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Improving planning analysis and decision making: The development and application of a Walkability Planning Support System

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ABSTRACT

Planning Support Systems are spatially enabled computer based analytical tools. They are designed to process spatial data and model *"what if"* scenarios in support of planning analyses. This paper presents how an existing land-use planning software was customised to create the Walkability Planning Support System. The paper describes the tool features including: (i) automated calculation of built environment variables; (ii) "sketch planning" functionality; and (iii) suite of indicators including a walkability indicator that estimates the probability that an adult would walk for transport. We discuss how the Walkability PSS enables urban planners to explore built environment scenarios and visualise their potential impacts on walkability. We present a suburban case study where we compare a baseline scenario with an alternative scenario developed with local planners that incorporated possible built environment interventions. Finally, we discuss potential applications for the tool and present how it could be refined along with recommended research directions.

1. Introduction

Given rapid urbanization rates worldwide (United Nations et al., 2015), many cities are growing and transforming, putting enormous pressure on urban planning and decision-making (Giles-Corti et al., 2016; Stevenson et al., 2016). Cities are made up of complex and simultaneously occurring systems e.g., transport; land-use; social, physical and digital infrastructure as well as energy and utilities. Planners need to understand and capture the collective effects of these systems when planning for healthy, sustainable development (Ainsworth and Macera, 2012; Allen, 2001). To facilitate this, data driven systems approaches can help planners appreciate how patterns and issues for cities (e.g., public health risks, green-house gas emissions) emerge from the interplay of complex systems (e.g., suburban urban form, location of employment, public transport systems). Data driven systems approaches can also help capture opportunities for improvement, for example in recognizing leverage points in the urban systems where interventions could lead to improved health and environmental sustainability outcomes (Diez Roux, 2011). Importantly the human interactions in these complex systems can be modelled and simulated. Given places are designed for people this is a critical consideration when planning future neighbourhoods and cities.

While it is established that regular participation in physical activity has positive impacts on individual physical and mental health and contributes to social cohesion (Van Dyck et al., 2015; World Health Organization and Calouste Gulbenkian Foundation, 2014), cities around the world face a dramatic increase in the rates of chronic disease, obesity and sedentary lifestyles. Over the last decade, there has been rapid growth in research into the built environment as an enabler or barrier to health and wellbeing. It appears that barriers to physical activity arise from the way cities are planned, designed, built or renewed and numerous studies have shown that city design influences walking behaviours (Heath et al., 2006; McCormack and Shiell, 2011; Ferdinand et al., 2012; Saelens and Handy, 2008; Saelens et al., 2012). Neighbourhoods are described as more "walkable" when they enable people to make walking their first transport mode of choice (Badland et al., 2013). Conversely, neighbourhoods that encourage motor vehicle dependency reduce opportunities for people to accumulate physically activity by way of active travel (Younger et al., 2008). Different design features influence different types of physical activity; key features found to be consistently associated with participation in transport-walking (Ainsworth and Macera, 2012), an active mode of transport, include: residential density, land use mix, street connectivity, proximity of destinations, presence of sidewalks, and access to public transport infrastructure (Adams et al., 2013). However, it is also understood that walkable environments arise from a combination of built environment

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attributes, typically described as a range of appropriate destinations easily accessible via connected street networks and supported by higher population densities (Christian et al., 2011; Frank et al., 2010; Grasser et al., 2013; Owen et al., 2007).

To date, there has been less emphasis on examining these relationships in dynamic simulation environments to examine the impact of urban planning decisions on health outcomes (Diez Roux, 2011). Yet, in the last decade, there has been a rapid proliferation of both evidence on walkability and active transports modes - including transport-walking (Lowe et al., 2014) - greater availability of high quality and fine-grained spatial data, and on-going advancements in smart city related information technologies, such as PSSs (Geertman et al., 2015). Planning Support Systems (PSSs) are spatial data driven tools designed for measuring, mapping, or evaluating impacts arising from likely urban development scenarios (Geertman, 2002; Geertman and Stillwell, 2004). When developed using best practice evidence, they can be applied to meaningfully derive information and analyse data to support spatial planning practices (Geertman et al., 2013). PSSs are designed to support collaboration throughout the urban planning process with simple user interfaces that allow testing and evaluation of various urban design scenarios (Arciniegas and Janssen, 2012; Geertman and Stillwell, 2004; Geertman et al., 2013), and are commonly built using Geographical Information Systems (GIS), designed to collect, analyse and visualise spatial data. In addition to the GIS core functions, PSSs include tools specially designed for supporting urban and regional planning including demographic analysis tools and environmental modelling functions (Brail and Klosterman, 2001). They support sketch planning processes where maps and drawing tools are employed to visually represent planning schemes and potential plans (Geertman and Stillwell, 2003; Vonk and Ligtenberg, 2010). Many examples of PSSs in transport management (Biermann et al., 2015), scenario planning (Levy et al., 2015) or public engagement (Jutraz and Zupancic, 2015) can be found in the literature (Geertman et al., 2017). The evolution of PSSs is taking place simultaneously with the development of new spatial methods and software technologies (Geertman et al., 2017). Such developments allow PSSs to display greater capacity in terms of visualisation, e.g., visualisation of multi-dimensional data or three-dimensional scenes time (Geertman et al., 2017) and perform complex tasks including the computation of complex algorithms in short periods of time (Widjaja et al., 2015).

These conditions have motivated the development of a PSS capable of simulating changes in the built environment and measuring the impact these changes would have on transport walking behaviours. Such a PSS could support decision-makers and urban planners to: (a) measure the walkability of an area; (b) test potential impacts of future policies and planning scenarios by allowing users to create and manipulate a virtual representation of an urban precinct (Diez Roux, 2011); and (c) assess selected health impacts of planning decisions for the community. Hence, the aim of this study was to customise an existing GIS-based PSS tool to create a “Walkability” focused PSS tool, operational for modelling and evaluating the impact of planning decisions on transport-walking outcomes. This paper focuses on the tool development, further research into the usability of the Walkability PSS and its suitability in planning practice has been reported elsewhere (Boulange et al., 2017b).

2. Methods

2.1. Study area

To test the Walkability PSS a case study was conducted in collaboration with the Victorian Planning Authority (MPA) and the City of Hume Council, who were undertaking at the time this research a large urban renewal project in the suburb of Broadmeadows in metropolitan Melbourne. This was an opportunity to engage with practitioners and to apply the Walkability PSS to a real example. Broadmeadows is located 16 km north from the Melbourne Central Business District as presented in the local context plan in Fig. 1.

The City of Hume is a growing, urban fringe municipality with well-established urban areas in the southern section that is closer to the city, and rural areas in the north. It also includes Melbourne's principal

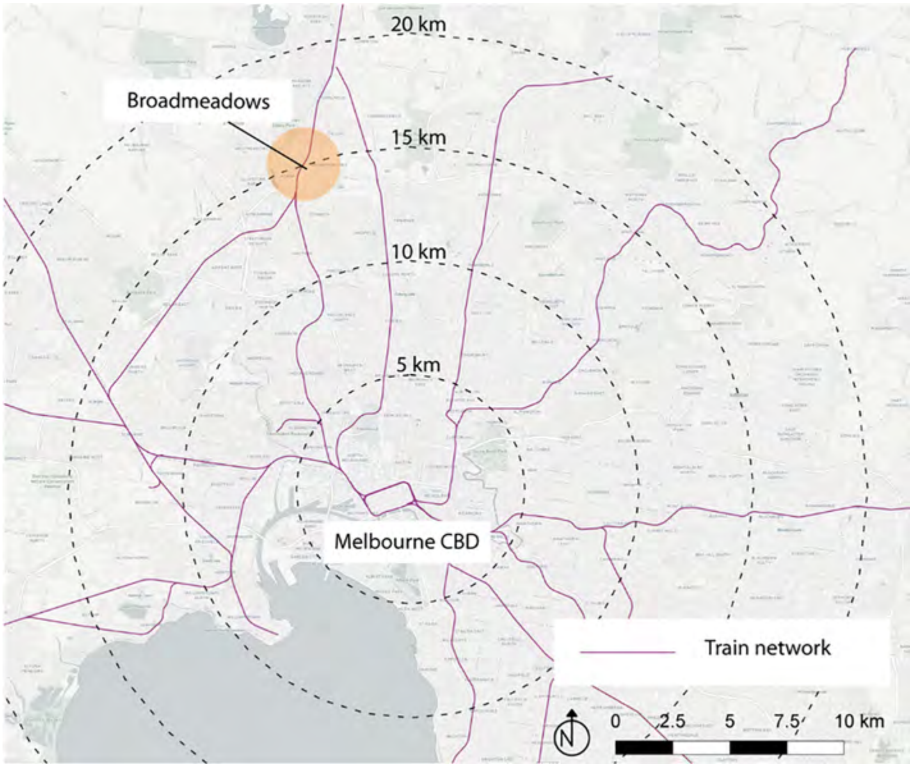

Fig. 1. Broadmeadows, local context plan.

airport, Tullamarine. Broadmeadows is situated in the southern part of The City of Hume and stretches over 840 ha. It is described as "an established industrial and residential area, with some military and commercial land use" (Community Indicators of Victoria, 2015). The 2011 Australian Bureau of Statistics (ABS) census (Australian Bureau of Statistics, 2011) measures the population as 10,630 people, with a population density of 12.59 persons per hectare (Profile.ID, 2016). Broadmeadows is a brownfield area i.e., an area previously used for industrial or commercial purposes re-zoned as residential and it is dealing with a range of planning issues. These include the provision of housing for a fast-growing population and meeting the challenge of maintaining local employment despite shifts in the local economy and decline in manufacturing jobs which previously were in Broadmeadows. The challenge, as Broadmeadows grows, will be to ensure that people have access to liveable and walkable neighbourhoods (Lowe et al., 2015). To respond to these challenges, the VPA and the City of Hume Council prepared the *Greater Broadmeadows Framework Plan*, a high level strategy to "revitalise the heart of Broadmeadows" and provide the current and future population with better access to affordable housing, jobs, services and transport (Metropolitan Planning Authority, 2016). In particular, the framework plan identifies opportunities for retrofitting declining commercial areas to higher density residential and mixed use areas as well as options for improving access to public transport and to the metropolitan rail network (Metropolitan Planning Authority, 2016).

2.2. Participatory workshop

The case-study involved a two-hour participatory workshop to facilitate dialog and co-learning among researchers and practitioners (Minkler et al., 2006; Minkler and Wallerstein, 2011). The event was conducted in May 2016 with seven spatial planners (i.e., urban and transport planners) from the Victorian Planning Authority (MPA) in Melbourne and one State government adviser from the Victorian Department of Health and Human Services. A MapTable (http://www.mapsup.nl) was utilised in this workshop. This 46 in.-long touch table, works as an interface between users and a variety of planning tools, including CommunityViz 5.1. The table provides an interactive environment to support multi-stakeholder planning processes and is large enough to accommodate a group of about ten people (Pelzer et al., 2013).

In the first part of the workshop, the participants received detailed instructions on how the software interface works and how to sketch a scenario. After the initial training, they were invited to create an alternative scenario as per the *Greater Broadmeadows Framework Plan* (Metropolitan Planning Authority, 2016) in which they had to examine the effect on walkability and the probability of transport-walking in developing the Broadmeadows area because of:

- including a new railway station;
- including a new shopping centre;
- and allowing for commercial and housing growth through the re-zoning of appropriate areas.

In the second part of the workshop, the participants worked with the workshop facilitator (lead author of the present paper) and used the software to sketch all the above interventions (i.e., place a railway station, edit the zoning) and save the outputs into an "alternative scenario". The data from the baseline and alternative scenarios were then exported to an archive file. The workshop facilitator helped the participants create a project report using the software functions with summary information for the baseline and alternative planning scenarios presented as displayed in Table 3 and Fig. 2.

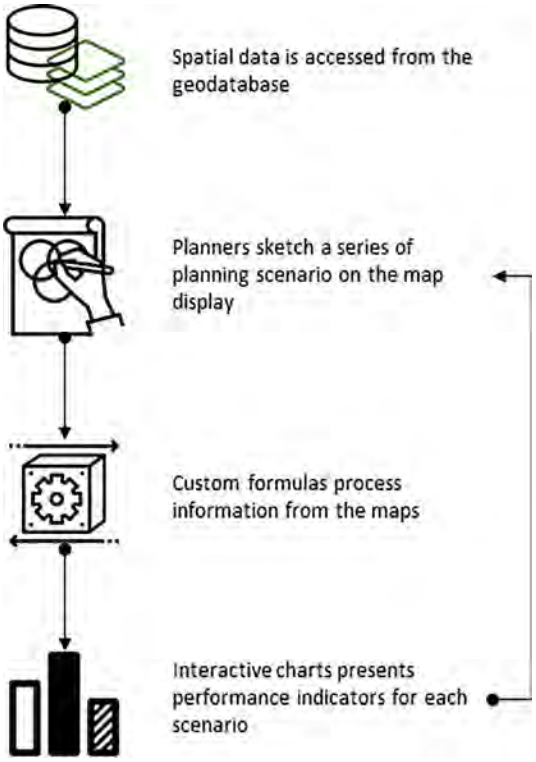

Fig. 2. The Walkability PSS workflow – supporting interactive scenario exploration.

2.3. Software selection

PSSs for building custom interactive models using spatial data already exist. CommunityViz 5.1 is one example of a PSS software package specifically designed to simulate, measure and communicate the impacts of planning decisions with decision makers in real-time. Other such PSS software packages include the Online What if? (Pettit et al., 2013), Index (Allen, 2001), UrbanSim (Waddell, 2002) and UrbanFootprint (Calthorpe Associates, 2012). CommunityViz 5.1 is a commercially available software package owned and administrated by City Explained Inc. It was selected for this research as it is readily customisable and is an extension of ESRI's ArcGIS, a widely used GIS platform (Walker and Daniels, 2011). This extension can produce 3D scenes, maps and reports, charts, graphs, and interactive scenarios (Walker and Daniels, 2011) and is designed to help users visualise, interrogate, analyse and evaluate planning scenarios. It is a multi-purpose and versatile type of PSS software package with the capacity to set-up custom interactive spatial interfaces, develop complex spatial models, and provides linked visual representations (e.g., maps linked to graphs) of different planning scenarios.

In addition to the generic ArcGIS functions (e.g., querying and displaying spatial data, measuring distances between features, calculating spatial statistics) the extension adds a "dynamic" interface to support sketch-planning processes. Once the extension is enabled, the user can edit or create new spatial objects, for example represent new roads; change the location of feature points such as bus stops; or draw new polygons to represent some new areas suitable for commercial development. Once the user modifies the spatial objects, all attribute values are simultaneously updated. For example, if the user transforms the contours of a polygon, the attributes "perimeter" or "area" for that polygon automatically recalculates. Custom models can be built to operationalise built environment variables and relate them to outcomes of interest (e.g., participation in transport-walking). CommunityViz 5.1 includes a toolbox library with a range of basic analytical tools. For example, toolbox has functions to count the number of point features within a polygon, or measure distances between points. However, when the toolbox library becomes too limited for the analysis, users can upload libraries sourced from other software to create their own parametric custom equations. For example, it is possible to build custom regression models that relate spatial information to specific outcomes such as participation in transport-walking (Saelens et al., 2003), cardiovascular disease outcomes (Eichinger et al., 2015), energy use (Creutzig et al., 2015), greenhouse gases, and pollutant emissions (Wilkinson et al., 2007). CommunityViz 5.1 can calculate complex algorithms and generating results in real time. This makes the software package helpful for testing and refining urban planning scenarios in workshop situations (Boulange et al., 2017a; Geertman et al., 2013). It is also a well-accepted and respected PSS tool, which has been used internationally in several planning related studies (Giles-Corti et al., 2015).

2.4. Underlying walkability model

In an earlier study, multi-level multivariate logistic regression analysis was undertaken using the Victorian Integrated Survey of Transport and Activity 2009–10 (VISTA09) to examine the relationship between neighborhood environments (see Table 2) and transport-walking behaviours (see Table 3) (Boulange et al., 2017a). This model was adapted from previous walkability models and walkability indices (Frank et al., 2005; Giles-Corti et al., 2015; Krambeck and Shah, 2008; Krambeck, 2006). However, to maximise the policy-relevance of the study (Allender et al., 2009; Durand et al., 2011), the built environment measures were aligned with the Victorian planning policies including the Victorian State Planning Policy Framework (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2016) Plan Melbourne (State Government Victoria, 2014) and the Precinct Planning Guidelines (Growth Areas Authority, 2009).

VISTA09 is an on-going self-report one-day survey of travel and activity, conducted across Greater Melbourne and selected regional centres of Victoria, Australia. VISTA09 captured all trips made by individuals ($n = 42{,}002$) on a survey day, including trips, mode of travel, distance travelled, and trip origins and destinations. It also recorded socio-demographic information about participants and their household. Eligibility for inclusion in the earlier study were participants aged ≥18 years, residing in urban metropolitan Melbourne who had engaged in any transport activities in their residential neighborhood on the day they completed the survey ($n = 16{,}890$).

In this study, the findings from the multi-level multivariate logistic regression analysis were applied to the walkability algorithm.

$$\text{Estimate of } P(y_i = 1 \mid x_{i1,\ldots}x_{ip}\Big) = \frac{e^{(b_0+b_1 X_{i1}+\ldots+b_p X_{ip})}}{1+e^{(b_0+b_1 X_{i1}+\ldots+b_p X_{ip})}}$$

In this algorithm, the effect of each built environment variable (x_k) is "weighted" by its regression coefficient (b_k) to measure the probability that the dependent variable y taking on the value 1 ($y = 1$), if a participant undertakes at least one or more transport- walking trips. Coefficients from this model have been reported elsewhere (Boulange et al., 2017a) and are presented in Table 1. These results indicate that adults living in a neighborhood where there are a variety of destinations, higher residential density, various housing typologies, as well as a supermarket within 500 m, a bus stop within 400 m and a train station within 800 m have greater odds of participating in transport-walking.

2.5. Development of the walkability PSS with Broadmeadows data

A geodatabase was created in the GIS (see Table 2) and loaded with the spatial layers required for calculating the built environment variables which had been found to impact participation in transport-walking. The spatial layers included: land use mesh-blocks (polygons) (Australian Bureau of Statistics, 2011); residential mesh-blocks (polygons) (Australian Bureau of Statistics, 2011); local living destinations (points) (Pitney Bowes Ltd., 2014); public transport stops (points) (Public Transport Victoria, 2012) and street network dataset (polylines and points). The spatial layers were cropped to the boundaries of the study area.

Table 1
Adjusted regression coefficients for participation in transport-walking in the neighborhood based on Boulange et al. (2017a).

Built environment variable	Coefficient (Std. Err.)
Street connectivity	0.00350 (1.52)
Land use mix	0.409(1.67)
Local living destinations	0.168*** (8.22)
Housing diversity	0.0945** (2.64)
Dwelling density (gross)	
< 10.0 dph	Ref.
10.0–14.9 dph	−0.341* (−2.42)
15.0–19.9 dph	−0.0350 (−0.21)
20.0–29.9 dph	0.668** (3.17)
30.0–39.9 dph	1.022*** (3.51)
≥40 dph	0.927* (2.46)
Distance to closest supermarket	
Over 1000 m	Ref.
Between 500 m and 1000 m	0.0673 (0.69)
Within 500 m	0.405*** (3.63)
Distance to closest train station	
Over 800 m	Ref.
Within 800 m	0.224** (2.70)
Distance to closest bus stop	
Over 400 m	Ref.
Within 400 m	0.296*** (4.03)
Constant	−4.164*** (−16.13)

Model adjusted for clustering at the census area and household levels.
Key: dph = dwellings per hectares; Ref. = reference; Std. Err. = Standard Error.

* significant at the level $p < 0.05$.

** significant at the level $p < 0.01$.

*** significant at the level $p < 0.001$.

Next, a suite of custom formulae were programmed into CommunityViz 5.1 to operationalise the built environment variables. The formulae were designed to extract information from the data loaded in the geodatabase and calculate a suite of built environment variables including: land use mix; intersection density; dwelling density; housing diversity score; local living score; closest supermarket; closest train station; closest bus stop (see Table 2).

After the built environment variables were programmed, the walkability indicator was built in a custom formula. To estimate the probability that an individual participates in transport-walking, the formula takes in the values for each built environment variable (Table 3) multiplied by the corresponding regression coefficients, and summed with the constants (Table 1).

Finally, dynamic charts were programmed into CommunityViz 5.1. The dynamic charts represent the values taken by the indicators (e.g., the proportion of dwellings within 400 m of a bus stop, the probability that an adult participates in transport-walking) that exist in the analysis. The information presented in the dynamic charts change in response to alterations to the spatial layers according to the planning scenarios being tested within the Walkability PSS. The ability to dynamically link the maps and charts provided a powerful visual analytics approach to support urban planners in exploring user generated walkability scenarios (Pettit et al., 2012). After the development was completed the Walkability PSS was operational for use as presented in Fig. 2.

Table 2
Spatial layers.

Spatial layer	Description, data preparation	Geometry
Land use mesh-blocks	Mesh-blocks are the smallest geographic region in the Australian Statistical Geography Standard and identify types of land use including residential, commercial, agricultural, parkland, industrial among others. The mesh-block-level census data was sourced from the Australian Bureau of Statistics (2011).	Polygons
Residential mesh-blocks	Residential mesh-blocks contain approximately 30 to 60 dwellings. Mesh-block-level census data were sourced from the Australian Bureau of Statistics (2011).	Polygons
Local living destinations	Convenience destinations (i.e. convenience store, newsagent, or petrol station); supermarket; speciality food destination (i.e. fruit and vegetable, meat, fish, or poultry store); post office; bank; pharmacy; general practice/medical centre; dentist; community centre or hall; childcare facility; and library (Badland et al., 2017). Destination data were sourced from geocoded business points data (Pitney Bowes Ltd., 2014).	Points
Public transport stops	This was a subset of the local living destinations spatial layer. All the points representing public transport stops found in the local living destinations layer were extracted from the local living destination layer. This was because the original local living destination layer contained 12 unique destination types, each represented by different coloured symbols with poor readability. Separating the public transport points from the original local living destinations spatial layer improved readability significantly. Public transport data were sourced from Public Transport Victoria (2012).	Points
Street network dataset	A street network dataset was created to perform the connectivity and accessibility analyses on the road centrelines (i.e., distance to destinations along the street network). Prior to analysis all freeways were removed from the dataset, as they were inaccessible to pedestrians. Street network data were sourced from the *VicMap Transport* (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2012).	Polylines

3. Results

Table 3 compares the built environment variables in the baseline scenario to the alternative scenario (Fig. 3, Table 4) which includes the additional infrastructure of a train station and a supermarket in the south-east precinct and the provision of new residential dwellings. Table 3 also presents the predicted values for the outcome "probability that an adult participates in transport-walking" in the baseline and alternative scenarios.

Under the alternative scenario, the residential dwelling density increased dramatically (about four times higher than the baseline scenario) with new residential dwellings applied around the new railway station in the south-east precinct. The addition of a railway station and a supermarket had negligible effect on the distance between residential dwellings and the distance to the nearest supermarket which was on average for all residential dwellings 1680 m in the baseline scenario, and 1529 m in the alternative scenario. The land use mix slightly changed under the alternative scenario: the alternative scenario had a higher proportion of residential area and lower proportion of commercial area compared with the baseline scenario. Under the alternative scenario, the probability that adults did some transport-walking trips increased from 30% to 56% (Fig. 3, Table 4).

4. Discussion

The aim of this study was to develop, apply, and trial a functional and practical Walkability PSS with local spatial planners. We demonstrated that models of the relationship between the built environment

Table 3
Description and calculation of the built environment variables.

Built environment variable	Description	Spatial data source
Land use mix	The land use mix measure was calculated using the following entropy formula, which was adapted from Frank et al. (2005) and is the same used by Christian et al. (2011) $LUM = -1(\sum_{i=1}^{n} pi{*}\ln(pi))/\ln(n)$ LUM = land use mix i = land use classes of interest (i includes residential, retail, commercial, industrial and "other") pi = (Area covered by land use i)/Total area in square kilometres n = number of land use classes of interest ($n = 5$)	Land use mesh-blocks (Australian Bureau of Statistics, 2011).
Intersection density	(Count of the number of 3 or 4-way intersections in the intersections spatial layer)/Total area in square kilometres	Street network dataset (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2012).
Dwelling density	(Count of the number of residential dwellings)/Total area in square kilometres	Land use mesh-blocks (Australian Bureau of Statistics, 2011).
Housing diversity score	A sum function was used to count the number of housing typologies by mesh-blocks and present in the area. A maximum score of eight was achievable representing the eight several types of housing.	Residential mesh-blocks (Australian Bureau of Statistics, 2011).
Local living score	A sum function was used to count the number of local living destination categories by mesh-blocks and present in the area. A total score of twelve was achievable representing twelve types of destinations present.	Local living destinations (Pitney Bowes Ltd., 2014).
Closest supermarket	An indicator set equal to 2 when a supermarket was present within 500 m of the residential dwellings, to 1 when a supermarket was present within 500 and 1000 m of the residential dwellings and zero otherwise.	Local living destinations (Pitney Bowes Ltd., 2014). Street network dataset (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2012).
Closest train station	A binary indicator set equal to 1 when a train station was present within 800 m of the residential dwellings and zero otherwise.	Street network dataset (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2012).
Closest bus stop	A binary indicator set equal to 1 when a bus stop was present within 400 m of the residential dwellings and zero otherwise.	Street network dataset (Department of Department of Environment Land Water and Planning and State Government of Victoria, 2012).

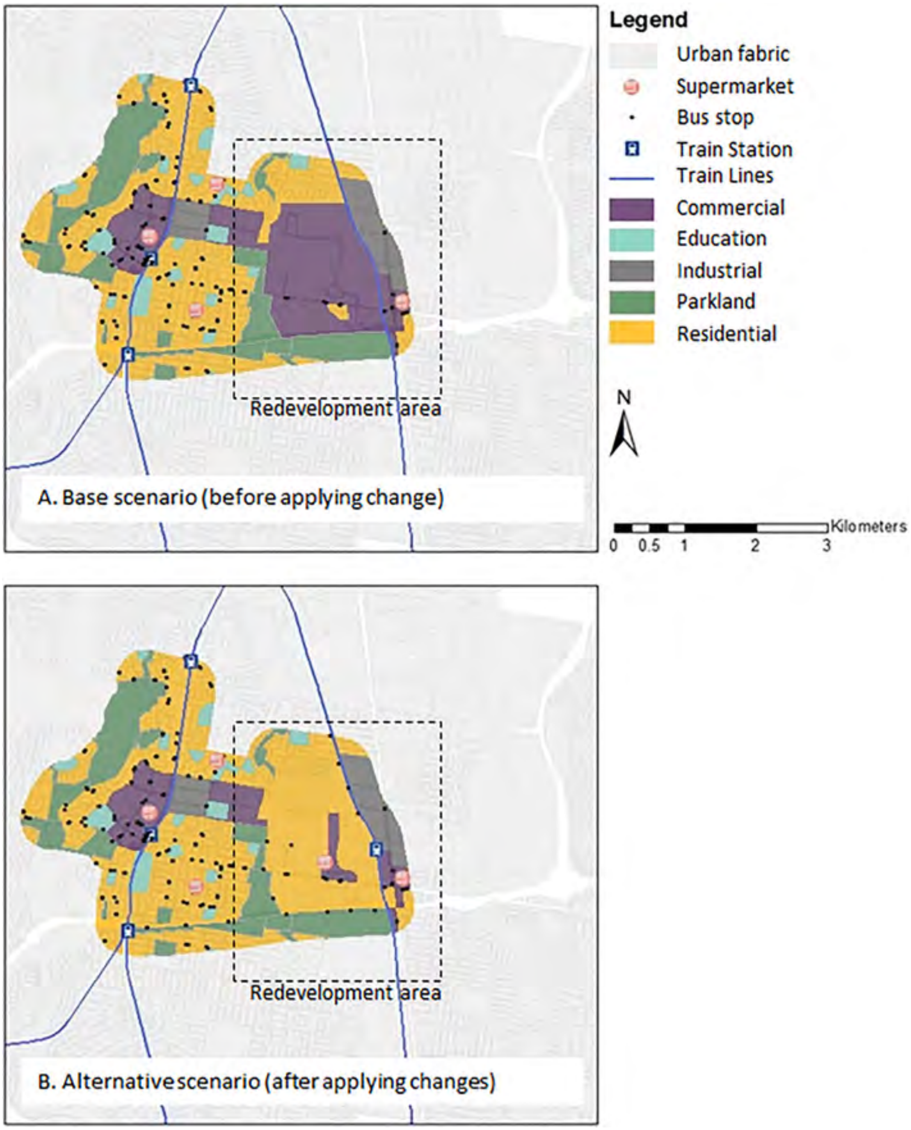

Fig. 3. Study area before (A) and after (B) applying changes in the workshop.

and health-related outcomes can be accommodated within CommunityViz 5.1 to create dynamic and interactive analytical tool that could be used by practitioners to evaluate walkability impacts and test scenarios where changes in the built environment are being considered. The Walkability PSS brings new possibilities to urban planners by allowing them to assess different planning scenarios when developing new areas. The visual aspect of the Walkability PSS - supported by its underpinning GIS platform - may help uncover previously unseen spatial relationships that supports their decision-making(Maantay, 2002).

The Walkability PSS can be applied to study areas across metropolitan Melbourne to evaluate walkability impacts and test different scenarios where changes in the built environment are being considered. Moreover, the Walkability algorithm presented in this study can be refined and improved as data with higher spatial and temporal granularity become available. Because the Walkability PSS was built on a customizable system, the proposed methodology can be applied to build further PSSs applicable to other countries and differing contexts. Although there would be a cost associated with development, future research may draw upon the growing number of open source software development initiatives (McInerney and Kempeneers, 2015).

In this case study, the alternative scenario offered noticeable improvements against the baseline scenario: population density was increased by converting commercial areas to a variety of residential dwellings. However, the alternative scenario offered no significant improvements in terms of service accessibility: the addition and relocation of infrastructure alone had negligible effect on the average distance people must walk to reach these services.

The case study enabled a group of spatial planners to test in real time, the effects of increasing residential zoning to increase population density and understand how this increased the probability of transport-walking. Including a new train station, supermarket and providing proximate access to commercial areas also led to an increase in the probability of transport-walking, by providing destinations to which residents could walk. Such an increase is not surprising: increasing access to destinations is now well established in the built environment literature as a means of increasing local walking (Hajna et al., 2015; King et al., 2015; Knuiman et al., 2014). However, it is rare for decision-makers to be able to model this in real-time to explore different scenarios and the likely outcomes of these decisions. The Walkability PSS moves beyond conventional analyses providing decision-makers with the opportunity to trial different scenarios of planned or potential interventions and to assess them against health-oriented indicators (Boulange et al., 2017b). It is also relevant for introducing academic

Table 4
Comparison between the baseline scenario and the alternative scenario prepared in the workshop.

	Baseline scenario (existing conditions)	Alternative scenario (after applying changes)
Interventions	N/A	New features applied: ■ Railway station ■ Supermarket ■ Residential zoning ■ Commercial zoning ■ Residential dwellings
Average residential density	10 dwellings per ha	39 dwellings per ha
Land Use Mix	44% Residential	59% Residential
	26% Commercial	10% Commercial
	19% Parkland	19% Parkland
	6% Industrial	6% Industrial
	5% Education	5% Education
Residential dwellings: distance to the nearest railway station (average)	1680 m	1529 m
Residential dwellings: distance to the nearest supermarket (average)	1567 m	1563 m
Probability that an adult participates in transport-walking	30%	56%

evidence-base to the world of practitioners and decision-makers who rarely use evidence or PSSs in practice (Russo et al., 2017).

There are some limitations with this research. First only one alternative scenario was developed for the case study. Ideally more than one alternative scenario should be tested so that more than one set of interventions in the built environment could be considered. However, given the time constraints of this workshop (i.e., two hours) this was not possible. In this case study, no interventions were made on the street network to make more connections between the residential dwellings and local living destinations. These interventions warrant further investigations and could be deployed in another alternative scenario. There are also limitations associated with the underlying walkability model including the fact that the travel data was self-reported and based on a single day. Other built environment variables may also impact on the participation in transport-walking for example the presence/absence of footpaths or traffic volume but these were not operationalized and tested in the regression model. Finally, the linear modelling approach has limitations because it does not take account of the dynamic environment in which walking is undertaken. To better simulate the complex pathways through which neighbourhoods' design influences walking, there is a need for dynamic system models capable of describing the evolution of walkability under various planning scenarios.

5. Conclusions

The Walkability PSS could be further developed to include other health and environmental outcomes as well as other built environment variables. For example, future PSS research could incorporate urban sustainability analyses and models (Chen and Crawford, 2015) into customised formulae. This would enable the environmental co-benefits of urban design interventions to be presented using interactive indicators within a PSS i.e., levels of greenhouse gas emission associated with planning scenarios as is included in another PSS such as the Envision Scenario Planner (ESP) tool (Trubka et al., 2016). As the complexity of developing PSSs increases, there is potential for PSSs to be abstracted from urban planners hindering their adoption for planning purposes (Waddell, 2011). Waddell (2011) explains that transparency matters for building trust and facilitating adoption since “models will not have credibility as tools for decision support in complex, conflict-laden domains such as land use, transportation and environmental planning, unless they can be explained with a sufficient degree of transparency” (Waddell, 2011). Yet an over-simplification of models within PSSs also poses a problem as it reduces precision, validity and eventually credibility (Waddell, 2011). Hence, it is recommended that future research examines the trade-off of model complexity, transparency and PSS interactivity and further usability test be undertaken of the Walkability PSS tool to understand and address potential barriers of adoption by planning professionals.

In this study, we have demonstrated that the Walkability PSS can be used to evaluate the walkability of an area and for measuring how this will change under various built environment scenarios. The tool could be used to evaluate the retrofitting of established areas on transport-walking outcomes or the planning of green field areas. Importantly, it could also be used for advocacy purposes for designing communities supportive of health behaviours, since the PSS can record the incremental changes in the built environment for each planning scenario. Thus, the Walkability PSS becomes a powerful tool for evaluating competing scenarios that would otherwise be costly to build.

In Western Australia, health outcomes have been found to be associated with policy compliance designed to create more walkable neighbourhoods (Hooper et al., 2015). Thus, the Walkability PSS could be expanded to evaluate policy compliance and coherence with planning standards, by creating indicators that reflect local policy requirements. To help in evaluating both the costs and benefits of built environment infrastructure decisions, research is currently underway towards expanding the Walkability PSS to include an economic evaluation of interventions designed to create more walkable neighbourhoods. Working with decision-makers, the Walkability PSS will be used to identify the most realistic and highest impact built environment scenarios that would create neighbourhoods to maximise transport walking. In future, the Walkability PSS will be expanded to include costing data to enable economic evaluation of the built environment scenarios.

6. Software and data availability

The development of the Walkability PSS was realised in the software ArcGIS 10.4 (www.esri.com) and its extension CommunityViz 5.1 (www.city-explained.com). No special hardware is necessary. All example presented in this study were run on a PC computer equipped with a 3.5 GHz processor and 8GB of memory. The open-access spatial data was sourced from the Australian Bureau of Statistics, Public Transport Victoria, the Victorian Department of Environment, Land, Water and Planning and can be accessed on the Victorian government open data portal (www.data.vic.gov.au). Destination data were data previously purchased from Pitney Bowes Software Pty Ltd., the largest distributor of digital spatial data products in Australia (www.pbinsight.com.au).

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