The effects of topography on walking and cycling in suburban centres:

A comparison of flat Salisbury with hilly Golden Grove in Adelaide's north-east

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Abstract

Previous research on walking and cycling as primary modes of local access for local centres in metropolitan areas, have focused on the role of the street network, urban design quality, socio-economic characteristics and urban form as predisposing factors to walking and cycling. A neglected factor is that of terrain as an impedance to walking and cycling for access to a local centre. Whilst most suburban areas in large metropolitan areas tend to be in locations with minimal topographical variations, there are substantial portions of Australian cities that are hilly and have local streets with gradients that are steep enough to present a significant challenge to walking and cycling. This paper details the methodologies used and the results of a comparative analysis of two metropolitan Adelaide suburbs (Salisbury and Golden Grove) with public transit interchanges that service a predominantly residential neighbourhood precinct within their respective local catchments of approximately a 1.6km radius, to determine the impact of topography on local transport modal choice. Both Salisbury and Golden Grove are located approximately 20km from the centre of Adelaide city centre in Adelaide's north-eastern suburbs and both have similar intensity of retailing activity and style and density of residential development. However, Golden Grove is extremely hilly with changes in elevation varying by up to 90m up to a maximum height of 214m above sea level, whereas Salisbury is predominantly level at an elevation of approximately 35m. This paper concludes with transport and urban planning policy implications of considering the influence of topography on local modal transport choices in suburban centres.

1. Introduction

Walking has always been a fundamental transport mode in considering the design of local neighbourhood precincts, even in the low density, car oriented suburbs of Australia's cities. Generally developers have usually favoured development sites that have little or modest gradients (i.e. up to +/-10%), both to minimise the construction costs of buildings and the provisioning costs of infrastructure such as roads and utilities. Steep sites also create additional environmental challenges in terms of the need for excessive cut and fill construction and the attendant risks of erosion, unstable surfaces and greater bush fire risks. The utilisation of rate of land is also much less efficient unless developers are prepared to invest in more substantial earthworks such as retaining walls and deeper, more robust foundations for structures.   This is not to say that areas with significant topographic relief are avoided, because often, easily developed level land can be scarce.   Furthermore, Australian homeowners are often so enamoured by beautiful natural settings, that many homes are often built on very steep sites to capture a prized view such as that of bushland, the ocean or a valley.

Many of the more recently created suburbs on the metropolitan fringe Australia's capital cities have housing in areas that would have been avoided before the age of affordable mass car ownership because without motorised transport, such areas would have required too much personal effort to access or commute back and forth from. The modern fossil fuel powered car, however, has effectively negated the restrictions of terrain in gaining access to development located in steep terrain, with gradients as steep as 35% relatively easily negotiated. In Adelaide, the modern car allows homeowners at Mount Osmond and Stirling, dormitory suburbs of Adelaide within 15km of Adelaide's CBD, to locate their homes high above the Adelaide plains. In order to reach these homes from Adelaide's CBD which is at an elevation of approximately 50m above sea level requires a considerable climb in altitude of approximately 300m for Mount Osmond and 600m for Stirling. Considerably more energy therefore has to be expended for vehicles negotiating this change in elevation than would be the case if the origins and destinations were located at the same elevation. To some extent the energy expenditure may be balanced out on a return journey, however, because of the need to waste energy in braking effort in travelling downhill to avoid excessive speed, this type of travel is rarely as efficient as travel on level ground. Anecdotally, as a resident of the north-eastern Adelaide suburb Golden Grove, I find that the my car typically uses one third more fuel on the return trip to Adelaide's city centre from home (involving a climb of 220m altitude). Over a return commute distance of 44km this type of journey results in an average urban fuel consumption of 7.6l/100km in free flowing traffic conditions, compared with 6.6l/100km on level ground in the flat Adelaide suburbs. Hybrid vehicles with regenerative braking may be able to recapture a greater proportion of the energy that is otherwise lost in travelling downhill than is the case for conventional motor vehicles, nevertheless, given that the bulk of Australia's private motor vehicles are not hybrids, motor vehicle traffic in hilly urban areas is likely to operate with much less energy efficiency than motor vehicle traffic in flat urban areas.

Travel in urban areas with dramatic topographic relief also tends to be less efficient because in contemporary planning practice, a fine grained grid street network is rarely imposed on the landscape because of the requirement to avoid excessive road gradients. However, there are exceptions. San Francisco in California in the US provides a dramatic example of an orthogonal grid network of streets imposed on a city with very hilly terrain. Gradients are often excessive and intersections result in abrupt gradient transitions from steep to level road surfaces. San Francisco's 19th century tram network required pulleys embedded in the road surface to drag trams up the hills because steel wheels on rails could never gain the necessary traction to move up the steep hillsides (up to 32% in the case of San Francisco's Filbert Street). Paradoxically, in modern 20th century urban planning, environmental concerns centred on development that was better integrated and more sympathetic to the landscape within which it was located, often resulted in roads that followed the contours performing a zig-zag pattern in connecting origins and destinations, but which involved greater environmental impacts with vehicle emissions due to longer travel distances than would have occurred when travelling within an orthogonal grid network of urban streets on level terrain. The application of road hierarchy principles in the design of urban road networks, with its tacit acceptance by design professionals of greater urban trip distances to ensure adequate separation of local access traffic from through traffic for greater efficiency in longer trans-metropolitan road trips and improved safety and amenity in local areas, has also contributed to much greater travel inefficiencies in local areas. Contemporary urban planning experienced a significant backlash to urban street networks designed around optimising traffic safety and long distance car travel, as exemplified by the New Urbanism movement and recognition of the need to re-orient western cities away from car-oriented urban road networks to public transit networks, anchored by transit nodes in the form of transit interchanges with high density urban development clustered around them.

Whilst it is relatively easy to appreciate the impacts on energy usage (and its associated emissions) of urban street gradients on motor vehicle operation, what is less well known is the impact that large topographic relief has on walking effort at the level of the local neighbourhood precinct, given that it often results in more circuitous routing for many local trips. The complicating and sometimes confounding factor is that in response to the lack of directness of local trip routes that is associated with urban estates in hilly areas, urban designers and planners will often integrate pedestrian pathway links that short-circuit the road network, and which ultimately provide local trip routes that are reasonably direct, albeit with the trade-off of the routes being much steeper and in isolated locations. The case study suburb of Golden Grove typifies this approach, with many local road routes up to double the length of the Euclidean distance between origins and destinations, but integrated within the suburb's open space system, there is a concrete pedestrian pathway network that links most homes reasonably directly to the Golden Grove Village shopping centre, community centre and School complex. The trade-offs of the approach taken in Golden Grove, is that land has had to be set aside which forms a contiguous open space network and the informal surveillance offered by street users of a conventional urban street setting are absent.

With this in mind, this research set out to investigate whether the significant topographic relief evident in the north-eastern Adelaide suburb of Golden Grove (20km north-east of Adelaide's CBD and 200+m above sea level) does result in a much less efficient area to walk within when compared with a suburb without any significant topographic relief. The control suburb selected for this purpose was Salisbury, 19km north-north-east of Adelaide's CBD, a generally level suburb at an elevation of about 35m above sea level. Both suburbs have similar levels of population and urban densities. Table 1 compares the key attributes of the two suburbs using data derived from the 2011 ABS Population and Housing Census. In terms of housing, urban form and transport usage patterns, the two suburbs are similar. The Census data for Golden Grove is somewhat distorted in deriving indicators however because the area includes a large portion of a nearby semi-rural area and the Cobblers Creek Reserve.

2. Methodology

2.1 The "Pedshed" concept

This research aimed to provide a comparative assessment of "walking efficiency" from the edge of the "pedsheds" to the centre of the respective pedsheds for the two case studies, Golden Grove and Salisbury. The pedsheds are simply defined as the pedestrian catchment or area that is within walking distance around a node such as a major road intersection, shopping centre, school or transit interchange. In traditional neighbourhood precinct urban planning theory, the radius of the theoretical minimum pedshed is normally taken as the Euclidean distance of 400m (Howard 2008, Perry 1929). In this research, the size of the theoretical pedshed has been taken out to the absolute practical limits of a walkable distance to a radius of 1.6km, which depending on the directness of pedestrian routes in the network could equate to a 2.4km walk (i.e. about 30 minutes walking time at 5km/h). The actual pedshed as presented in the analysis that follows was then adjusted to reflect what would equate to a maximum 1.6km walk (as permitted by the road/pedestrian networks) from the central node of the pedshed. This often results in the pedshed extending significantly beyond the theoretical minimum pedshed as described by the radius for a perfect circle around the pedshed's central node. However, where the network falls considerably short because of a major impenetrable barrier to pedestrians such as creek or railway line or vegetated area, the pedshed can contract to quite a bit smaller than the theoretical pedshed. The term "walking efficiency" is expressed as a percentage ratio of the actual energy expended in walking the Euclidean distance to the centre of the pedshed from the edge of the theoretical 1.6km pedshed and the actual distance through the available road/pedestrian network by the shortest practical route. In earlier research by Allan (2001, 2002), a

pedestrian network assessment tool was developed known as street network permeability indices, which were based on either the time or distance required to travel through the street network by the most practical route expressed as a ratio of the straight-line distance and/or travel time. For the purposes of this research, only the distance based index is of relevance (Allan, 2001):

$$PDI = AD / DD \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

Where PDI=Permeability Index; AD=Actual distance through the network; DD=Direct Distance through the network.

2.2 Applying a Walking Energy Efficiency Index to a Pedshed

The limitation with the Permeability Distance Index for assessing the walking efficiency of a street/pedestrian network is that it neglects the impact that changes in elevation will have on the effort required to walk a particular route. An energy-based measure would overcome the limitation of the distance-based index in taking into account the effects of changes in elevation on walking efficiency in an energy usage context.

Whilst there is a considerable body of research that evaluates the "walkability" of urban environments from the perspective of the characteristics and directness of the road and pedestrian networks, the supportiveness of land use to walking (including urban form, urban density and nature of activities) and attractiveness of the local environment to walking activity, there is little planning literature on the effect of gradient on walking pedsheds in local areas.

From human physiology research (McArdle et al, 2010; Giles-Corti & Donovan, 2002; MacKenzie 2002), it is known what the energy demands of exercise are on the human body (whether that be walking or running) and under differing climatic conditions and for people of varied physical characteristics and health levels. One constant that is reasonably constant in a locality is the force of gravity, although there are very slight changes in the size of this constant with respect to the distance one is from the centre of the earth. Hence, gravity will decrease with altitude, but at the relatively small altitude changes that are experienced in the two case study areas, this is unlikely to have any measurable effect on the research outcomes. Using the formula from physics for work done, Work (in Joules) =Force (mass x acceleration due to gravity in metres/second^2) x Distance (in metres through which the force is applied), the extra walking effort required to negotiate an increase in elevation in traversing a given horizontal distance, is added to the walking effort (in Joules) involved in walking on level ground between an origin (i.e. the centre of the pedshed) and the destination (1.6km from the pedshed origin). If there is a net decrease in elevation in traversing that distance, then this will have the effect of reducing the horizontal walking effort. Traversing steep downhill changes in elevation does involved additional muscular effort in walking, however, for the sake of simplicity, this research assumed that the reduction in effort would be directly proportional to the drop in elevation. Distances through the road/pedestrian network, Euclidean distances and spot elevations in each of the case study areas were obtained using Google Earth (see figure 3). The Walking Energy Efficiency Index (WEEI) developed for a particular route in the pedshed was:

$$WEEI_{(for\ route\ r)} = (HWE_{Euclidean\ distance}) / (HWE_{(for\ route\ r)} + VWE_{(for\ route\ r)}) \times 100\% \dots\dots\dots\dots\dots\dots(2)$$

Where

$HWE_{Euclidean\ distance}$ = Horizontal Walking Effort for a radial from where the route r intersects with the edge of pedshed to the centre of pedshed in kiloJoules (kJ)…………………………………………………………………………………………...…………………..(3)

$HWE_{(for\ route\ r)}$ = Horizontal Walking Effort of the shortest practical route through the road and pedestrian network from the edge of pedshed to the centre of pedshed in kiloJoules (kJ)……………………………………………………………...………………(4)

$VWE_{(for\ route\ r)}$ = Vertical Walking Effort in kiloJoules (kJ) for route r determined by the vertical distance travelled (in metres) with a force equivalent to gravity either above the elevation of the pedshed origin (negative adjustment) or below the elevation of the pedshed origin (positive adjustment)………………………………………………………………………………………………….(5)

For an adult person with a body mass of 73kg, walking at 4.8km/h on level ground, their energy expenditure would be 18.4 kJ/minute.

Hence, (3) and (4) are calculated by:

HWE = $M_{\text{(body mass in kg)}}$ x $E_{\text{(Joules/minute for walking at 4.83km/h)}}$ x $D_{\text{(route r in metres)}}$ x 60_{minutes} / 4.83km/h…………..(6)

The vertical walking effort is determined by:

VWE$_{\text{(for route r)}}$ = acceleration$_{\text{(gravity at 9.80665 metres/second squared)}}$ x mass$_{\text{(kg)}}$

x height change$_{\text{(negative for up, positive for down)}}$ …………………………………………...……(7)

The average WEEI for a precinct was then determined through averaging all of the WEEI indices for the pedshed.

2.3 A Measure of Pedshed Spatial Efficiency

In terms of determining whether there were sufficient network paths from the centre of the pedshed to the edges of the pedshed, another useful index that was derived in this research was the pedshed network spatial coverage efficiency. For a perfectly circular pedshed with a radius of 1.6km, optimum access for a pedestrian network on the edge of the pedshed would be every 100m along the circumference of the pedshed, which would result in approximately 100 access nodes evenly distributed around the perimeter of the pedshed. The aggregate network link lengths from the pedshed centre to the perimeter of the pedshed required to access this would be 160km. The spatial efficiency of the pedestrian network could be described by taking the ratio of Euclidean distances of the actual pedshed links to the optimal pedshed link distances for a perfectly circular pedshed with a radius of 1.6km and expressing this as a percentage.   The formula for estimating this is:

PNSCEI =

(PL$_{\text{Actual aggregate Euclidean distances (0 to n links)}}$ / PL$_{\text{Optimal aggregate Euclidean distances (100 for a 1.6km diameter pedshed)}}$)

x 100% ....……(8)

Where

PNSCEI = PEDSHED NETWORK SPATIAL COVERAGE EFFICIENCY INDEX

PL=Pedshed Link

2.4 The Case Studies: Golden Grove and Salisbury

For each of the case studies selected for this research (see figures 1 & 2), a 1.6km radius pedshed (or pedestrian catchment) was drawn around what was judged to be the centre of the suburb. Table 1 compares the characteristics of the two suburbs. The data in table 1 does not represent the actual pedsheds for the two case studies, although the pedsheds do fall wholly within the ABS derived statistical areas that were used in this comparison. The estimated pedsheds for Golden Grove and Salisbury are show in figure 4.

2.4.1 The Golden Grove Case study

For Golden Grove, this was chosen to be the intersection of two major arterial roads, the Grove Way and the Golden Way. Although the shopping centre and bus interchange is located in the north-western quadrant of this intersection, the local planning intention is to have the centre of Golden Grove at this intersection. The reason that this has not happened to date is a lack of developer commitment to provide the preferred type of development around this hub and resistance from the existing Golden Grove Village District shopping centre to a rival development being built. Indeed, several development proposals have been put forward to the City of Tea Tree Gully in recent years, but none have progressed beyond the concept stage.

The pedshed of Golden Grove is largely of low residential density, although the centre of the pedshed is disrupted by the shopping centre and a super-school/community uses precinct

that has limited pedestrian access across it, and there are deep valleys, natural reserves and Cobbler Creek, which further constrains the extent of the pedshed.

Pedestrian routes were taken either via the road network or pedestrian network from the centre of the pedshed to the roads terminating at the edge of the pedshed or closer to the pedshed centre if it happened to be a cul-de-sac head. A truncated pedshed link often occurred because of an impenetrable barrier (such as a creek, continuous property boundary or open space area). For Golden Grove, its 102 pedlinks averaged only 1.3km in length rather than the 1.6km that would be expected for uninterrupted pedlinks which were 1.6km in length.

Table 1: The attributes of the Adelaide suburbs of Golden Grove and Salisbury compared.

Attributes	Golden Grove	Salisbury
Area	26.6 km^2	21.1 km^2
Distance from Adelaide CBD	20km (north-east)	19km (north-north-east)
Elevation	200+m (range of 130m-220m)	40m (range of 23m-40m)
Establishment date	1985 (Master Planned Community by Delfin Lend-Lease)	1848 (incremental, organic growth)
Population	9,046 (original target was 10,000)	26,975
Population density	3.4 persons/Ha	12.8 persons/Ha
Housing	3,704 dwellings	11,231 dwellings
Housing types	80.6% houses 12.7% medium density homes	74.6% houses 19.0% medium density homes
Housing density	1.39 homes/Ha*	5.3 homes/Ha
Centre	Golden Grove Village District Shopping Centre	Salisbury District Shopping Centre
Public Transport	Bus Interchange providing direct access to Elizabeth and city via OBahn (30 minutes)	Bus-Rail Interchange providing direct access to city (26 minutes)
Commuter Travel Patterns	4208 commuter trips: 87.5% car 8.9% public transport 0.9% walking 0.2% bicycle	9684 commuter trips 88% car 6.8% public transport 1.5% walking 0.4% bicycle
Street network pattern	Precincts with curvilinear road hierarchy. Pedshed formed into quadrants by two intersecting high speed arterial roads.	Orthogonal Grid modified with a road hierarchy. Pedshed bisected by the northern suburbs commuter railway and Salisbury Highway.

*Includes the Cobblers Creek reserve and semi-rural areas.

2.4.2 The Salisbury Case study

For Salisbury, the centre of the pedshed link was chosen to be the main entry point to the Salisbury commuter railway station. The Salisbury Railway Station is part of a bus-rail interchange. Perhaps surprisingly, Golden Grove with just its bus interchange had a larger modal share of public transport usage than Salisbury (8.9% versus 6.8%), which offered commuters both buses and trains. The transport interchange facility was chosen as the centre of the pedshed because for commuters, it would represent the focus of many of the public transport trips into and out of the suburb. Unlike the suburb of Golden Grove, Salisbury was not a master planned community. The area within the pedshed is dominated by a retail precinct in the centre and low density residential development beyond the centre. There are pockets of light industrial development in the suburb, adjacent to the eastern edge of the retail precinct. A natural reserve to the north of the centre has resulted in limited access to the northern half of the pedshed. The suburb does have a road hierarchy imposed on top of an orthogonal grid street network.

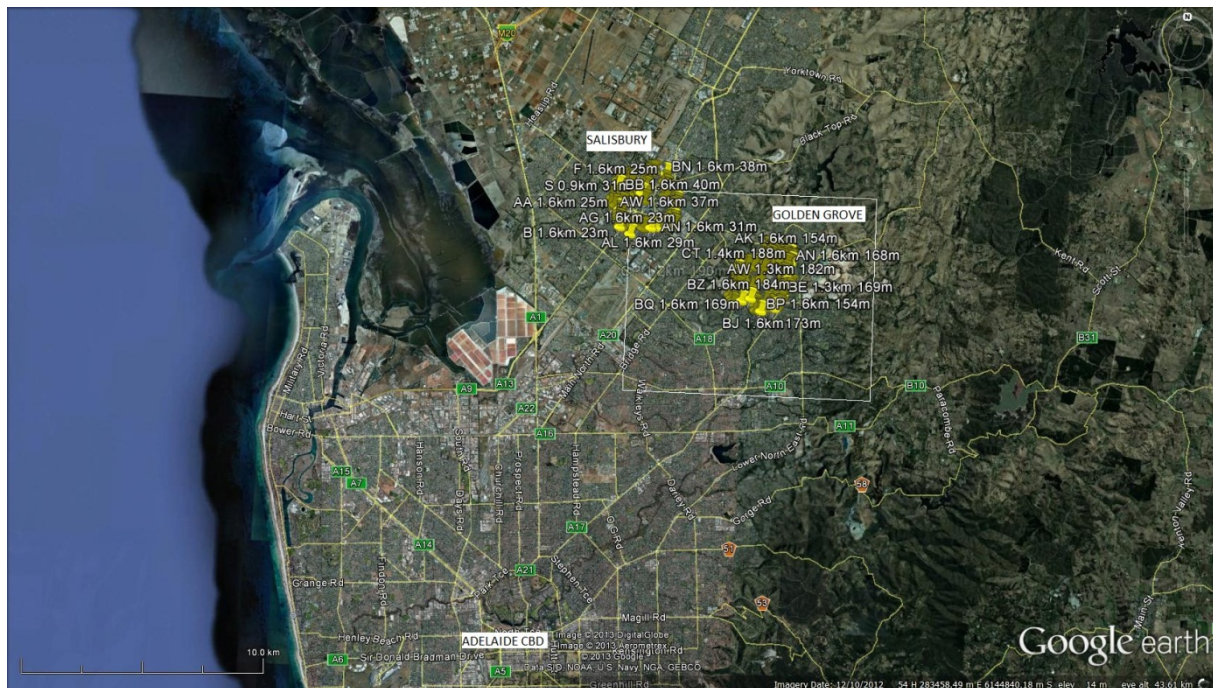**Source: ABS 2011 Census, Community Profiles**

Figure 1: Location of the two case studies, Golden Grove and Salisbury (see yellow markers)

Source: Google Earth, 2013

Figure 2: Aerial view of Golden Grove looking north (left) and Salisbury looking north (right).
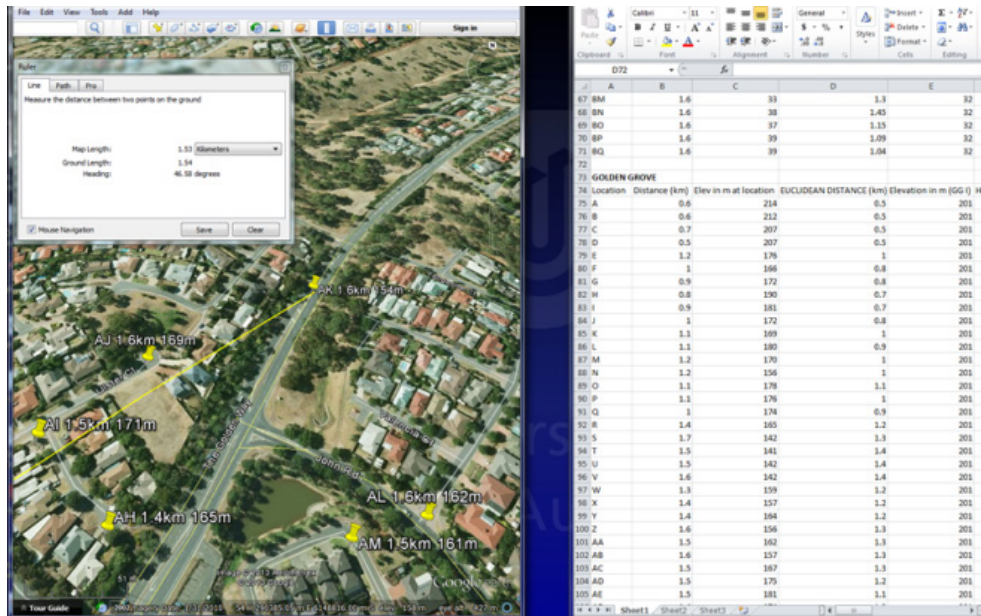
Source: Google Earth, 2013

Figure 3: Mapping of pedshed using Google Earth markers and line/path distance functions.

Source: Google Earth, 2013

Figure 4: Maps of pedshed using Google Earth markers path distance function showing Golden Grove on the left and Salisbury on the right.

Source: Google Earth, 2013

3. Results and Discussion

The analysis and research outcomes are presented in table 2 for the two case studies, Golden Grove and Salisbury.

Notwithstanding the fact that Golden Grove was a master planned community, its topographic setting is unusual to say the least, nestled as it is on top of a set of ridgelines 200m above sea level and the Adelaide Plains. The average elevation difference for the pedshed links relative to the pedshed centre for Golden Grove was 22m, eleven times that for Salisbury's pedshed links. Given that the terrain relief in the Golden Grove area is around 90m, the master urban planners have managed to create a geometrically balanced pedshed that has maximised the settled area in the most easily developed land, which has resulted in a Pedshed Network Spatial Coverage Efficiency Index (PNSCEI) of 70.9%

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Table 2: Performance of the Adelaide suburbs of Golden Grove and Salisbury compared.

Performance measure	Golden Grove	Salisbury
1.No. of pedshed points (actual)	**102**	**69**
2. No. of pedshed points (optimum)	100	100
3. PL$_{Actual}$ aggregate Euclidean distances (0 to n links) (see equation 8 above)	113.5 km	81.0 km
4. PL$_{optimal}$ aggregate Euclidean distances (*100 for a 1.6km diameter pedshed*) (see equation 8 above)	160 km	160 km
5. PNSCEI (see equation 8 above)	**70.9%**	**50.6%**
6. PL$_{Actual}$ average Euclidean distances	1.1 km	1.2 km
7. PL$_{Optimal}$ average Euclidean distances	1.6 km	1.6 km
8. Average Pedshed Link distances using road/pedestrian network	1.3 km	1.5 km
9. Total Pedshed Link distances using road/pedestrian network	137.6 km	103.1 km
10. Pedshed Centre Location	Lat.-34.790462 Long.+138.697404	Lat.-34.762821 Long.138.642826
11. Average elevation difference relative to pedshed centre (expressed as the 'climb' required to reach centre from edge of pedshed)	+22.2m	+2.0 m
12. Aggregate elevation differences of all pedshed routes above pedshed centre (climb required to reach centre from edge of pedshed)	+2267 m	+140 m
13. Aggregate energy expended walking horizontally for all pedshed links (person of 73kg walking at 4.8km/h @ 18.4kJ/minute)	31,406 kJ	23,566 kJ
14. Average energy expended walking horizontally for all pedshed links (person of 73kg walking at 4.8km/h @ 18.4kJ/minute)	307.9 kJ	341.5 kJ
15. Aggregate vertical energy expended for all climbing all pedshed links (for a person of 73kg)	1623 kJ	100 kJ
16. Average vertical energy expended for climbing all pedshed links (for a person of 73kg)	15.9 kJ	1.5 kJ
17. Total aggregate energy expended for walking all actual pedshed links (horizontal + vertical energy) for a 73kg person (see items 13 and 15)	33,029 kJ	23,666 kJ
18. Average energy expended for walking actual average distances of pedshed links (horizontal + vertical energy) for a 73kg person	323.8 kJ	343.0 kJ
19. Total aggregate energy expended for walking all theoretical Euclidean distances of pedlinks (horizontal + vertical energy) for a 73kg person	25,874 kJ	18,507 kJ
20. Total average energy expended for walking average theoretical Euclidean distances of pedlinks (horizontal + vertical energy) for a 73kg person	253.7 kJ	268.2 kJ
21. WEEI (see equation 2) for horizontal components of actual Pedshed links	**82.4%**	**78.5%**
22. WEEI (see equation 2) for horizontal and vertical components of actual Pedshed links	**78.3%**	**78.2%**

Note: Energy values used in rows 13 to 20 derived from MacKenzie (2002)

that substantially exceeds the value of 50.6% achieved for Salisbury, a suburb in a conventionally developed urban area on largely flat ground characterised by incremental and organic growth. The historical reason for Salisbury's somewhat lop-sided pedshed is due to the need to avoid development within the floodplain of the Little Para River which bisects the northeastern portion of its pedshed. The northern commuter rail corridor and the need to maintain a buffer with the massive General Motors Holden factory to the east of Salisbury's shopping centre also contributed to a smaller than expected pedshed. From a design perspective, Golden Grove achieved a high PNSCEI by having many more pedshed links than Salisbury (102 versus 69), and indeed, Golden Grove's pedshed links exceeded the 100 pedshed points optimum for a 1.6 km radius pedshed. The aggregate distances of pedshed links emanating from the pedshed centre at 113.5km was 40% larger than that for Salisbury with 81km. Part of the explanation for this is that the street network design for Golden Grove adopted a hierarchical curvilinear street network that packed in much larger local access road/pedestrian path coverage into the same area. Most if not all of the cul-de-sac heads are connected by pedestrian links and the open space system integrates seamlessly with the road network to provide amazing levels of permeability which are not readily apparent from a superficial examination of aerial photos of the road network. Interestingly, if this analysis had been restricted to just the road network, Golden Grove's performance would perhaps have been much worse than Salisbury's, because it is the pedestrian network which ensures direct pathways from the edges of the pedshed to the pedshed centre.

The analysis demonstrated that the increased energy effort for negotiating changes in elevation (of 1.5 kJ for a 73kg person) whilst walking the pedshed links in Salisbury's pedshed were found to be negligible (i.e. 0.5% extra effort). By contrast, indirect pedshed links increased the walking effort by 28% to an average of 343 kJ for all of Salisbury's pedshed links, demonstrating that indirect pedshed links impose a much greater energy burden on pedestrians than do changes in elevation.

As expected, the situation for Golden Grove is different, by virtue of its relatively dramatic terrain relief, but it's not as great as one would think. For Golden Grove, the significant change in elevation increased the walking effort across all pedshed links by 15.9 kJ to an average of 323.8 kJ (i.e. resulting in an increased effort of 4.9%). Perhaps most surprisingly, the longer pedshed links in Salisbury meant that on average, the pedshed links required 6% less effort to walk. This is because the average pedshed link distance for Golden Grove was 1.3km compared to 1.5km for Salisbury, suggesting that the 1.6km pedshed for Golden Grove is underutilised. Nevertheless, Golden Grove's pedestrian and road network is still not optimised for directness because on average, it requires 27.6% more walking effort for its pedshed links than what direct Euclidean pedshed link distances would require. It is remarkable that both case studies have the same level of routing inefficiency, although part of this is due to the challenge of much more dramatic terrain relief in the case of Golden Grove

The Walking Energy Efficiency Index (WEEI) for both case studies was virtually identical at around 78%. When the effects of elevation were discounted for Golden Grove, however, the WEEI improved to 82.4%, which demonstrates that the significant effort invested in Golden Grove's direct pedestrian network did produce an appreciable improvement in accessibility for pedestrians and to some extent offset the disadvantages of large changes in elevation.

4. Conclusion

Pedsheds are a very useful spatial planning tool for visually appreciating the degree of pedestrian accessibility around a centre, such as a transit interchange, school, shopping precinct or retail centre. Pedshed mapping can be done according to distance or time. The use of pedshed contour thresholds can indicate the spatial limit of walking as a modal choice around such centres. They can also visually highlight causes of severance that distort a geometrically perfect spherical pedshed around a centre. In the case studies examined, for Golden Grove, a large super-School and challenging terrain disrupted accessibility in the central part of the pedshed and limited its extent around its perimeter because of deep valleys and a creek line. Salisbury's pedshed was also rendered less than sub-optimal, paradoxically because of the northern commuter rail line bisecting the pedshed and because of the floodplain of the Little Para River valley.

In recognising the analytical limitations of pedshed mapping, this paper has developed alternative performance measures that build on the principles of pedshed mapping, that allow performance comparisons to be made with an optimal pedshed, where pedshed links from the pedshed centre to the pedshed perimeter are optimised. This work extends the earlier work of the author on street network permeability indices based on time and distance. The two important diagnostic and assessment tools to emerge in relation to pedshed mapping for local areas, is the Pedshed Network

Spatial Coverage Efficiency Index (PNSCEI) and the Walking Energy Efficiency Index (WEEI), which takes into account the effect of changes in elevation. This paper illustrated that by and large, distance is still the major determinant of walking effort in a pedshed, even in Golden Grove where the average changes in elevation across all pedshed links was 22m. Despite the efforts invested in accommodating a walking network in Golden Grove that addresses shortcomings in the directness of the curvilinear hierarchical local street network, walking and cycling with less than 0.9% and 0.2% modal shares respectively have a virtually negligible presence in the journey to work commute, according to the most recent 2011 ABS Census. This may be because the pedestrian network in Golden Grove was developed largely as a recreational system and it does not have high visibility. Much of the pedestrian network is also off-road and runs between the back fences of homes, making it feel less secure at night. It is interesting to note that in Salisbury, where comparatively less effort has been invested in a pedestrian network, there is little difference with Golden Grove in the take-up of walking and cycling in the journey to work commute. Work by Soltani (2006) on commuting travel behaviours and urban form in metropolitan Adelaide's outer suburbs (specifically Para Hills and Golden Grove), found that large commuting distances to the Adelaide CBD predisposed residents to long distant private car commuting, making large investments in walking and cycling networks apparently redundant.

Although beyond the scope of this paper, it does suggest that if land uses within the centre of a pedshed do not include high levels of local employment, an excellent local transport network for walking, will not ensure that walking will have a high modal share for local transport activity. Further work is needed on what is the optimum size of a pedshed. This research selected a pedshed of 1.6km based on the practical limits of what pedestrians can walk to and the catchments of district shopping centres. Pedshed analysis could take into account the varying physical capabilities of a population to better reflect what distances individuals within that population are comfortable with walking.

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