

A simulation-based Planning Support System for creating walkable neighborhoods

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Abstract

Evidence support a link between neighborhoods built environment and modal share of walking. New Planning Support System (PSS) tools for assessing changes in levels of walkability are needed that take advantage of available GIS built environment measures and intelligent simulation techniques. Based on a literature review and an empirical study, a walkability PSS developed in ArcGIS's extension CommunityViz is proposed. Relevance of the walkability PSS is examined through a workshop involving a group of potential users.

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1. Introduction

Sprawling suburban residential development around city centers is now the dominant pattern of urban growth in Australia, as ‘affordable’ new housing is generally provided through the development of new land on the urban fringe. These new communities tend to be lower-density, and have poorer access to social services, local employment opportunities, shops and public transport services, than inner city areas (Lowe et al. 2014; Giles-Corti et al. 2014). Urban sprawl in Australian cities has led to increasing reliance on private motorized vehicles for transport, even for short distances, thus causing increased traffic congestion, sedentary behavior, social alienation, and health risks (e.g. decreased physical activity, increased obesity) (Frank et al. 2007). For example, over 70% of trips in most Australian cities are undertaken by car, and a high proportion of these car journeys are for distances under 2 km (Dodson and Sipe 2008). As an example, in the outer metropolitan areas of Melbourne, 25% of short trips under 2 kilometers (km) are made by walking (Victorian Department of Transport 2010).

In Australia there is an increasing awareness of the potential social, health, and environment benefits of creating and providing *walkable* environments (also said to have high levels of walkability). This is when the built environment is designed in a way to foster walking to nearby destinations rather, than requiring individuals to rely on automobiles (Giles-Corti et al. 2010). In the past two decades, research has shown how urban planning and urban design can influence a neighborhood’s levels of walkability: higher residential densities, good street connectivity based on grid networks, mixed land use and high quality active transport infrastructure are now known as the essential components of an urban form that enables high levels of walking and cycling for transport (Giles-Corti et al. 2014). A number of studies have shown that this particular form creates shorter and more convenient walking and cycling routes between homes and jobs, retail and essential infrastructure and services (Sallis et al. 2011; Kent et al. 2011; Dannenberg et al. 2011).

Thus, the Australian urban planning community is increasingly aware that the built environment can either support or impede walking in neighborhoods, depending on how land use patterns, movement networks and design features are delivered (Lowe et al. 2014; Transportation Research Board 2005). Planners are also increasingly aware that the act of walking for transport is an important source of physical activity, which provides significant cardio-metabolic health benefits (Hamer and Chida 2008; Gordon-Larsen et al. 2009).

Physical inactivity is a priority issue in Australia as it is one of the leading causes of death and disability. More than 50% of Australian adults do not

engage in adequate levels of physical activity (Australian Bureau of Statistics 2012), and this proportion of inactive Australians is increasing (Australian Institute of Health and Welfare 2012). Therefore, increasing the number of people walking for short trips could be an effective population approach to improving health outcomes.

2. Problem formulation

To implement walkable environments in cities requires urban planners to be aware of the complex interplay of built environment variables that affect walking behaviors, and knowledge translation is critical to generating this awareness (Lowe et al. 2014). Australian urban planners can now access a variety of resources such as the Healthy spaces & places guidelines (developed by the National Heart Foundation of Australia in collaboration with the Planning Institute of Australia and the Australian Local Government Association) (Heart Foundation 2009) to identify what the essential components of a walkable urban form are.

It is critical that reliable spatial measures exist and are available to urban planners to enable systematic evaluations of the strengths and weaknesses of an urban area in terms of walkability. Collecting data using systematic measures of the built environment is fundamental in urban planning: it is the core of the urban diagnosis, a procedure widely used in the initial stage of a project to identify the needs, or what challenges, and to develop effective strategies to address these.

Geographical Information Systems (GIS) provide powerful spatial analysis routines that can be used to measure the physical location of areas, boundaries, people, and services, or to classify types of land use and features in a systematic fashion. In the active living research field, the development of GIS-based measures to quantify and describe neighborhood built environment variables known to impact on walkability has become increasingly widespread. Likewise, a variety of Planning Support Systems (PSS) have been developed over the last few decades and made available to urban planners to support decision-making about urban developments. Most of the PSS tools used in urban and transport planning have been coupled with GIS, for example the What If? collaborative planning tool (Klosterman 1999; Pettit 2005) and the more recent online version of this tool (Pettit et al. 2015), CommunityViz a simulation extension to ESRI's ArcGIS (Walker and Daniels 2011; Kwartler and Bernard 2001).

GIS measures exist to quantify and describe neighborhood built environment variables known to impact on walking behaviors. PSS that combine GIS and intelligent simulation techniques to support decision-making are also available and are being used more widely to undertake sustainable urban planning and development (Geertman et al. 2013). There are a number of walkability tools which are now being combined with GIS to become

PSS tools such as the Agent based walkability tool developed to model and communicate walkability patterns from points of interest (Badland et al. 2013) and the online AURIN walkability tool for calculating and visualization walkability metrics including land use mix, density and street connectivity (Giles-Corti et al. 2015). However, there has been little research and development in the design and application of walkability tools to be used in group decision-making.

Group decision-making workshops are techniques increasingly being used in land use planning and are showing promise in engaging key stakeholders in interactive with data and making evidence-based decision (Arciniegas and Janssen 2012; Salter et al. 2009). The CommunityViz GIS software tool combined with an interactive map tables provides a PSS software and hardware environment which is supporting a range of spatial planning activities, including for example collaborative land use planning (Arciniegas et al. 2011) and sustainable development (Pelzer et al. 2013), environmental planning and transport-oriented development (Pelzer et al. 2015) in the Netherlands. Our research focuses on the development and testing of such a PSS tool which incorporates walkability metrics and indicators with a case study application in Melbourne, Australia. We believe this to be the first such Walkability PSS which utilizes the functionality of the CommunityViz data visualization environment supported by the multi-user friendly interactive map table.

The intended outcomes of this research are twofold:

1. To create an experimental GIS-based walkability PSS where measures of walkability can be generated and updated in real time as the user makes land use changes on the map or to formulas linked to the calculations.
2. To engage and document the experience of expert planners whilst interacting with the walkability PSS.

3. Methods

The walkability PSS project involved developing a spatial model that calculated a series of walkability measures from the built environment conditions experienced at a site. The project was carried out in three phases. Two phases were necessary to design the walkability PSS: a conceptualization phase and a computation phase. The third phase consisted of a workshop where the walkability PSS was presented to a group of local experts and tested by them.

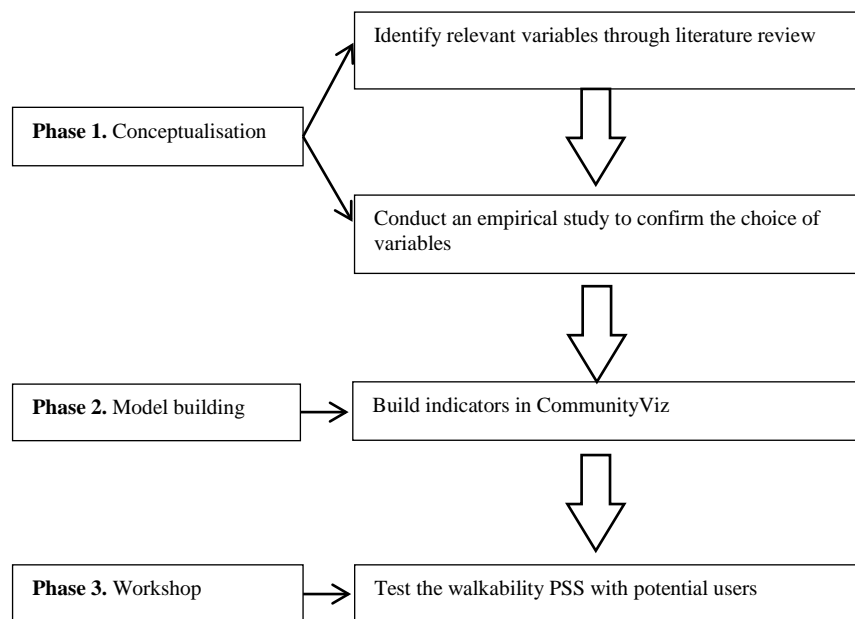


Figure 1. Project workflow

3.1 Conceptualization phase

The first stage was the conceptualization phase. Mixed-methods were employed. First, we conducted a literature review to identify built environment variables that: (i) were strongly associated with walking for transport; and (ii) could be measured using GIS techniques. In order to identify all relevant reviews, the search was conducted in a methodical manner. Searches were conducted in the PubMed, ISI Web of Knowledge and Scopus databases using the terms: “review”, “built environment”, “urban design”, “physical activity”, “walking”, “walkability” and “active transport”. The Google Scholar search engine was also used to conduct more general searches. Only review articles published in English were included and the results were supplemented with manual searches. After screening the obtained reviews for relevance, six reviews published between 2003 and 2011 were considered (Owen et al. 2004; Saelens et al. 2003; McCormack and Shiell 2011; Saelens and Handy 2008; Badland and Schofield 2005; Ewing and Cervero 2010). The variables were identified through summarizing existing reviews of the literature, and the final selection included in the walkability PSS was rationalized by the availability of spatial data.

Second, we tested correlations between the built environment variables (proxy measures of the level of walkability) selected from the literature, and the modal share of walking around activity centers across metropolitan

Melbourne. The modal share of walking is the dependent variable while the built environment variables are the independent variables.

Various datasets were used to collect information about: (i) the mode share for walking and driving (*travel data*); and (ii) the built environment surrounding the activity centers.

The travel data used in this study were drawn from the 2009 Victorian Integrated Survey of Travel and Activity (VISTA), a cross-sectional survey of travel and activity undertaken by individuals living in Victoria, Australia (Department of Transport 2009). Randomly selected households are asked to complete the VISTA travel diary for a single specified day and to enter all their personal travel information including mode of transport, the addresses they travel from and to. Thus, the VISTA dataset contains extensive information about trips made by individuals, including the mode of transport used (e.g. vehicle driver, vehicle passenger, walking, cycling) as well as spatial information (including geo-references) about the origin and destination of each trip.

The Melbourne metropolitan area was selected as the study area for the analysis and information about trips undertaken within this area were extracted. The selected trips were then characterized by distance (in kilometers). To define the length of “short trips” we investigated the minimum distance a person should walk daily to meet the recommended levels of physical activity (Australian Institute of Health and Welfare 2012). The Australian Department of Health advises people to “*aim for 30 minutes (or more) of moderate-intensity activity most days of the week*”. We analyzed the VISTA dataset and estimated the average distance people living in metropolitan Melbourne walk in 30 minutes. The average value we obtained is 1.6km for 30 minutes.

Trips that were less than or equal to 1.6 km were thus identified as “short trips” and extracted from the dataset. The short trips selection was further refined to short trips for which the mode of transport was “driving” or “walking” as in this study we decided to compare only the two modes walking and driving as two divided outcomes.

ESRI's ArcGIS 10.3 was used to map the short trips routes undertaken by walking or driving. The output was a segment layer representing 24,528 short trips (15,544 short trips undertaken by walking and 8,984 short trips undertaken by driving).

103 activity centers across metropolitan Melbourne were selected as the study area. The Melbourne metropolitan planning strategy, *Plan Melbourne* shows that these location “*attract high numbers of people and generate a significant volume of trips in metropolitan Melbourne*” (Department of Transport Planning and Local Infrastructure 2015). In fact, “many residents of Melbourne need to travel on a daily basis” in order to “access Melbourne's activity centres” (Department of Transport and Metropolitan Planning Authority 2014). Plan Melbourne also stresses that

“to promote increased physical activity”, these areas should present “a variety of land uses, high-quality public open space, and opportunities for social interaction (such as town squares).” (Department of Transport and Metropolitan Planning Authority 2014)

The activity centers were identified from the document Plan Melbourne (Department of Transport and Metropolitan Planning Authority 2014) and then ArcGIS was used to map their specific location. The output was a point layer representing the 103 activity centers.

We used the *Service area* tool to generate a road network service areas (region that encompasses all accessible streets within the specified cut-off distance) based on a 1.6 km distance along the road network for each activity center. The output was a polygon layer representing the service areas around each activity center. The 1.6 km distance along the road network was set in order to capture the area where short trips to or from the activity center occur.

The short trips layer was then overlaid onto the service areas layer. We used the *Tabulate intersection* tool to obtain the count of short trips per mode and per activity center. The output was a table containing the count of all trips, the count of short trips undertaken by walking and the count of short trips undertaken by driving for each activity center area. We then calculated, for each activity center, the modal share of walking and driving.

The modal share of walking was calculated by: number of short trips undertaken by walking divided by the total number of short trips. Similarly, the modal share of driving was calculated by the number of short trips undertaken by driving divided by the total number of short trips.

We then computed seven built environment measures selected from the literature for each activity center (described below). All the measures were calculated using ArcGIS 10.3.

Net residential dwelling density; Net commercial dwelling density; Portion of area in residential use and Portion of area in commercial use: A census dataset from the Australian Bureau of Statistics (Australian Bureau of Statistics 2011) containing counts of the total usual resident population, total dwelling count and land use category (e.g. residential, commercial, industrial, agricultural or parkland) was used to compute these four measures.

Net residential dwelling density was calculated by: number of residential dwellings divided by the area (ha) of residentially zoned (and constructed) land.

Net commercial dwelling density was calculated by: number of commercial dwellings divided by the area (ha) of commercially zoned (and constructed) land.

Portion of area in residential use was calculated by: the area (ha) of residentially zoned (and constructed) land divided by the total area of the service area.

Portion of area in commercial use was calculated by: the area (ha) of commercially zoned (and constructed) land divided by the total area of the service area.

Intersections density: the service areas layer was overlaid onto a road network layer representing road intersections and road segments across Melbourne metropolitan area. Using the *Select by location* tool, all the intersections that were within the center boundaries were identified and attributed as being located within that respective center. For each activity center, the formula used for *intersections density* was: the total number of intersections divided by the total area of the service area.

Number of public transport stops accessible within 1.6 km and number of modes of public transport accessible within 1.6 km: A dataset containing the geocoded locations of all public transport stops and information about the service (including the mode of transport available at that stop) across the Melbourne metropolitan area was used to map all the public transport stops within the activity centers. Using the *Select by location* tool, all the public transport stops within the center boundaries were identified and attributed as being located within that respective center. The number of modes of public transport available in each activity center area was then computed.

3.2 Model building phase

The walkability PSS was designed within the CommunityViz software shell. CommunityViz works as an extension to ESRI's ArcGIS, and it contains a number of interactive tools which can be used to model, analyze, and visualize geographic information (Pelzer et al. 2015).

One component of CommunityViz, *Scenario 360*, was used in this project. Scenario 360 is an open modeling framework where a dynamic map is linked to custom formulas, indicators, and charts, which all update in real time as the map or the formulas are modified (Walker and Daniels 2011). CommunityViz and the embedded Scenario 360 component have been used in a number studies to assess the economic, environment or even social impact of proposed development plans, land-use regulations, and infrastructure investment. (Nedovic-Budic et al. 2006; Pelzer et al. 2015)

We selected five indicators to add to our baseline scenario. The table 1 below presents how spatial variables affect the various indicators.

For this particular study we only created five indicators. The rationale was to create first a relatively simple model which would be transparent and understandable to the workshop participants in the third project phase.

Table 1. Evidence-based indicators to assess walkability level

<i>Indicator</i>	<i>Indicator is sensitive to</i>	<i>Will be updated when</i>
<i>Number of modes of public transport accessible within 1.6 km</i>	The count of unique values occurring in the field: “public transport mode” found in the public transport stops point layer.	The value “public transport mode” is modified (e.g. changed from “bus” to “train”)
<i>Number of public transport stops accessible within 1.6 km</i>	The count of all features found in the public transport stops point layer.	The location of public transport stop is modified or when stops are added/removed
<i>Number of intersections per sq. km</i>	The count of all features found in the intersections point layer.	The location of intersections is modified or when intersections are added/removed
<i>Percentage of area in residential use</i>	The land area allocated to residential use calculated from the land use polygon layer.	The land use layer is modified (size or value is changed)
<i>Percentage of area in commercial use</i>	The land area allocated to commercial use calculated from the land use polygon layer.	

3.3 Workshop

This workshop was the second of the *Planning Walkable Healthy Communities* workshop series organized by the lead author. 14 experts participated in the first workshop in March 2014, which uncovered methods and tools (from paper-based checklist through to GIS-based software) for measuring walkability.

Eight local experts, including land use and transport planning practitioners, representing private sector, local governments, state government and university could attend the second workshop. Most of the reasons for dropout were due to inability to attend the workshop because of schedule conflicts. This second workshop lasted 90 minutes and included a 20 minutes presentation by the lead author. The purpose for the participants was to learn about the walkability PSS tools, test it and then ascertain their views and opinions on the application of the tool in urban planning practice.

The workshop was conducted on a touch-enabled hardware tool known as the MapTable. The MapTable is a large touch table (46 inches), developed

by Mapsup (<http://www.mapsup.nl>). The MapTable works as the interface between users and a large variety of planning tools, in that case with CommunityViz. Because table is large enough to accommodate a group of 10 people, it provides an interactive environment to support multi-stakeholder planning processes.

The lead author conducted a 20 minutes live demonstration for participants to understand the language used to describe the various component of the PSS and to learn how to use the tool.

One exercise was designed for participants to experiment the walkability PSS. First, the workshop's participants were presented with a base scenario of the study area and the five walkability indicators set up in CommunityViz. As presented in Figure 2. The base scenario included various spatial layers of road network, land uses and public transport. The walkability indicators were linked to dynamic charts which provide instant visual feedback about how changes to the plan affect the indicators.

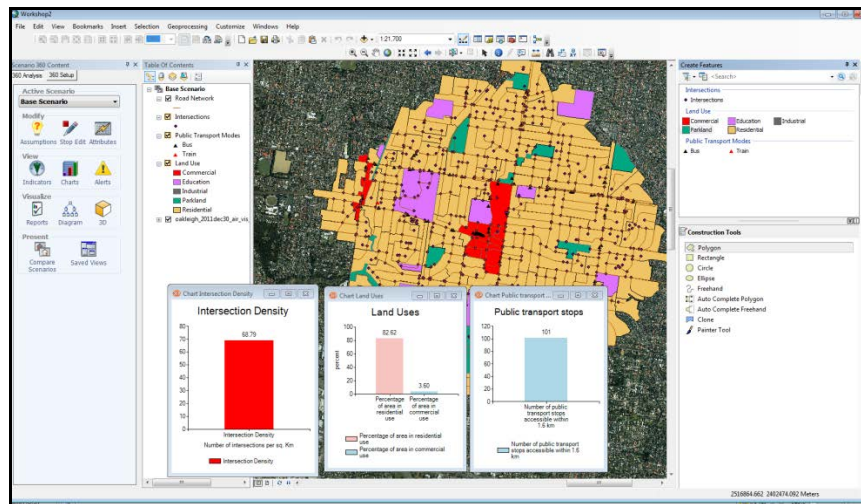


Figure 2. Screenshot of the Glen Waverley case study

The study area is known as Glen Waverley, it is an activity center located in the Eastern metropolitan region, about 20 km away from Melbourne Central Business District. Our previous analysis revealed that in this area driving is the dominant form of transportation for short trips: only 23% of short trips are walked in Glen Waverley.

Secondly, the participants were presented with the table 2 below which summarizes the characteristics of the ten activity centers in which we found the modal share for walking is superior or equal to 77%. We defined these characteristics as the *best-case scenario* guidelines for the exercise.

We asked the participants to prepare a new scenario for Glen Waverley in order to improve its level of walkability. The objective was to develop a scenario where Glen Waverley would present built environment characteristics similar to the best case scenario guidelines. They had to modify the baseline scenario (e.g. change land use classes, add/remove public transport stops, modify the road network) and to use the dynamic charts

Table 2. Characteristics of the ten activity centers with the highest modal share for walking

Name	Modal share of walking	Intersections per Sq. km	% Land Use Residential	% Land Use Commercial	Number of PT stops	Number of PT modes
Fitzroy-Brunswick Street	96%	210.80	33%	29%	169	3
Carlton Lygon Street	95%	199.07	32%	28%	155	3
Fitzroy-Smith Street	88%	186.34	38%	26%	115	3
South Melbourne	87%	166.30	32%	14%	132	2
Richmond-Bridge Road	83%	171.41	43%	12%	99	3
Prahan/South Yarra	83%	223.92	59%	13%	122	3
Richmond-Victoria Stret	82%	150.99	44%	16%	85	3
Richmond-Swan Street	81%	170.38	42%	10%	96	2
Brunswick	79%	101.13	65%	11%	138	3
Port Melbourne-Bay Street	77%	162.36	47%	10%	87	2
Mean		174.27	44%	17%	119.8	2.7

4. Results

4.1 Conceptualization phase

The literature review identified population density, land use mix, street connectivity, proximity of destinations, presence of sidewalks, and access to public transport services were built environment variables associated with walking for transport (Owen et al. 2004; Saelens et al. 2003; McCormack and Shiell 2011; Saelens and Handy 2008; Badland and Schofield 2005; Ewing and Cervero 2010). Although recognized as being important, it was not possible to measure the “presence of sidewalks” as no spatial data were available. Our final GIS measures were: *access to public transport, street connectivity, population density and land use mix* (Table 3).

Table 3. List of GIS measures derived from the literature

Number of modes of public transport accessible within 1.6km	Access to public transport
Number of public transport stops accessible within 1.6km	
Number of intersections per sq. Km	Street connectivity
Net residential dwelling density	Population density
Net commercial dwelling density	
Percentage of area in residential use	Land use mix
Percentage of area in commercial use	

We tested correlations between the seven built environment measures and the proportion of trips undertaken by walking around the 103 activity centers across metropolitan Melbourne. The results of the analysis are presented in Table 4.

Table 4. Correlation matrix

Variables	1	2	3	4	5	6	7	8
<i>1 - Percentage of short trips undertaken by walking</i>	1							
<i>2 - Number of modes of public transport accessible within 1.6 km</i>	.641**	1						
<i>3 - Number of public transport stops accessible within 1.6 km</i>	.730**	.613**	1					
<i>4 - Number of intersections per Sq km</i>	.501**	.255**	.488**	1				
<i>5 - Net residential dwelling density</i>	.788**	.540**	.749**	.778**	1			
<i>6 - Net commercial dwelling density</i>	.693**	.360**	.645**	.752**	.784**			
<i>7 - Percentage of area in residential use</i>	-.339**	-0.176	-.244*	-.419**	-.498**	-.382**	1	
<i>8 - Percentage of area in commercial use</i>	.689**	.546**	.702**	.672**	.796**	.657**	-.623**	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

As shown in Table 4, we found that in our sample of activity centers, the percentage of short trips undertaken by walking was strongly associated ($|r| > .5$) with the number of modes of public transport accessible within 1.6 km, the number of public transport stops accessible within 1.6 km, the number of intersections per sq. km, the net residential dwelling density, the net commercial dwelling density the percentage of area in commercial use. The magnitude of the association between the percentage of short trips undertaken by walking and the percentage of area in residential use was moderate ($.5 > |r| > .3$).

These results supported the selection of GIS measures and allowed us to progress into the next phase where we developed indicators in CommunityViz.

4.2 Model building phase

Throughout the model building phase we found that CommunityViz offers a powerful and flexible environment to create custom indicators. The construction of a baseline scenario and indicators in CommunityViz does not require a high level of expertise in urban informatics. Since CommunityViz is an extension for Esri ArcGIS, the product's familiar environment makes it easy to install and learn.

For this particular study, only five indicators were created. Perhaps because these indicators are defined by relatively simple equations (involving counts and *where* statements) we found that the Structured Query Language (SQL) queries were very simple to manipulate to set up the indicators.

We found the primary advantage of using the CommunityViz system is that once the base scenario and the indicators are set up, all the calculations and the visualizations refresh as soon as the spatial layers or numerical inputs are modified. We found this is useful to communicate in a very clear fashion about the outcomes of spatial transformations.

4.3 Evaluation phase: workshop.

After the demonstration and experiments, the participants filled in a survey in which they (i) assessed the level of relevance to practice of the walkability PSS; and (ii) provided feedbacks for improvement.

The potential applications of the PSS and barriers to use them were addressed in the survey in order to gain information on the users' needs.

The statements on the policy-relevance revealed that all the participants would consider using CommunityViz in their practice. All the participants rated the walkability PSS as highly relevant to their practice.

In terms of barriers to use CommunityViz, the participants designated the need for expert training, the cost of the software (purchase of the license) and the availability of spatial data. The participants identified one major barrier to use the Maptable being the cost of the hardware.

A number of areas for improvement were identified through the workshop: additional GIS measures to add the walkability PSS were identified by the participants. These measures include: surface of car parks, presence of essential destinations (e.g. health, welfare and community services, retail, employment, recreation and entertainment facilities), length of sidewalks, types of roads and lot layout. All the participants believed that these particular measures could inform further indicators on walkability.

All the participants said that they were interested in further developments of the walkability PSS, in particular the design of a predictive model that estimates the changes in modal share for walking upon changes in the built environment.

5. Conclusions

To better capture the likely impacts of urban policies and development plans, a variety of PSS have been developed. The walkability PSS presented in this paper is still under development. However, it provides a set of evidence-based walkability indicators which are presented to the end users in a graphical rich interface made possible through the use of the GIS based CommunityViz extension.

The Walkability PSS has been constructed to support group decision-making and in this paper we report on some of the preliminary results and feedback from this first workshop with planning practitioners.

In the course of the study a number of potential improvements were noted that would help further refine the analysis and the tool. When data and resources become available various improvements will be considered. We plan to develop distance-based measures to daily destinations (including retails and trade, health welfare and community services, recreation, leisure, arts and entertainment services) and population density measures.

The built environment and travel behaviour shall next be measured at the individual level. In this particular study these information were collected at the activity centre level. However address level participant data will be

used in the future as it will increase the precision of the analysis. With such individual data built environment measures can then be developed for the unique neighbourhood accessible from each participant's address location. Likewise, the time and distance travelled by walking daily can be measured at the individual level.

At this stage the walkability PSS only provide feedback about built environment measures which indicate how walkable the study area is. However we believe that it is worthwhile to further model the complex causal relationship between the built environment and modal share of walking using structural equation modelling techniques. It is the longer term goal of our research to embed a predictive model in CommunityViz and to create an indicator that estimates the changes in modal share for walking upon changes in the built environment.

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