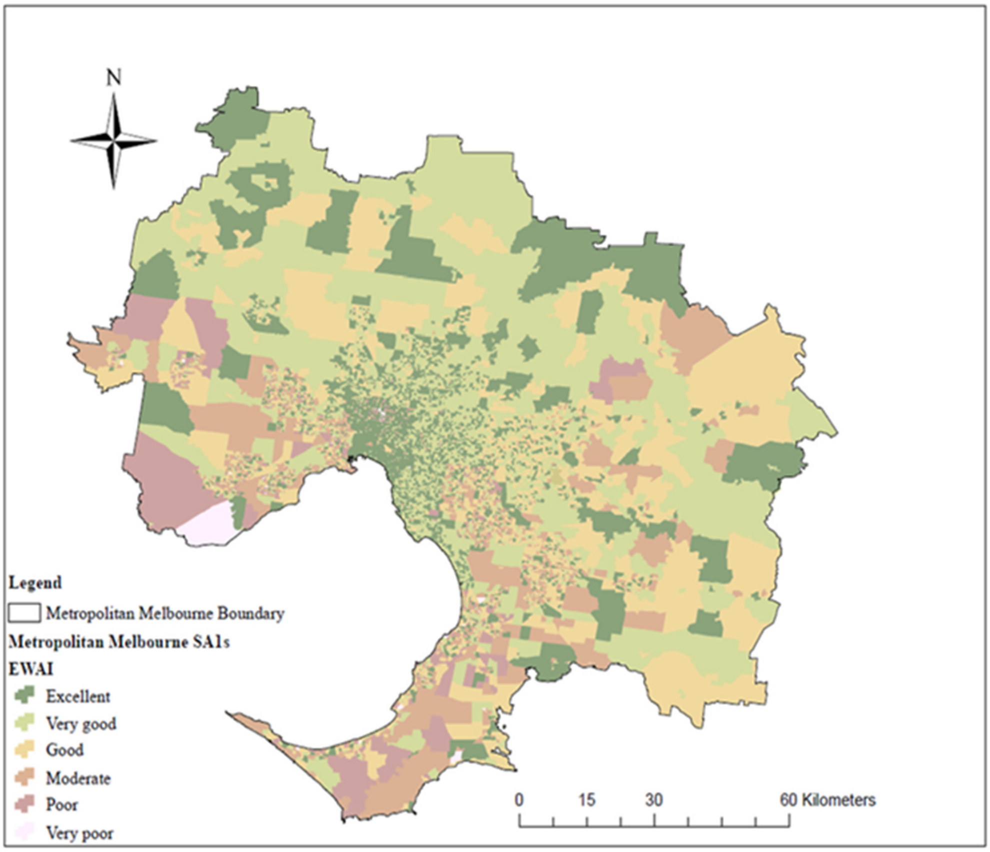

Figure 5. Distribution of walking access levels in different SA1s in metropolitan Melbourne using OWAI1 (Natural Breaks (Jenks) method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

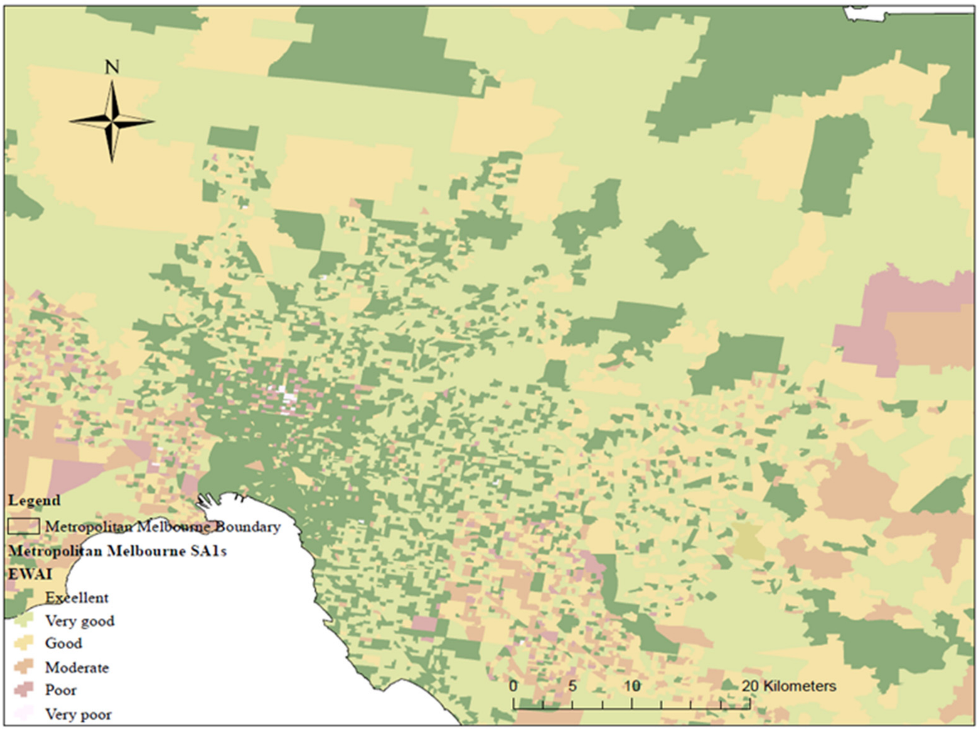

Figure 6. Elderly walking access level, zoom in visualisation, OWAI1 (Natural Breaks (Jenks) method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

Figure 7. Distribution of walking access levels in different SA1s in metropolitan Melbourne using OWAI1 (Geometrical Interval method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

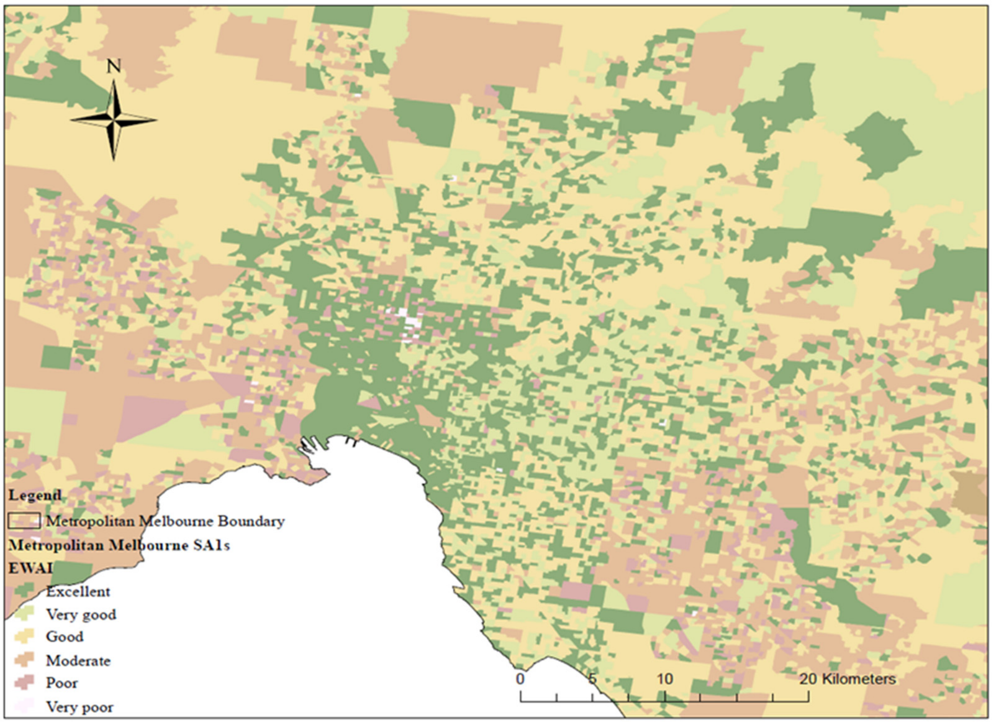

Figure 8. Elderly walking access level, zoom in visualisation, OWAI1 (Geometrical Interval method, https://desktop.arcgis.com/en/arcmap/latest (accessed on 12 October 2022) [77]).

6. Discussions

Measuring the older adult walking accessibility using OWAI1, it is observed that many SA1s are either not within the walking range or not easily accessible for the older adult. Only around 15% of SA1s are categorised as excellent in terms of older adult walking access. As shown in Figures 3–8, the walking access level differs from area to area in metropolitan Melbourne for older people. All parts of metropolitan Melbourne (inner, middle and outer) experience poor to excellent walking access levels.

If an SA1 is classified at a very poor level, it indicates that a longer walking travel time is required to reach that specific destination from a specific SA1. From Table 7, most of the shopping centers are inaccessible by walking for the older adult. Around 67% of SA1s have very poor and poor older adult walking access to shopping centers. Shopping centers generally cover a wide area, and the walking route to a shopping center route from the place of origin is not straightforward. This increases the total travel time. Similarly, more than 50% of SA1s are categorised as very poor and poor in terms of walking access levels to health care centers for older adults. However, education centers and recreation centers have better walking access for older adults. Specifically, the recreation centers have satisfying walking access levels for almost every SA1 in metropolitan Melbourne. One of the main reasons for these poor accessibility levels is that comparatively close facilities take more time to reach by walk, as it does not cover all the destinations in SA1s. Therefore, older adults take more walking time and effort to reach their destinations. Easy access to the surrounding neighbourhoods is necessary for the health and well-being of older adults. Depending on access levels, travel information can be updated, including the locations of frequently visited POIs, maps, alternative routes to reach popular destinations, estimated travel time, and estimated time of travel specifically for older travelers. Statistical areas classified as having very poor and poor levels of walk access levels can be prioritised to upgrade services.

Both developed indexes (OWAI1 and OWAI2) can be applied as a measure to identify the walking access level of the older adult. If the datasets for built-in-environment variables (such as LUMIX, street connectivity, and safety) are readily available, OWAI2 can be applied to measure walking access levels for different spatial areas. Although OWAI1 has higher accuracy in measuring walking accessibility in smaller statistical areas, OWAI2 can be more appropriate for larger spatial areas. The LUMIX, street connectivity and safety rate are more meaningful variables and may have a stronger correlation in the broader spatial areas.

7. Spatial Transferability and Implementation of OWAIs

7.1. Spatial Transferability of OWAI1

OWAI1 can be used for identifying walking access levels to other geographic and statistical areas. A study by Fatima et al. (2020) [91] presents the older peoples' walking accessibility for three home sub-region (inner, middle, and outer) of metropolitan Melbourne. Table 8 represents the summary of the OWAI1 assessment within the Metropolitan Melbourne home sub-region.

Table 8. Summary of Walking Accessibility Comparison, using OWAI1 [91].

Melbourne Elderly Walking Accessibility (%)			
Access Level	**Inner**	**Middle**	**Outer**
Very Poor	3.29	4.56	23.27
Poor	8.64	5.71	21.57
Moderate	11.74	9.87	15.86
Good	31.93	29.34	16.77
Excellent	44.40	50.52	22.53

Table 8 summarises the elderly walking accessibility comparison. From Table 8, it can be observed walking accessibility is higher in Melbourne's inner region than in Melbourne's middle and outer regions. The Inner Melbourne region has more walking access to the destination compared to the other two home sub-regions. More than 76% of SA1s are categorised as having a good and excellent level of elderly walking access. Although the outer region identifies the opposite results, around 45% of outer region SA1s are assessed as having very poor and poor levels of walking access for the elderly.

7.2. Implementation of OWAIs

This study applied GIS techniques to objectively measure walking access levels for older adults in a metropolitan region. The OWAI provides a practical measure to assess levels of accessibility within metropolitan areas. The results of OWAI access levels can be used to better understand older people's accessibility requirements and preferences and the availability of POIs and PT stops/stations. OWAIs can easily be transferable to another city/statistical/geographical than SA1 (Example: Section 7.1). The index can also be used for other destinations that older people visit frequently.

In many transport models, several variables, including socioeconomic characteristics, are considered independent variables. Therefore, a weighted accessibility index is easily applicable to identify access levels and predict future travel behavior for any specific group of commuters (in this study, older adults). Depending on access levels, travel information can be updated, including the locations of frequently visited POIs, maps, alternative routes to reach popular destinations, estimated travel time, and estimated walk time of travel specifically for older travelers. Geographical areas classified as having lower levels of walking access can be prioritised to upgrade services.

Since OWAIs consider the elderly population, the results provide precise access levels for specific areas for this age group. Based on the results, transport planners can plan a separate shuttle service for older people to minimize total walk time. The OWAI may also be suitable for the measurement of walking accessibility for physically disabled people. OWAIs can also be modified for other adult commuters according to walk time thresholds and population densities. In this study, the outcomes from the indexes are classified into six different levels. This classification helps better understand the walking patterns and access levels in detail. For instance, in metropolitan Melbourne, the education centers and recreation centers are more reachable by walking than the other destination types for older adults. According to the results, half of metropolitan Melbourne contains very low walking access to different major destinations for the older adult. Specifically, if the older adult wants to reach a shopping center by walking.

The urban planner and transport policymakers can use these indices to identify older adult walking access for different neighbourhoods or POIs. In addition, they can easily identify the areas that need more attention to resolve the issue. The results from this research can be used to improve older adults' walking access to different POIs. For example, different healthcare centers, such as medical centers with a pathology, medical centers without pathology and hospitals' walking accessibility, can be accessed separately. Additionally, population analysis for a specific area can help identify the need and demand for the POIs. Frequent street signs/directions and seat installation (on the footpath) between different origins and destinations can provide the elderly with more confidence to walk [92].

The OWAIs also apply to newly developed areas where the older people's walk time and population size can be considered for equal transport access opportunities, specifically for older and disabled commuters. The OWAI indicates a clear location and area where the improvements are needed most according to the needs of the target population group. Land use distribution for older peoples' accommodation and frequently visited POIs can be planned to use OWAI.

Furthermore, policymakers and urban designers may use these indexes to decide the location for increasing footpath accessibility, clearing footpaths of obstructions (e.g., tree debris or rubbish), ensuring minimal footpath gradients, providing ramps/escalators/lifts on high-gradient footpaths, ensuring sufficiently wide ramps to avoid difficulty maneuvering at turning points [51].

8. Conclusions and Future Research Directions

Walking is one of the primary modes to reach transport facilities such as public transport and different short-distance destinations. Lower walking accessibility always indicates a negative impact on social life and essential everyday travel. This paper introduced two walking accessibility indices, including OWAI1 and OWAI2. This study investigated the associations between access level and walking influential factors. Each of these factors (walk time, population, LUMIX, street connectivity and safety) have an impact on any travelers walking behavior. This study analyzed the detailed access level around Metropoltital Melbourne for older adults.

However, this presented approach has some limitations. A weakness of this presented approach is that the index is estimated based on the four most popular travel destinations by the older adult. The study also only focused on older travelers' weekday walking travel. Future research may include more destinations and weekend travel in the analysis. The proposed older adults' walking accessibility index can be calculated for other POIs that older adults visit frequently. This study did not consider some variables, such as sitting facilities near footpaths, outdoor public information for citizens, pavement materials (suitability for walking), pavement management conditions, street lightning and hilly/flat areas; these components are more suitable for micro-level analysis, which is not always readily available. Future research may consider these factors for any specific areas. The proposed indices are time-based and use available census data to validate the measures. The time-based index emphasizes the walk time and population of older people toward different destinations.

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