Introducing the Pedestrian Accessibility Tool (PAT): open source GIS-based walkability analysis

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ABSTRACT

The indices for walkability proposed so far are mostly ad-hoc and refer generally to the closest amenities/public transport stops and the existing network structure. They are ad-hoc as the weights of the attributes are generally arbitrary and do not reflect the independently measured preferences of the users and residents. Furthermore, they do not include design attributes such as the location of crossings and walkway design features, which are very relevant for actual planning decisions.

In this paper, we propose a walkability index that can be behaviorally calibrated and has been implemented as a GIS tool and is published as Open Source software. The Pedestrian Accessibility Tool allows evaluating existing and future urban plans with regards to walkability. It calculates Hansen-based accessibility indicators based on customizable specification of generalized walking cost and user-defined weights of destination attractiveness.

The basic user work flow of the tool is summarized and three case studies show real-world applications of the tool to support the planning of pedestrian infrastructure in an urban context. By indicating potential areas of improvement that have been reported by pilot users working in an urban planning department, we conclude also giving hints for future research.
INTRODUCTION

The potential of active travel modes, such as walking and cycling, to address both environmental and public health concerns while being very space efficient modes of transport, has resulted in a growing body of research across different fields that aims to capture how the built environment influences travel behavior. From various meta-analysis reviews, (1–3), one can conclude that the built environment directly influences travel mode choice.

A shortcoming of previous studies is that they assess the influence of built environment variables from a macroscopic perspective. While the behavioral data of those studies usually stem from travel diary surveys, the variables that describe the built environment are typically only available in spatially aggregated form.

Based on a network survey of physical characteristics, location factors, and user factors of a pedestrian route, link or crossing (4), pedestrian network audits allow for a spatially fine-grained, multi-criteria assessment of walkability. Such assessment tools can include factor-specific weights recognizing that certain factors are more important to pedestrians than others (5).

Data collected with revealed and stated surveys allows to quantify how pedestrians actually value different factors and how these factors influence the walking experience and ultimately impact route and mode choice behavior.

In this paper a software tool is presented that integrates the results from behavioral surveys with data collected in a network audit on a link level. This software tool has been developed in conjunction with Singapore’s Urban Redevelopment Authority (URA) as part of a larger project that aimed to quantify the walkability of Singapore’s city center.

The software tool computes a behaviorally founded walkshed and pedestrian accessibility index and combines the concept of accessibility with observed user preferences as identified in dedicated surveys. The disutility or impedance of a walking trip is thereby not only be quantified by the walking distance, but also takes into account how well the built environment supports the pedestrians’ desire for a safe, comfortable and pleasurable walking experience.

The relevance of such a tool is not limited to accessibility analysis, but is also for useful for a wide range of applications, such as the calculation of safe and convenient routes to schools, transit catchment areas and access to health care for the elderly.

The remainder of this paper continues with a literature overview, followed by an outline of the requirements and functionality of the developed pedestrian accessibility tool. To highlight the usage of the pedestrian accessibility tool, a detailed outline of the workflow is provided. Subsequently, to demonstrate the usage of the pedestrian accessibility tool a number of case studies is presented.
LITERATURE REVIEW

Level of service

A range of methodologies are used in research and planning practice to assess how well a particular urban environment supports the needs of pedestrians. The most simplistic approach applies the concept of Level of Service (LOS) to pedestrian traffic. The LOS concept was originally developed to categorize the quality of traffic for highways based on the flow of traffic. Levels of quality, ranging from A (best) to F (worst), are assigned to quality levels based on performance measures such as speed and density.

Network audits

Appreciating that pedestrian comfort is not only a function of the level of crowdedness but also includes factors such as pavement quality, lighting and urban design characteristics, various researchers and planning bodies have conducted pedestrian network audits to collect such information on a link-by-link basis (6). Whereas in the past pedestrian network audits have primarily been conducted using a paper and pencil approach, mobile GIS applications allow to collect, digitize and consolidate the collected data in a central database. The use of Google Streetview, if available for the area of interest, seems also a meaningful option (7) but might have limitations if additional criteria such as traffic noise, facade transparency or pedestrian footfall should be included in the audit. Specialized software has been developed (8) to provide a comprehensive, quantitative assessment of the pedestrian environment and allow for objective comparisons of the level of service quality for pedestrians along different routes and also generate suitable graphical output for public consultation and decision making.

Pedestrians’ preferences

Revealed preference studies are a suitable research method to quantify pedestrian preference and have been applied in various contexts. In a study conducted in Florida, it was identified that distance to school and the availability of a sidewalk significantly impacts student’s willingness to walk to school (9). For shopping trips under a mile and access trips to rail stations urban design qualities have the most pronounced impact (10). In Singapore, distance was to be the most significant factor influencing mode choice, but crossing a road is perceived as much as an additional distance of about 55m. Similarly, climbing an overhead bridge was perceived as 90m distance; crossing a car park adds another 36m to the actual walking distance (11). In the city of Calgary the importance of distance over other factors such as the level of congestion, safety or visual attractions was identified (12). In San Diego and Minneapolis a short distance had the strongest association with route choice; presence of a greenway, sidewalks and availability of destinations were positively associated with route choice as well (13).

In the city of Portland, Oregon, it was found that pedestrians were sensitive to attributes of the pedestrian network, intersection crossing aids, and elements of the street and block face environment along urban routes (6). Pedestrians were accepting detours to use more attractive facilities, although the tolerance with regards to the additional distance such detours involve was limited. In addition, it became clear how neighborhood-scale commercial streets serve both attractive destinations and walking routes.
A limited number of studies applied stated preferences techniques to describe pedestrians’ preferences. Climbing stairs and escalators was valued twice as much as descending a flight of stairs and 4.2 times more than in-vehicle travel time (14). The width of the sidewalk, separation from traffic, availability of trees and greenery as well as presence of other people to make a street more attractive for pedestrians were found to significant in image-based stated preference survey (15).

### Accessibility

Besides the quality of the pedestrian infrastructure to provide a safe, comfortable and pleasurable environment (16), access to destinations in walkable distance is another important aspect of walkability. The concept of accessibility refers to the ability to reach desired goods, services, activities and destinations. While measuring accessibility for motorized forms of transport is already well established in transport planning for quite some time (17), only recently the concept was also adapted and applied to measure pedestrian accessibility (18, 19). WalkScore (20), a web-based service assesses the walkability of a particular place by accounting how many amenities can be reached within walkable distance; in recent versions, network distances along road centrelines have been included. However, using a pedestrian network matters. For Singapore it has been shown that the accessibility to jobs decreases when pedestrian network distances are used (21).

### In conclusion

There are three strands of research to assess walkability that remain unconnected so far. The Level of Service approach is certainly a useful assessment method if the key challenge is overcrowding of pedestrian facilities. By including aspects that account how well a pedestrian facility is integrated into the urban design, the LOS approach can be extended to a multi-criteria assessment to describes the walking comfort for pedestrians. However, since walking often is not a means to an end but usually a mode of transport to reach a destination to conduct a certain activity, the LOS approach lacks the important aspect of accessibility. Recent work that quantifies walkability by describing the amount and diversity of destinations that can be reached from a given location within walking distance neglects the preference of the users with regards to design quality and different types of pedestrian infrastructure. At the same time, researchers have been able to quantify such preferences based on revealed and stated preference surveys including mode and route choice experiments.

### PEDESTRIAN ACCESSIBILITY TOOL

#### General aim

The aim of PAT is to compute the shortest perceived walking distances from one or several access points to all other access points that can be reached within a pre-defined walking time threshold. To obtain a perceived rather than an actual walking time, PAT incorporates various factors contained in a pedestrian network that help to describe the quality of a walk, i.e. the level of greenery along a link or whether stairs and crossings with traffic lights need to be traversed. Each link attribute should be weighted by a specific parameter. It is assumed that pedestrians perceive certain attributes dependent on the time they are exposed to it, for instance, greenery.
Transversely, certain attributes are assumed to be independent of travel time. The presence of traffic lights or a flight of stairs are examples of such attributes. The travel time of one link is then defined as given by Equation 1:

$$tp_i = \beta_{\text{time}} (1 + \sum_{ik} \beta_{ik} X_{ik}) t_k + \sum_{jk} \beta_{jk} X_{jk}$$  

(1)

with

- $t_{pi}$: time perceived along link i
- $\beta_{\text{time}}$, $\beta_{ik}$, $\beta_{jk}$: preferences for resp. travel time, time dependent and time independent attributes
- $X_{ik}$, $X_{jk}$: time dependent and time independent attributes

The pedestrian accessibility of one starting point is then defined according to Equation 2:

$$A_i = \sum_j O_j \cdot e^{-\beta \cdot t_{pij}}$$  

(2)

with

- $A_i$: Accessibility of point i,
- $O_j$: Opportunities at destination point j,
- $\beta$: Distance decay parameter, usually estimated to fit observed trip distance distribution,
- $t_{pij}$: time perceived walking between point i and j.

The accessibility measure $A_i$ can be interpreted as the perceived distance discounted sum of all destination opportunities.

**Requirements**

In several meetings with the URA’s Urban Planning Division a series of requirements for the Pedestrian Accessibility Tool (PAT) were set. These requirements varied from the software platform to be used to the various performance indicators that should be calculated. The requirements are listed in Table 1. Above all, urban planners were interested in a tool that was responsive enough to use in an interactive design session.

**Table 1 Requirements for the pedestrian accessibility tool**

| **Software platform** | - Given the prevalence of ESRI’s products within URA and, PAT should be developed as an ArcGIS Add-in. In this way, existing and new file geodatabases could easily be used with PAT |
| **Input data** | - PAT should be able to read the pedestrian network from a shapefile and/or geodatabase as well as read link attributes stored in these data sources. - PAT should be able to read the access points to the network from a shapefile and/or geodatabase as well as read point attributes stored in these data sources. |
To support future analyses, the attribute names and the number of columns should be flexible and not hard-coded.

**Computation**
- The user should be able define the distance decay parameter $\beta$.
- The user should be able specify the function how the perceived walking duration $d_{ij}$ is calculated based on a series of link attributes and corresponding parameters.
- To improve an iterative and interactive design process, planners should be able to make changes to the network, link attributes and cost parameters and be able to perform an accessibility analysis within 30 seconds.
- To make the analyst’s workflow more convenient, access points and the pedestrian network should be matched within PAT and not by the analyst.
- The output should include a cumulative opportunity index as well as a Hansen-based accessibility index with a custom distance decay parameter.

**Output**
- The output should show the difference between ‘perfect’ walkability and the walkable area according to the perceived walking costs should be shown.
- The output should contain the traversable costs per link as well as the cumulative costs per link from the selected starting point, so that stored results can be visualized at a later stage.

**Additional requirements**
- It is envisaged that a user wants to change network topology prior to using PAT. To check whether the updated network topology is valid the user should be able to use ArcMap’s shortest path algorithm.

**Implementation**

PAT was implemented as an ArcGIS Add-In; ESRI’s ArcGIS Desktop is considered to be the leading commercial geographic information systems (GIS) platform in the market. Add-ins can be written and developed in .NET or Java. Java was selected as the programming language as the skills were available in the project team.

Figure 1 provides a schematic overview of the implementation of the pedestrian accessibility tool. Four layers combined provide the necessary input data for PAT; these are shown on left-hand of the flow chart.

- **Network layer**: A network layer is a special type of layer that relates junctions (graph nodes) and roads (graph links) stored in other layers. The Network Analyst Extension of ArcMap provides a tool to generate a network representation from a simple line or polyline layer.
Walkways layer: The walkways layers contain the geometrical information of the pedestrian network as well as the link attributes.

Junction layer: The junctions layer stores geometry and other information of nodes.

Entries layer: PAT requires an entries layer representing destinations.

Figure 1 Schematic overview of the pedestrian accessibility tool

Several intermediate data structures are created by PAT:

- **Cost parameters**: A cost map that contains the mapping between link attributes and the perception of the link costs.

- **Weighted graph**: Using the 3-layer network representation and the cost function defined by the cost map, a weighted graph object is created in Java which is optimized for graph algorithms.

- **Walkways to paths**: This map saves information of each walkway in the region of interest and works as a bridge between the walkways layer (input from ArcMap) and the paths layer (output to ArcMap) in the Java program.

- **Walkways to points**: This map relates each location included in the entries layer with a walkway.

Running PAT results in three output layers, shown on the right hand side of the flow chart in Figure 1. The source code of PAT has been published as Open Source software (30).
Workflow

The graphical user interface guiding the PAT user through the scenario definition and computation process are shown in Figure 2. The front-end of PAT consists of four buttons in the ArcMap application. These four buttons are named Prepare, Parameters, Calculation and Batch Calculation and are ordered from left to right to represent the user workflow.

Figure 2 Pedestrian accessibility tool in ArcMap

Prepare

In the first step (1a), the user sets a scenario name and defines which network layer and corresponding network data set, as well as the entries layer should be used for the analysis. In the second step (1b), the user is asked to select which columns are to be considered to define the pedestrian experience (cost function). In the third and final step (1c), the user selects which column (attribute) should be considered to represent the weight of an individual access point. PAT will then generate a Java network object and relate the access points to the two nodes of the nearest (perpendicular) link.

Parameters

By clicking the button ‘Parameters’, the user is prompted to specify parameters for all network attributes that were previously selected to be relevant for the scenario (Figure 2, window 2).
The window consists of two parts. The upper part contains settings of relevance for the analysis:

- The maximum distance is the distance from a single point that will be considered for single and multi-point analyses.
- The walking speed is the average speed of pedestrians.
- The parameter “b_time” represents the value of time and is used for the time dependent variables in the lower part of the “Parameters” window.
- The lambda parameter represents the distance decay factor.
- The weather condition describes the weather condition under which the assumed weather conditions the scenario will take place.

The bottom part of the “Parameters” window shows the additional parameters specified in a separate text file. For each parameter, the beta value is stated, whether the parameter is time dependent and whether the parameter is different under different weather conditions.

By pressing “Apply” the link costs will be updated: each link in the network will have the perceived time to traverse a link assigned to it. This perceived time will be used in the routing algorithm.

**Calculation & batch calculation**

Once the analyst has selected a starting point for analysis and starts calculation, PAT will prepare a sub-graph and perform a one-to-n shortest path computation using the Bellman-Ford algorithm. In the case for a 500m radius, the calculation process should take about 20-40s.

**Output**

After the calculation is completed, a pop-up “Results” window (window 3) appears that shows key performance indicators. In addition, several layers are added to the ArcMap document.

The following link statistics are included the output:

- Number of accessible links;
- Total accessible distance (sum of link length)
- Total perceived time (sum of the perceived time it takes to traverse each link)
- Accessible area: the area of the convex hull around the accessible access points.
- Perceived distance ratio: total perceived distance spent on the links divided by the total link length. In this case, the perceived distance ratio is larger than 1, indicating that the perceived length in longer than the actual link length.
- Links walkshed ratio: the area reached divided over the entire area circle buffer from the starting point.

The following statistics for reached entries are included: (1) the number of accessible entrances, (2) the total accessible size: the number of accessible entries multiplied by their respective weight (3) the total weighted size: the number of accessible entrances, where the weight of each
entrance is discounted according to the perceived walking time to reach it according to the distance decay function and its parameter lambda.

Additionally, three layers are created:
- A layer with paths with the minutes perceived walking time to reach this link from the selected starting point as well as the perceived walking time to traverse each link.
- A layer with entries with the perceived time it took to reach each entry. A layer with the perceived walkshed and the maximum distance (circle buffer).

**Updating results**

If the network topology and attributes are not changed, the analyst can simply update the parameters and run subsequent analyses with varying start locations, distances thresholds and cost parameters.

**CASE STUDIES**

In this section three case studies are presented to showcase how PAT can be applied to (1) illustrate how perceived and actual distance differ due to the respective pedestrian network attributes, (2) to quantify the impact of adding new pedestrian infrastructure with regards to the accessibility of one particular location and (3) to quantify the impact of improving several locations at simultaneously.

**Pedestrian network data**

An extensive pedestrian network covering the whole central planning area of Singapore provides a series of relevant variable describing the characteristics of the walkway and immediate built environment serves as basis for the presented case studies. The pedestrian network covers an area of about 4.7 km², contains almost 420 kilometers of walkways and 3,200 individual links. The network was audited in 2015 in the context of the aforementioned project in conjunction with URA. In addition, a data set featuring the location of more than 4,700 building entrance points and related building information is used for analysis with PAT.
Behavioral parameters

Behavioral parameters have been estimated based on a dedicated survey that integrated stated and revealed preference data of pedestrian route choice behavior and was conducting in Singapore (22). The utility function that describes generalized walking time given by Equation 3 has been identified based on the combined results of revealed and stated preference surveys that have been conducted as part of the same research project and combines a series of variables that have been identified to significantly influence the perception of walking time. The corresponding parameter values are indicated in Table 1.

\[
tp = \beta_t \cdot \text{time} \cdot (1 + \beta_{\text{min}} \cdot \text{minor} + \beta_{\text{maj}} \cdot \text{major} + \beta_{\text{ub}} \cdot \text{under/throughblock} \\
\cdot (1 + \beta_{\text{utb}} \cdot \text{sunny} + \beta_{\text{utb}} \cdot \text{rainy})) \cdot (1 + \beta_g \cdot \text{greenery}) \cdot (1 + \beta_s \cdot \text{shops}) \cdot (1 + \beta_c \cdot \text{cover} \cdot (1 + \beta_e \cdot \text{sunny} + \beta_e \cdot \text{rainy})) + \\
\beta_s \cdot \text{stairs} + \\
\beta_{\text{esc}} \cdot \text{escalator} + \\
\beta_{\text{ut}} \cdot \text{trafficlight} + \\
\beta_{\text{zc}} \cdot \text{zebra_crossing}
\]

(3)

Depending whether the individual variables are modelled as summand or interaction term, the respective parameters have to be interpreted by direct comparison with the walking time parameter or as a factor that describes how much a certain attribute increases or lowers the relative perceptions of walking time.
Table 2 Default parameters for case-study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Walkway characteristics</th>
<th>Default value</th>
<th>Interaction term</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_t$</td>
<td>along major road</td>
<td>-0.019</td>
<td>-</td>
<td>walking time measured in minutes</td>
</tr>
<tr>
<td>$\beta_{maj}$</td>
<td>along minor road</td>
<td>0.593</td>
<td>yes</td>
<td>Walkway through park as reference category</td>
</tr>
<tr>
<td>$\beta_{min}$</td>
<td>leads through a building</td>
<td>0.473</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$\beta_{u, tb}$</td>
<td>dummy for sunny weather conditions</td>
<td>-0.169</td>
<td>yes</td>
<td>cloudy weather as reference</td>
</tr>
<tr>
<td>$\beta_{u, tb_s}$</td>
<td>dummy for rainy weather conditions</td>
<td>1.5</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$\beta_{u, tb_r}$</td>
<td>with relevant greenery with active frontage</td>
<td>-0.228</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$\beta_g$</td>
<td>covered walkway</td>
<td>-0.175</td>
<td>yes</td>
<td>cloudy weather as reference</td>
</tr>
<tr>
<td>$\beta_c$</td>
<td>dummy for sunny weather conditions</td>
<td>1.8</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$\beta_{c_s}$</td>
<td>dummy for rainy weather conditions</td>
<td>3.1</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>$\beta_{c_r}$</td>
<td>stairs</td>
<td>-0.04</td>
<td>No</td>
<td>equals 2 minutes walking time</td>
</tr>
<tr>
<td>$\beta_{esc}$</td>
<td>escalator</td>
<td>-0.02</td>
<td>No</td>
<td>equals about 1 minute walking time</td>
</tr>
<tr>
<td>$\beta_{tl}$</td>
<td>Traffic light</td>
<td>-0.02</td>
<td>No</td>
<td>average waiting time corresponds to 1 minute walking time</td>
</tr>
<tr>
<td>$\beta_{zc}$</td>
<td>Zebra crossing</td>
<td>-0.01</td>
<td>No</td>
<td>Corresponds to about 30 seconds walking time</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>-</td>
<td>330</td>
<td>-</td>
<td>Parameter to defined distance decay function, refers to cloudy condition with average walking distance being 330m</td>
</tr>
<tr>
<td>$r$</td>
<td>-</td>
<td>500</td>
<td>-</td>
<td>Considered radius for computing pedestrian walkshed</td>
</tr>
</tbody>
</table>

The flexible architecture of PAT also allows that both the number of attributes considered and the level of the corresponding parameters can also be altered according to the user’s need. In this
way it is very easy to expand the functions that describes generalized walking time with new aspects such as the width of the walkway or to specify a scenario that better represents the behavior of elderly.

**Case study 1: Representation of perceived as compared to actual walking distance**

A rather simple, but very helpful output of PAT is the indication of a consolidated factor that describes the perceived as compared to the actual walking distance for each link in the network. Figure 4 depicts a map section covering Singapore’s CBD area around Raffles Place. Links representing traffic light controlled crossings feature the highest values of perceived distance given that we assume a penalty of an equivalent of about one minute walking time to account for the average waiting time at traffic lights. Furthermore, it is visible that the extensive underground, air-conditioned walkway network with partially active frontages yields relatively low perceived distance values for sunny weather conditions when compared to the reference category of a walkway that leads through a park. As back lanes are often characterized by inactivated frontages and come without any greenery or cover to protect from the tropical sun results in walking distances that are perceived as substantially longer than they actually are.

**Figure 4** Perceived walking distances relative to walking through a park.
Case study 2: Replacing pedestrian overhead bridge with at grade crossing

In this section the usage of the pedestrian accessibility tool is highlighted by means of a case study near South Bridge Road. The number of at grade crossings alongside South Bridge Road is limited. For instance, along the 240-meter stretch (or 3-minute walk) between Pickering Street and Cross Street no grade crossings are present. Alongside this stretch are two pedestrian areas. Located on the east side of South Bridge Road is Nankin Road and Pickering Street, two carefully designed pedestrianized areas with a range of restaurants and cafes. Located on the west side is a pedestrianized area with, among other, Hong Lim Complex and Chinatown Point. These two areas are connected mid-block by a pedestrian overhead bridge. The situation is depicted in Figure 5.

Figure 5 Pedestrian overhead bridge connecting Nankin Road and Hong Lim Complex

The current situation was taken as the base line; as a starting point for this analysis the stair case has been used. The what-if scenario involves the introduction of a level crossing at the location of the overhead bridge. The pedestrian network surrounding the area was carefully evaluated prior to conducting the analysis. The current situation was taken as the base line; as a starting point for this analysis the stair case has been used. The what-if scenario involves the introduction of a level crossing at the location of the overhead bridge. The pedestrian network surrounding the area was carefully evaluated prior to conducting the analysis. The lower graph in Figure 6 highlights the hypothetical scenario when a grade crossing is introduced at the location of the overhead bridge. By introducing this crossing, the pedestrianized areas along Nankin Road and Pickering Road are easily accessed within a
perceived walking time between 2 and 4 minutes; a reduction of 3 minutes. 38% more area and
47% more entrances can be accessed in the what-if scenario.

Case study 3: assessing the impact of pedestrian infrastructure for multiple points of interest.

The batch calculation feature of PAT allows the user to compute Hansen-based accessibility
measures for a selected set of points of interests though a single command. To showcase this
feature we expanded then pedestrian network at three intersection in Singapore’s CBD that
currently only feature three crossing opportunities by adding a fourth pedestrian crossing, as
indicated in Figure 7. In a first step, we calculated the Hansen-based accessibility measure for
each point of interest (in this case those refer to building entrances) in the map section for the
baseline network. As defined in Table 1, we use a radius of 500 meters as distance threshold and
the standard distance decay function for cloudy weather conditions. We use gross floor area data
that is available for each building to describe the attractiveness of destinations. Subsequently, we
computed the same measure, but bases on the adapted pedestrian network that features the three
additional crossing opportunities which all were modelled as traffic light controlled crossings.
For each point of interest we then can calculate the absolute and relative change in accessibility
that those network improvements yield. As expected, the accessibility from buildings that are
located close to the new crossing opportunities benefit most. The relative accessibility gains of
more than 50% as compare to the baseline scenario indicate the effectiveness of the proposed
intervention. However, given the rather steep distance decay function (calibrated based on the
observed average walking distance of about 270m) the spatial extent of the impact must
considered are limited to the more immediate surroundings.
Figure 6 Pedestrian walkshed in baseline scenario with pedestrian bridge (top) and with at grade crossing (bottom)
**CONCLUSION**

The Pedestrian Accessibility Tool (PAT) offers planners to evaluate how attractive it is to walk to surrounding destinations from a given starting point. Hence it is both suited to evaluate how improvements in pedestrian network connectivity and urban design variables enhance the walkability of an area with the basic unit of analysis being an individual building.

PAT is intended to be used as a strategic planning tool, but is not necessarily the ideal tool to quantify upgrade works as they are typical after minor construction in a particular road. A typical case-study could involve the improvement the pedestrian experience of a certain area, or the improvement of the pedestrian network connectivity between two major pedestrian demand generators, for instance a train station and an office area.
The methodology and software implementation was done in a way that it can be directly transferred to assess any urban area for which a pedestrian network and the location of building entrances is available in a GIS data format. While the rather extensive design of the network audit was clearly tailored for research purposes, we recommend for practical application to restrict to a range of key attributes that are relevant for the given area and application. For the case of Singapore, those attributes should at least include link type, the availability of a cover, the width of the walkway, separation of traffic, facade transparency, availability of greenery as well as the type of vertical links and crossings. Consistently including the number of steps required to traverse a link or cross a road would allow to enhance the scope of PAT to run analyses for people with special needs and to specify for example wheelchair accessibility.

While PAT has been developed as an add-in to ArcGIS, in several workshops the need for a simpler, web-based tool has been voiced that also can be used for stakeholder communication. Key audiences of such tool featuring a simplified interface and restricted functionalities are identified as urban and transport planning decision makers, local stakeholders but also the general public, e.g. through data journalism.

Published as Open Data, pedestrian network data could be used by developers to create applications that would help pedestrians find optimal routes according to personalized preferences and for example identify routes that optimally balance between exposure to rain and detour distance.

While PAT can help planners to evaluate the impact of infrastructure measures on pedestrian accessibility, its functionality is not ideally suited to identify where network improvements convey the best potential and make most pedestrians benefit from it. To this end, we recommend to develop a pedestrian demand model that allows to predict pedestrian link flows based on data that describes for each building or destination how many pedestrian trips it generates and attracts. Findings from the tracking survey and revealed preference experiment could then be used to calibrate such a model with regards to the walking distance distribution and pedestrian route choice. Implemented as another ArcGIS Add-In it would ideally complement the functionality of PAT to prioritize and assess pedestrian infrastructure improvements.

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