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**Densification, Pedestrian Catchments and the Battle for Middle Earth.
Can Agent Based Pedestrian Modelling be Used to Inform Urban Morphology?**

Smart Growth planning strategies designate growth boundaries and encourage the increase of residential developments within walking distance from public transport – ‘walk-ability catchment areas’ in an attempt to contain urban sprawl and achieve more sustainable cities. These catchments are often illustrated using 400m and 800m radius circles (representing 5 and 10 minutes walking distances respectively), drawn from a central point typically of a railway station. This strategy reflects the desire to attain denser more connected and sustainable cities but oversimplifies the problem and makes the assumption that street layouts are radial, or people move ‘as the crow flies’.

Research for a more accurate technique for connectivity analysis has been undertaken within an architectural practice in Melbourne, Australia using relatively cheap 3D animation software used for crowd simulation, similar to technology used in Peter Jackson’s film of Tolkien’s *Lord of the Rings*. This technique enables designers to send out an “agent crowd” walking from a central node (eg. railway station) interacting with street layouts, intersections and topography to attain a more accurate shape for the walkable catchment – how far people can *actually* walk in 5 and 10 minutes.

The technique can be used for assessing existing walkability and design decision support whilst testing proposed urban designs. Almost real-time comparative studies can be undertaken: does street layout option ‘A’ have a larger pedestrian catchment area than option ‘B’? The technique can also inform decisions on where increases in residential density should occur.

This paper will discuss the logic behind pedestrian catchment analysis, the agent based modelling of such analysis and the opportunities this method presents to better manage increased density in a sustainable way.

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Introduction:

Like many other cities, Melbourne, Australia is currently attempting to implement an urban consolidation planning strategy that aims to address concerns for housing a growing population sustainably. The approach is consistent with the *Smart Growth* concept of planning involving an increasing emphasis on accessibility to public transport nodes, Transport Oriented Development (TOD) and urban growth boundaries aiming to contain suburban sprawl. In 2002 the Victorian State Government released the planning document 'Melbourne 2030-Planning for sustainable growth', which sets out the urban growth boundary shape for Melbourne, and highlights key transport nodes within the boundary known as 'Activity Centres'. The policy suggests that within these designated areas, a higher level of density than is typical in Australian suburbs should be encouraged. This increased density includes more retail, commercial and particularly residential development. The policy also suggests that the location of the increased density should be in close proximity to existing services and infrastructure such as railway stations and public open space.

I will not go into a detailed debate about the advantages and disadvantages of the concept of Smart Growth within this paper; instead, I will concentrate on the practical application of such a policy at an individual suburb level. I will focus particularly on the tools to measure proximity to services comparing outcomes of; traditional methods, contemporary GIS based methods and an alternative agent based method. I will also highlight the opportunity for the agent based method to be used for both analysis and synthesis of urban form by linking pedestrian accessibility directly to building heights.

Principles for the application of Smart Growth - Pedestrian catchments

The key objective of Smart Growth is the containment of 'suburban sprawl' through the adoption of planning techniques at the macro level which set up a growth boundary for a city and specifying development nodes within that boundary for 'vertical growth'. There are many reasons used to argue for vertical instead of lateral urban extension; decreased dependence on cars and fossil fuels leads to less pollution, (Newman & Kenworthy 1989)¹, less economically productive time lost to commuting (Tranter 2004),² but most importantly, if the framework encourages people to walk to facilities instead of driving, there is potentially an enormous public health benefit, (Doyle et al 2004)³.

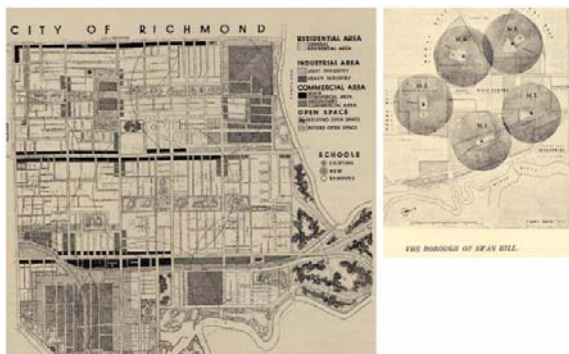


Figure 1 Diagram from We Must Go On (1944) showing five minutes walking distance catchment measured from centre of key nodes.

Planners have known about the relationship between proximity and choice of transport for many years. The likelihood of a person walking to services instead of driving is increased greatly if the services are close by. There are many different theories about exactly how close the services need to be but commonly used distances are 400m and 800m which represent five and ten minutes walking distance at average walking speed of 1.33 metres per second. These are the amounts of time people are willing to walk to shops and transport respectively (Pushkarev 1975)⁴. But these 'cut off' distances should be used as a guide only, as individual people may be happy to walk more or less distance depending on lifestyle, age, and health.

For the most part of the 20th Century these measurements have been used in Australia to gauge proximity to services (Barnett, Burt, Heath 1944)⁵, using the Radial Catchment Method (RCM). RCM involves the architect or planner choosing the node for analysis, for example, a primary school, and then drawing a circle in plan with radius 800m around the school. RCM can be applied quickly and gives a clear graphic representation of who can get to what, but the method is simplistic and does not take into account many factors such as street layout, non-pedestrian accessible areas, busy highways heavily disconnected street layouts (cul-de-sacs) etc. Despite the simplicity, this is still the main method used in Melbourne planning to assess connectivity, (See Figure 2).



Figure 2, Diagram from Melbourne 2030 Planning for Sustainable Growth (2003), showing five minutes walking distance catchment measured from centre of transport interchanges.

New methods of pedestrian connectivity measurement

Over the last decade, many planners have moved to Geographical Information System (GIS) such as MapInfo and ESRI GIS. These systems offer new methods of analysing pedestrian connectivity. The GIS packages are set up to hasten repetitive tasks for analysis such as; Block Length Ratios (measuring the lengths of blocks in an area), Block Density (number of blocks per square km), Street Density (length of streets per square km), Link Node Ratios (the number of street intersections per square km) and Pedestrian Route Directness (distance between two nodes navigating through street network). Each of these measurements have been shown to correlate to better pedestrian connectivity, but are relatively abstract concepts and can seem like a kind of GIS 'black box' – where data goes in and magically comes up with the answer. Of these methods the most effective measurement is Pedestrian Route Directness (PRD) (Dill, 2004)⁶. By measuring the distance between two nodes by navigating street layout, the urban morphology can impact upon the measurement and be expressed a ratio: route distance to straight-line distance between the two points (as the crow flies), urban interventions (such as a new pedestrian link) can be assessed. For example, if the PRD rating between a school and the town swimming pool is 0.4, and if a railway overpass were built would make the PDR rating 0.8, then this might be enough to justify the local council building the over pass. On the other hand, if building an overpass only improved the PDR rating to 0.45, then it could be assumed that the council's money could be better spent elsewhere. In this fictional example, PDR is a valuable tool for informing a strategic planning decision for the connection of two key community nodes. When assessing catchment areas, a combination of the Radial Catchment Area and PDR method can be used which involves a chosen radius circle eg. 800m centred on the chosen node eg. railway station, and all possible 800m walking paths being traced out from the railway station. The area overall polygon created with the multiple paths can then be measured and compared to the area of the circle (Figure 3). This technique is called Pedestrian Catchment Area (PCAP) (Scholssberg et al., 2005)⁷ or a Ped-shed. A variation on this is an IPCA Impeded Pedestrian Catchment Area (Scholssberg et al., 2004)⁸ similar to PCA but using only minor roads, and 'cutting off' connectivity when reaching major pedestrian-unfriendly roads. Unfortunately, both PCA and IPCA can be difficult to calculate and time consuming and their computational complexity renders them difficult to use for policymaking and consequently are rarely employed by planners. (Dill, 2004)⁹.

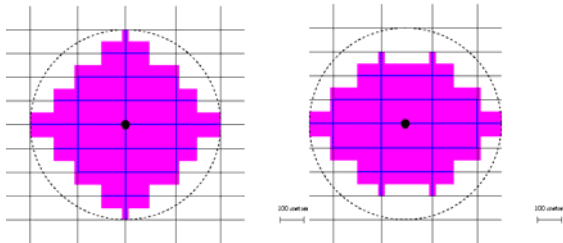


Figure 3 PCA used in Melbourne to assess moving a tram stop to middle of block. (LHS) PCA is 65 per cent. (RHS) PCA of 57 per cent. Relocation of a tram stop leads to a reduction in 'walkability' by 12 per cent in relative terms <http://www.ptua.org.au/myths/midblock.shtml>

Using PCA as the base analysis method, I have been developing an agent based method of pedestrian analysis for catchments. Over the past 5 years there have been great leaps forward in Artificial Intelligence and agent based crowd simulation. Specialist fire engineering/egress software such as: Legion™, Exodus™, and Myraid™, use agents –virtual humans– to simulate the behaviour of crowds of people attempting to escape a burning building. Even more advanced is the technology used for crowds of Orks fighting humans, elves and dwarves in the *Battle for Middle Earth* in Peter Jackson's *Lord of the Rings* film trilogy. Jackson's team of animators use a purpose built software called *Massive™*, capable of programming thousands of individual agents to make complex decisions: to attack, to avoid danger, to defend, to retreat if outnumbered and so on. This software is extremely costly and requires specialised hardware, but the development of this type of crowd animation has filtered down to low-end programs.



Figure 4. Image from Peter Jackson's *Lord of the Rings* – agent based crowds using *Massive™*

Both Maya™ and 3D Studio Max™ now have built in crowd simulation capacity. With some minor software 'tweaking', both *Crowds* and *PFlow* in 3D Studio Max are capable of producing 'semi artificially intelligent' agents capable of interacting with street layouts, intersections and topography to attain a more accurate indication of pedestrian movement. The level of programming is far simpler than in *Lord of the Rings*, as the agents are simply trying to demonstrate the Pedestrian Catchment Area, (close ups of the action are not required). To measure the PCA, the agents are programmed to begin at the key node (railway station) and navigate their way through surrounding streets to get as far away from the station as they can in 10 minutes. The agents are programmed to make basic decisions; to move at human walking speeds¹⁰, be *repelled* by the railway station (get as far away from the station as possible), *avoid* other agents (so as not to bump into one another), *avoid* walking through walls or onto train lines, be attracted or by other elements (supermarkets etc).

This agent based technique for measuring PCA and IPCA I call '*Ped-Catch*'. The simulation can be set up with as much or as little detail as is required - somewhere between *Pac-Man* and *Lord of the Rings*. If the model requires more accuracy, more 'intelligence' can be added to the agents; avoid fast moving traffic streets, stop at stoplights (based on stop-light cycle times), ground surface gradient can be used so pedestrians slow when they move along steep topography (White 2007)¹¹. Agent based PCA analysis can provide a powerful advocacy tool as their movements can be captured as an animation, and shown to local councils, residents and user groups to explain the catchment process.

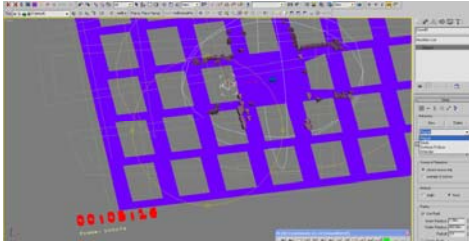


Figure 5. Screen grab showing timer and agents programmed with simple behaviours moving through a street grid.

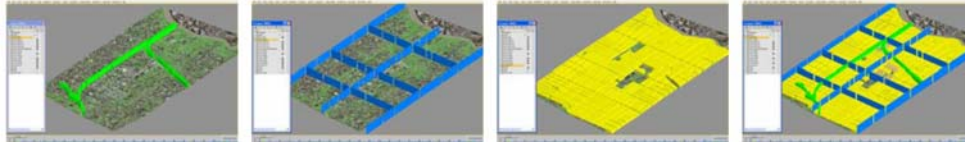


Figure 6. Digital 3D model of topography, and major ‘deflection barriers’, (L to R) railway lines, major roads, private land boundaries, all shown simultaneously. (Interestingly, the method for modelling major roads and railway lines is the same as building walls)

Validation and Verification

To simulate real human behaviour is an extremely complex exercise. There are an infinite number of factors that may effect a person’s movements from the width of a footpath, what time it is, to what a person had for lunch. For urban planning – measuring pedestrian catchments, the level of accuracy of pedestrian simulation does not need to go beyond what is required for an urban designer to be able to say with some confidence that ‘it is possible for people to be able walk from their home to the railway station in less than ten minutes’.

I have tested the accuracy of the Ped-Catch technique in two ways. Firstly, I have tested it against the manual creation of PCA, secondly I have tested it against groups of real pedestrians. In the first verification exercise I used a cadastral map of the area of Prahran, Melbourne in AutoCAD manually tracing all of the possible routes away from a chosen node. I then used an Auto-lisp routine called “enlengthen.lsp”, which extends or shortens poly lines to match a chosen distance (800m). I then measured the area of a polygon that traced each of the 800m points at the ends of the paths. I used this area compared to a circle with radius 800m drawn from the same centre point to calculate the PCA.

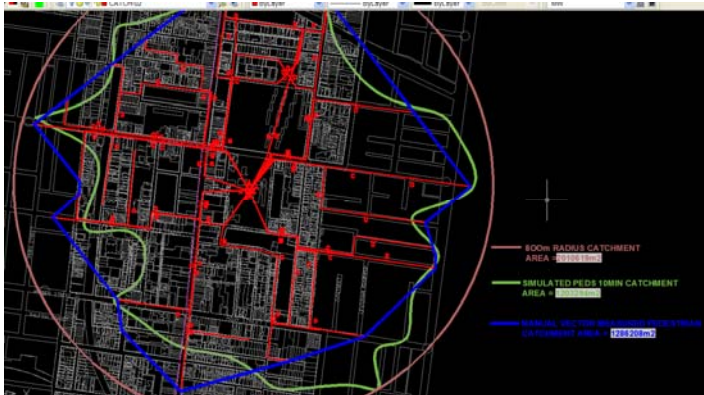


Figure 7. AutoCAD drawing showing possible routes from chosen node in Red. These routes are polylines with total length of 800m.

800m radius catchment area	2010619m ²	
Manual vector measured pedestrian catchment area	1286208m ²	(PCA=0.64)
Ped-Catch Simulated pedestrian 10min catchment area	1203294m ²	(PCA=0.60)



Figure 8. AutoCAD drawing with aerial photo background showing possible routes from chosen node in Red. These routes are polylines with total length of 800m.

The second verification technique involved testing Ped-Catch against the movement of 'real people' - architecture students from RMIT. The empirical research technique is similar that used by Daamen, W, & Hoogendoorn (2003)¹². The technique involved giving 30 students a piece of paper with a map of the suburb and one of the 30 pedestrian routes marked on. The students then walked along the given path using mobile phones to measure movement and time, marking times every 200m on the map, and marking time spent waiting at traffic lights. The results showed that the average distance travelled in ten minutes was slightly less than 800m. The average distance was 90% accurate compared to the manual PCA and when speeds were adjusted to factor in time spent at traffic lights the accuracy was closer to 95%.

Measured speed and distance covered.			
AV. DIST IN 10MIN			721m
AV. SPEED			1.20m/s
Corrected for traffic light stops			
AV. DIST 10MIN			746m
AV. SPEED			1.24m/s

This result would imply incredibly high accuracy for both the manual PCA measurement as well as the Ped-Catch method, though I feel that many more tests with many more pedestrians would be required for this study to be conclusive. There are many factors which may have contributed distorting the test, such as that all pedestrians were of similar age (all undergraduate university students) and similar fitness levels. The diversity of the general community was not covered. The tests were run in the middle of a weekday, so the footpaths were not congested. Had the test been conducted at peak morning (8.45am), the results may have been effected.



Figure 9. Pedestrian moving along path measuring distance and time.



Figure 10. Maps given to each student showing the 800m route they are to measure.

Case study A: Mega Mile – Railway Walk

The 'Mega-Mile' is an area between two Melbourne suburbs - Mitcham and Nunawading where the *Melbourne 2030* – smart growth policy is being implemented. MGS Architects are producing a Structure Plan for the area, setting up guidelines for buildings and highlighting urban intervention opportunities. One such opportunity involves the use of land to the north of the Nunawading railway station for a pedestrian connection. I applied the Ped-Catch technique to the existing conditions for the Nunawading station, which highlighted that the PCA was poor, particularly to the north of the station caused by a lack of direct access from the station to the main road (see Figure 13 LHS). There is also a vacant block and a piece of publicly owned land to the north, so MGS proposed acquiring this land for a pedestrian link. I ran the Ped-Catch simulation on this proposed scenario, which increased the PCA greatly. (Figure 13 RHS). This analysis was then presented to the planning department and to the council in the form of a multi page 'animated' PDF file (Figure 12). The proposed connection is set to go ahead with the support of the council, planners and local user groups.

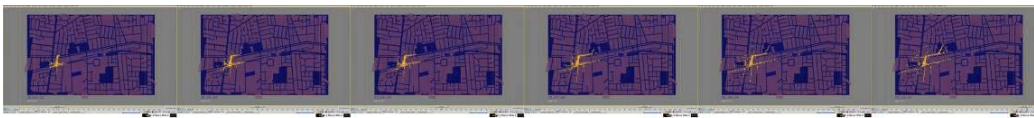


Figure 11. Frames from Ped-Catch pedestrian animation for 10 minutes walking distance - existing street layout for the Nunawading railway station precinct.

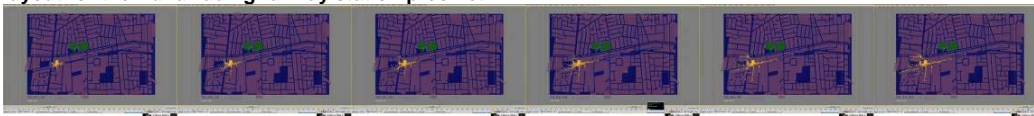


Figure 12 Frames from Ped-Catch pedestrian animation for 10 minutes walking distance - proposed street layout for the Nunawading railway station precinct.

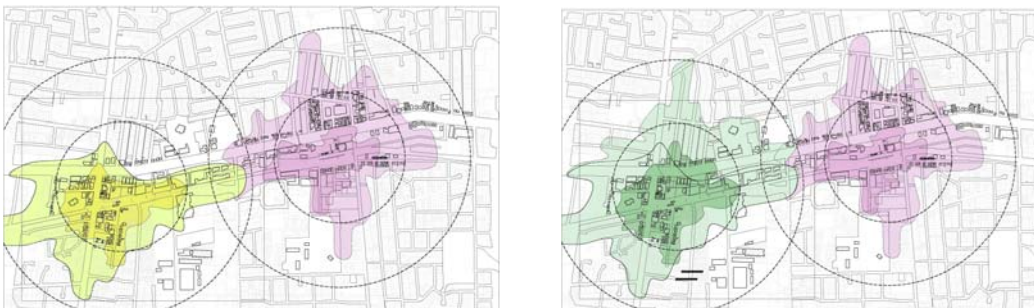


Figure 13 LHS, Catchment shape for 10 minutes walking distance existing street layout - RHS Catchment shape for 10 minutes walking distance proposed street layout (5&10 minutes walking distance illustrated by 400&800 m radius circles)

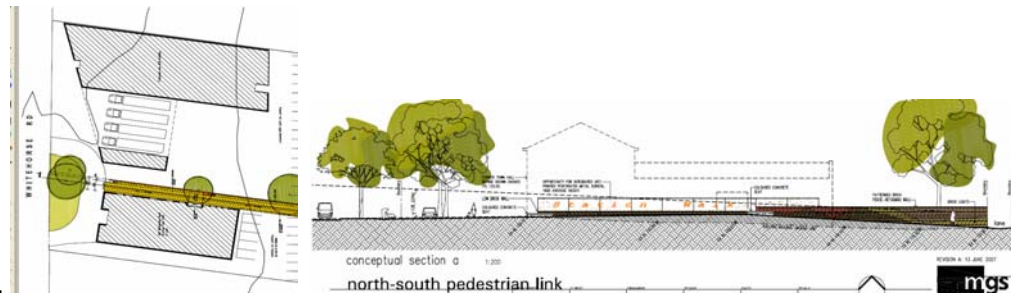


Figure 14. Drawings of proposed 'Station Walk' connection between railway station and Whitehorse Rd.

Case study B: Mega Mile Potential Urban Form Envelopes

Along side the Pedestrian link proposal, I was also conducting a hypothetical urban form generation exercise linking pedestrian catchment area to urban density and permissible building heights.

Though the PCA measurement is helpful in working out who can theoretically get to railway stations, schools, supermarkets etc, it does not mean that all people with in the PCA will walk to the chosen node. It is logical that the likely hood of a person walking to a node drops off the further away from the node they are. The likelihood of children walking to school drops off gradually as the further from school the child lives. Figure 15 shows the number of children walking roughly follows half of a Bell curve with an asymptote at zero. (This reflects our personal experiences of school, where almost all children living in the next block to the school walk and there always being a track and field nut child who would walk or ride to school no mater how far away they lived.)

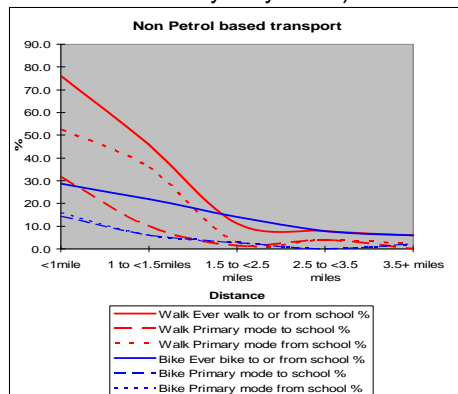


Figure 15, Non fossil fuel based transport : Graph by Marcus White using data from: (2006) Schollberg, M. Greene, J. Phillips, P. Johnson, B. and Parker, B School Trips: Effects of Urban From and Distance on Travel Mode

In current planning policy in Melbourne, this bell curve is not considered in how potential urban form is generated. It is not uncommon for planners to draw the RCA catchment circles and then simply select a few blocks for higher density/height eg 5 levels. This is a step in the right direction and if carried through to its natural conclusion could produce interesting results, (see Figure 16) but if this concept is taken further, using Ped-Catch, as well as the walking bell curve, a more direct relationship between walkability and urban form could be achieved.

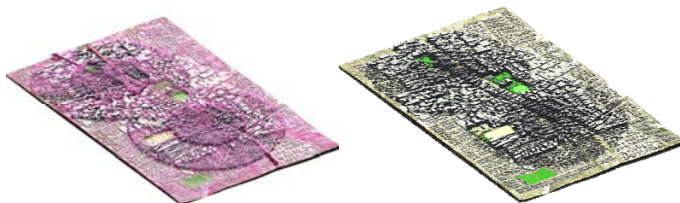


Figure 16, Literal model of using the RCA of railway station used to generate hight limits.



Figure 17, Pedestrians agents moving through a street grid deforming the 'height limit' surface.

A direct relationship can be set up with the pedestrian agents and a 'height limit' surface. I set the tool to deform the surface based on the movements of the pedestrians, the more pedestrians moving through an area, the higher the height limit becomes. I then adjusted the parameters of the surface deformation so that section of the surface can closely resemble that of Schollberg's Bell curve. This deformation can also be adjusted so that the resulting permissible envelope has sufficient volume to accommodate the predicted increase in population. Once the 'height limit' surface was established, I used a technique based on Tom Hudson's 'Greeble' program to produce random building forms, and then 'conformed' these buildings to the surface. This resulted in the sinuous skyline shown in Figure 19.

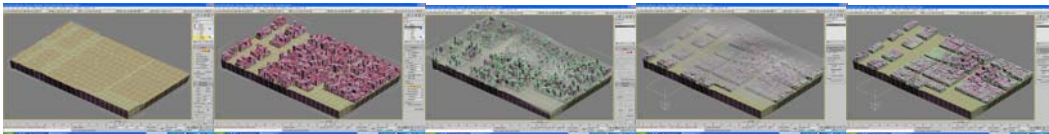


Figure 18, Random urban form generation conformed to height limit surface generated from Ped-Catch PCA and agent deformed surface.

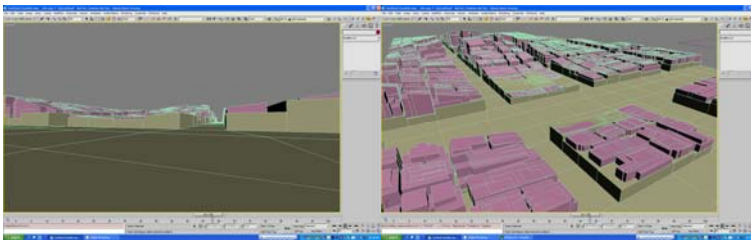


Figure 19, resulting perspective views of Mega-Mile.



Figure 20 Mega-Mile case study B: Urban form conformed to height limit generated from Ped-Catch PCA and agent deformed surface.

Conclusion

The Ped-Catch technique can give the urban designer the ability to make design proposals for new urban layouts, or alterations to existing urban layouts and test their potential connectivity rapidly. The technique can be used to aid the designer in locating additional services, supermarkets, schools, and transport. The tool can be used to suggest interventions such as pedestrian links as was the case for the Mega-Mile example where the PCA was stunted in one direction.

The initial results of the verification test showed the level of accuracy far surpasses that of the Radial Catchment Method, and is vary similar in accuracy to the manual vector tracing PCA method. The testing using real pedestrians confirmed this accuracy but I believe that many more tests with a more varied demographic are required for this to be conclusive.

Ped-Catch shows potential in being a powerful advocacy tool when communicating with councils, stake-holders and the general public. Unlike many of the 'black box GIS' techniques, viewers can watch the pedestrian-agent's movements and understand the shape of an existing catchment. This allows the designer to put forward proposals to improve the catchment with urban interventions such as new pedestrian over passes, sinking railway lines, new pedestrian links etc., and demonstrate a proposal's effect the pedestrian catchment.

The tool could also be used in requesting contributions from local retailers, if the traders can be convinced that the potential increased pedestrian traffic will lead to increased retail sales (Desylass 2007)¹³.

In the Mega-Mile case study, I illustrated the potential for pedestrian catchments to have a direct relationship to both street layout and to permissible building heights and density. The Schollberg et al (2006) research suggests that walking desirability tapers off with distance so doesn't it make sense that density tapers off at a similar rate?

If urban designers are serious in proposing Smart Growth as the planning policy the manner in which we implement the policy must be improved. We cannot expect that any type of planning policy to work if we rely on implementation tools from the 1940's. With so many benefits related to people walking and using public transport instead of driving; public health, fuel consumption, decreased carbon emissions, and time saved by commuters not stuck in traffic, it seems that far more work needs to be done to push the new available techniques to fulfil their potential. Can agent based pedestrian modelling be used to inform urban morphology? Yes. I believe that not only can agent based pedestrian modelling inform urban morphology, but it is completely necessary for connectivity and reasonable walking times to inform urban morphology if we are to have any hope of achieving sustainable urban growth. As Gandalf The Grey would say, 'All we have to decide is what to do with the time (10 minutes of walking) that is given us' (Tolkien 1949).

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