Pedestrian mobility and accessibility planning: some remarks towards the implementation of travel time maps

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Abstract

The objective of the paper is to propose a methodology for evaluating pedestrian accessibility in urban areas.
Accessibility is a quite recurring topic in the scientific literature, and emphasizes the strong interrelationships between land use and mobility. In the last decade, dependence on GIS-based approaches for accessibility assessment and management has grown considerably, and the crucial role of GIS techniques for the analysis of accessibility is nowadays well established.
With particular reference to the Organic Urban Planning vision developed in Italy in the '60s in Italy, the paper focuses on pedestrian accessibility as major mobility mode at the scale of the neighborhood.
But how is it possible to measure the level of pedestrian accessibility of a given territory and to map the results in a GIS environment?
First of all, there is a need to collect the different layers of information related to pedestrian mobility for the area, with particular reference to the road network, the location of pedestrian paths and sidewalks as well as the presence of physical barriers in the area that impede pedestrian permeability (built environments, railways, waterways surface...).
The proposed assessment methodology is based on the detailed discretization of the area being analyzed in a uniform grid of cells. In this grid a calculation algorithm is applied. This algorithm, on the basis of the information layers that overlap in each cell, assigns each cell a pedestrian travel time and evaluates the existing connections between the cell in question, and the cells adjacent to it. This model allows the creation of thematic maps that show the timing of pedestrian access to each cell.

1. Towards Accessibility Planning

1.1 Accessibility definitions

Many authors agree that a shift from Mobility-Oriented to Accessibility-Based Transport Planning is nowadays the key towards Sustainable Transport Planning (see, i.a., Banister, 2008; Bertolini & Le Clercq, 2002; Handy, 2002; Marshall, 2001). The World Business Council for Sustainable Development (WBSCD, 2001) states that «for mobility to be sustainable, it must improve accessibility while avoiding disruptions in societal, environmental, and economic well-being that more than offset the benefits of the accessibility improvements».
But what does accessibility exactly mean? How can it be measured and improved?
Accessibility is an essential feature of a well-functioning city or region, and represents a fundamental principle, because it provides a framework for understanding the reciprocal relationships between land use and mobility (Hull, Silva & Bertolini, 2012).
The Oxford English Dictionary defines mobility as «the ability to move or to be moved freely and easily», while accessibility as «the quality of being accessible», where accessible is an adjective used to describe a place that is «able to be reached or entered».
In the context of urban and transport planning, accessibility expresses the interactions between the activities located in a region and the transportation system serving it. There are many definitions of accessibility available in the scientific literature, and there is no universally used definition. According to Litman (2011), «accessibility refers to the ease of reaching goods, services, activities and destinations, which together are called opportunities». Le Clercq and Bertolini (2003) define accessibility as «the number and diversity of activity places that can be reached within an acceptable travel time...; what acceptable travelling time is depends on the purpose of the trip».
But, among the firsts and most quoted definitions of accessibility from the urban planning perspective there is probably the one of Hansen (1959), that refers to accessibility as «the potential of opportunities for interaction». In the '50s, the first efforts were made in the USA to study the interrelationship between transport and the spatial development of cities. Hansen, in his paper "How accessibility shapes land use" (Hansen, 1956), proposed the first mathematical formulations of accessibility and, hence, he was able to demonstrate for the city of Washington that locations with good accessibility had a higher possibility of being developed, and at a higher density, than remote locations (Wegener & Fürst, 1999).

But the concept of accessibility was really linked to transportation systems only since the end of the '70s (Nuzzolo & Coppola, 2013). According to a definition proposed by Dalvi (1978), accessibility denotes the ease with which any land-use activity can be reached from a location, using a particular transport system. Leonardi (1978) referred to accessibility as «the consumer surplus, or net benefit, that people achieve from using the transport and land-use system».

In 1996 the United States Department of Environment released its Planning Policy Guidance on Town Centres and Retail Developments, where accessibility was included as planning principle and defined as «the ease and convenience of access to spatially distributed opportunities with a choice of travel including the quality, quantity and type of car parking, the frequency and quality of public transport services, the range of customer origins served and the quality of provision for pedestrians and cyclists» (U.S. Department of Environment, 1996). From this perspective, it emerges clearly that the choice of the travel mode is an important attribute of accessibility: a destination is more optimally accessible if it can be reached by a wider range of transportation modes.

1.2 What does accessibility planning means?

The theory of accessibility within the framework of land-use and transport interactions was, subsequently, developed by Wegener & Fürst (1999). Their research is based on the recognition that trip and location decisions co-determine each other and thence, transport and land-use planning need to be coordinated. This is schematised in the so called "land-use transport feedback cycle" (figure 1), in which accessibility plays a crucial role.

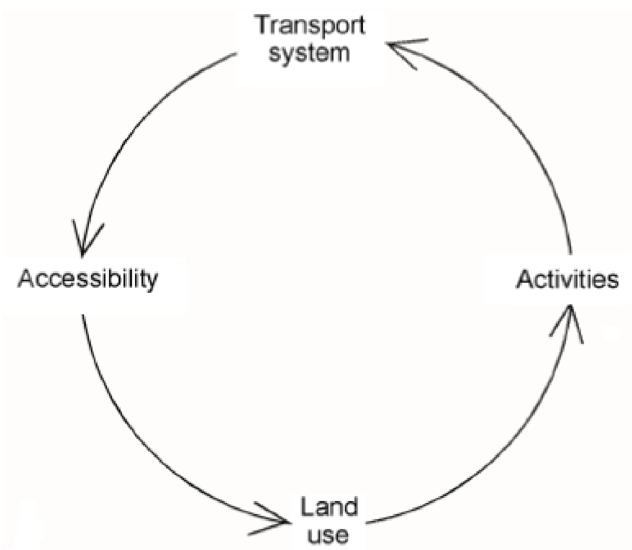

Figure 1 – The land-use transport feedback cycle as schematized by Wegener & Fürst. Source: Wegener & Fürst, 1999.

As it emerges from the cycle, the distribution of land uses (e.g. residential, industrial or commercial) over a given territory determines the locations of human activities such as living, working, shopping, education or leisure. But, the distribution of human activities in space requires spatial interactions in the transport system to overcome the distance between the locations of activities. Therefore, the distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as accessibility. Hence, the distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system (Wegener & Fürst, 1999).

More recently, Susan Handy (2002) suggested a radical shift from planning for mobility, to planning for accessibility. Handy defines mobility as the potential for movement, the ability to get from one place to another, and accessibility as the potential for interacting among different and distributed urban activities. In Handy's view, the final aim of accessibility planning is to increase the number of opportunities, within a fixed time, while mobility aims at increasing the number of kilometres travelled.

What people need is not a generic mobility but, rather, the opportunity to participate in spatially disjointed activities (Bertolini & Le Clercq, 2003). In other words, while mobility represents the "ease of movement", accessibility describes the "ease of reaching the desired activities". Mobility-enhancing strategies generally focus on improving the flow of traffic and improving the performance of the road system: e.g. the level of service is measured in terms of average speed and traffic intensity. Therefore, the construction of new roads and the expansion of existing roads represent the dominant transportation strategy.

Rather than to increase by any means the potential for movement, often without taking into account the externalities of mobility, accessibility enhancing strategies aim to increase access to needed and desired activities, by bringing activities closer to people, enhancing the alternative for reaching those activities, and expanding the choices among activities. Accessibility, encapsulates more than a measure of vehicle speed: the concept incorporates a focus on the proximity of origins to destinations, the concentration or spatiality of activities, the quality of mobility systems available to overcome spatial separation, and the perceptions, interests and preferences of people who live and work there (Hull et alii, 2012). According to accessibility principles, a destination is more optimally accessible if it can be reached with a wider range of means of transport. Transport planning and location of attraction points, like public services, should take into account the whole sequence of movements that constitute a journey, identifying appropriate solutions in close collaboration with urban planning.

For these reasons, it is not mobility, but accessibility that should be identified as the transportation system's inherent goal, and against which its negative external effects have to be balanced (Le Clercq & Bertolini, 2003). A focus on accessibility instead that on mobility stresses, once again, the fact that land use has major impacts on transportation issues.

1.3 How to measure accessibility

But, how can we actually measure accessibility?
Measuring accessibility is complex. Gould stated that «Accessibility...is a slippery notion...one of those common terms that everyone uses until faced with the problem of defining and measuring it» (Gould, 1969). Therefore, Geurs & van Eck (2001) argue that the definition of the concept of accessibility depends on the objective for which it is intended.
Accessibility analysis may be performed both ex-ante and ex-post. Ex-ante analysis aim at evaluating which is the optimal location of an attraction point or of a new urban development in relation to a given transportation network, and how the accessibility may change according to changes in the transportation offer (in this case the accessibility analysis may be seen as a decision support system). On the other hand, ex-post assessments are used to evaluate if the current transportation system provides enough access to a given territory. Accessibility analysis should consider different means of transport, with particular regard to non motorised mobility (walking and cycling) and collective transport.
In the context of this paper, accessibility will be assessed mainly using maps developed in a Geographical Information System (GIS) environment.
Isochrones represent the simplest accessibility measure and aim at identifying the area that is within a certain distance or time of a given origin or destination. An isochron is a line on a map connecting points having equal travel times, distances or costs. To realise precise isochrones the mobility infrastructure (e.g. road network, public transport lines...) is needed, in terms of road network, public transport routes, stops and stations, and walking and cycling paths depending on the transportation mode for which the isochrones map is built (Brainard et al., 1997; Calderon et al., 2014)). Otherwise, it is possible to use a "buffer" tool to realise simple or multiple-ring circle isochrones implemented using an average speed or distance for the chosen transportation mode. However, the outcomes of a buffer analysis demand an attentive consideration, because buffers are not capable to consider barriers like rivers, railways...
Isochrones are particularly suited for representing catchment areas: e.g. public transport catchment areas, as the portion of a given territory served by public transport facilities, or catchment areas of any important public service, like schools, hospitals, public gardens.... In this second case it is important to distinguish between "local" services, which should be reachable on foot, and other services. Isochrones can also be used to compare catchment areas based on different transportation modes.
A development of isochrones draws on the so called contour measures. Contour measures define catchment areas by drawing one or more travel time contours (i.e. isochrones) around a node and, then, adding up the number of opportunities (jobs, facilities,...) within each contour (Curtis & Scheurer, 2010; Geurs & van Eck, 2001; Papa & Angiello, 2012). Contour measures appraise the amount of opportunities reachable in a given time, distance or cost. The location of the opportunities is needed.
Finally, potential measures are very similar to contour measures although accessibility levels are considered to decay with distance of opportunities from origin. Thus, potential measures reflect the distance deterrence of accessibility (Papa & Angiello, 2012; Silva, 2013).
In the literature there are many other examples of increasingly more complex accessibility measures, that include competition measures, utility measures, network measures... (see, i.a., Curtis & Scheurer, 2010). And, in the last decades many and complex accessibility instruments and mathematical models have been built: a collection and description of some of them is presented in Hull, Silva & Bertolini, 2012.

2. Accessibility and pedestrian mobility in the Organic Urban Planning vision

2.1 The Organic Urban Planning vision

At the end of the '50s Vincenzo Columbo, Professor of Urban Engineering at the Polytechnic University of Milan, elaborated a vision of the urban structure that he labelled as "Organic". Within his vision, Columbo defined urban elementary units: neighbourhoods (*unità di vicinato*), districts (*unità di quartiere*) and communities (*comunità*) (Columbo, 1966).
The units were defined in relation to the daily movements of their inhabitants. For example, according to the organic urban planning vision, the neighbourhood is the place of proximity, where the elementary functions of daily life are located (basic shops, kindergartens...), while in the district the social life takes place and life centres (civil, religious and commercial functions) are located. Columbo's research aimed at giving a structure to living spaces by relating them to daily activities of his contemporary society. The organic urban planning vision is based on the analysis of technical implications arising from the satisfaction of individual and social human needs. Starting from the features of the technical layout of a

city (house, social services, shops, markets, schools, hospitals, urban parks and open spaces, streets, technological networks,..), the model has the objective to satisfy the specific needs of the citizen as an individual or as a community member, through the best use of those facilities (Busi, 2005). In this model the concept of neighbourhood is very important, and it is based on the criterion that the system of mobility for excellence, for moving into the neighbourhood, is walking. Columbo also systematised the "life centre" concept. With reference to their function, life centres can be civil, religious or commercial. As reminded also by Busi (2009), life centres tend to align themselves along an axis, which is called the axis of life. The axis of life, that is essentially characterised by pedestrian movement, refers to an urban linearity structured to make the best use of services and aimed at socialising (Busi, 2009).

and at the same time an effective area of influence for the project of a bus line.» (Tira, 2011).
And nowadays probably it is more than ever necessary to focus the attention on the individuals and to reaffirm a people-centred planning vision (see, i.a., Tiboni and Rossetti, 2012). Therefore, starting from Vincenzo Columbo's assumptions, since the '90s Roberto Busi has developed the «Friendly city» concept, and he founded at the University of Brescia a research centre for Friendly Cities called CeSCAm (Centro Studi Città Amica). Among the CeSCAm activities there are researches on the quality of life and on urban safety issues.

2.2 Accessibility in the Friendly City

As explained earlier in the paper, accessibility focuses transport planning on the connection of people and activities in-

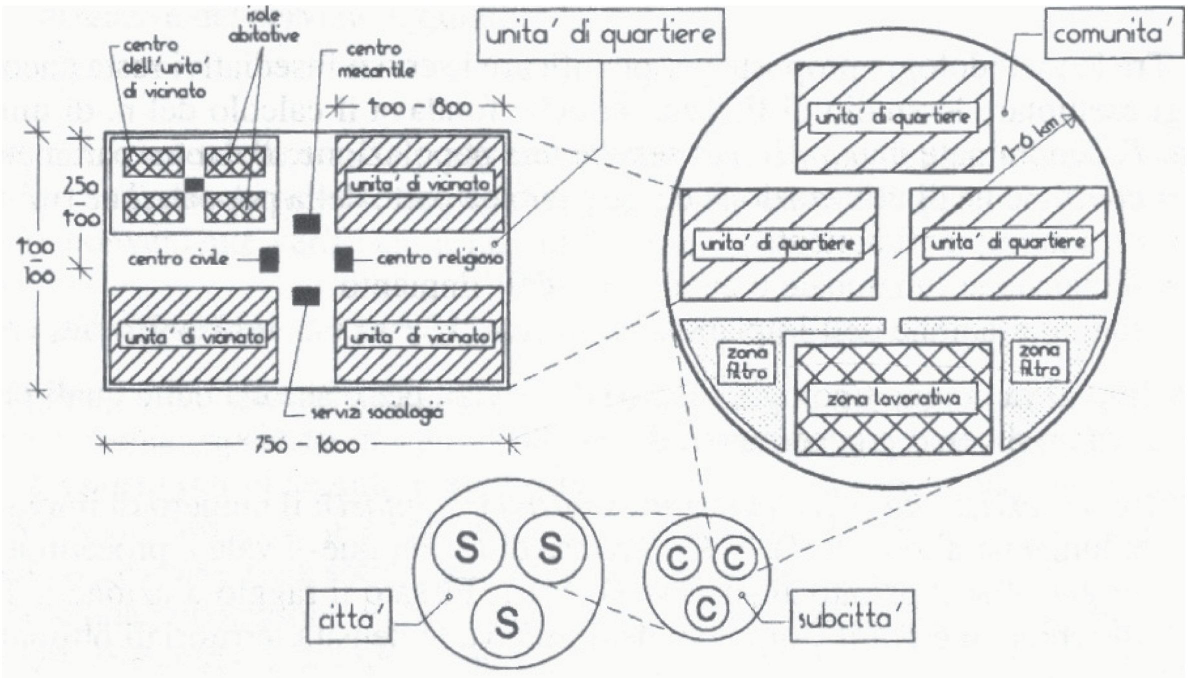

Figure 2 – The Organic Urban Planning vision. Urban structure scheme, articulated in neighborhoods (*unità di vicinato*), districts (*unità di quartiere*) and communities (*comunità*). Source: Columbo, 1966.

The "organic urban planning" vision was subsequently developed at the University of Brescia, in research works coordinated by Roberto Busi. Since the beginning of the '90s, Busi and his team have developed the theme of the Friendly City starting from Columbo's assumptions.
Tira (2011) argues that Columbo's "organic" vision is still alive and may be used to provide a solution to the problem of integrating urban planning and mobility. For example, as Tira states «the optimal distance of housing to public services is approximatly the same as the best bus stop range. The neighbourhood may therefore be an elementary urban unit

stead of on the transport system and enables the integration of land use and transport planning. Therefore, accessibility planning represents a shift of focus from the means, e.g. infrastructures and their performance, to the ends: the fulfilment of people's expectations (Silva, 2013). Accessibility involves a person-centred planning view: thinking in terms of accessibility represents a way of thinking in terms of people and individuals rather than on traffic. Furthermore, a focus on urban accessibility gives a further contribution towards a problem solving approach to urban form and mobility in contemporary towns.

For all these reasons, accessibility is a key concept within the People Friendly city vision (Tiboni and Rossetti, 2014). And Busi (2013) argues that researchers and urban planners should have in mind that the final aim of mobility is reaching the final destination, possibly in an easy and pleasant way.
People's daily lives are made up of a growing diversity of activities and locations, and mobility holds all of this together. People live in one place, work in a second, and shop, care for another person or seek entertainment in another (Bertolini, 2012). But, in Busi's opinion «the city and the land are too often designed in such a way as to prevent them being used easily and calmly by the most vulnerable citizens. The city is therefore seen by them to be inaccessible and even hostile» (Busi, 2009).
According to Tira (1999), accessibility means that the use of a space is guaranteed for everybody. Therefore, land uses, public spaces, facilities and residential areas should be planned and designed considering the possibility to be reached, and considering the different modes of transport.
This is why, in the friendly city, accessibility is strongly related to multi modality and to the concept of the "chain model" of movements: according to this model, door to door mobility (e.g. from house to workplace or to desired activity) goes through a combination of different modes, with the pedestrian movement always in odd number position (Busi, 2013; Busi, 2011). The final aim of the chain is to guarantee access to the final destination; therefore each ring in the chain should work properly, starting from pedestrian movements.

3. Developing an algorithm to assess pedestrian travel times

The crucial role of GIS-based analysis to assess and manage accessibility issues in nowadays established, at least within the scientific community. Arguably, the dependence on GIS techniques for accessibility analysis has significantly risen in the last decade (see, i.a., Delamater et al., 2012; Hull, Silva and Bertolini, 2012; Bonotti *et al.*, 2015;). GIS programs are well-known in the scientific literature for their capability to analyse, model and visualise geographical data. Furtherore, a GIS map can incorporate many and various layers of information that are associated to a geographical database, and that can be displayed in innovative ways (Wu & Hine, 2003).
But how is it possible to measure the level of pedestrian accessibility of a given territory and to map the results in a GIS environment? This section describes a methodology to assess pedestrian travel times starting from a land use georeferenced database.
First of all, there is a need to collect the different layers of information related to pedestrian mobility for the area, with particular reference to the road network, the location of pedestrian paths and sidewalks as well as the presence of physical barriers in the area that impede pedestrian permeability (built environments, railways, waterways surfaces…).
Then, the proposed assessment methodology bases on the detailed discretization of the area being analyzed in a uniform grid of cells. In this grid a calculation algorithm is applied. This algorithm, on the basis of the information layers that overlap in each cell, assigns each cell a pedestrian travel time and evaluates the existing connections between the cell in question, and the cells adjacent to it. This model allows the creation of thematic maps that show the timing of pedestrian access to each cell. But how does the model work?
The model is based on a uniform grid of squared cells, interconnected according to the following scheme: from the X cell it is possible to move to cells 1, 2, 3 and 4. The crossing time is an attribute of each cell, and can be modified as needed.

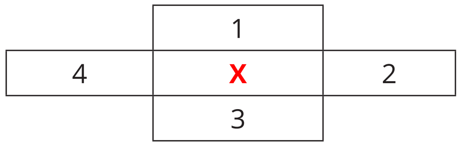

Figure 3 – A scheme of the grid that compose the proposed model.

The mathematical algorithm determines the time needed to reach each cell of the matrix, starting from an assigned cell, and determining the path with the shortest travel time. The algorithm is used to search for access time to the destination cell, and bases on a group of recursive algorithms known as 'Backtracking algorithms' (Wirth, 1976), widely applied within the Information Sciences to solve optimization problems. The method applies a kind of floodfill starting from the destination cell and following a backwards path, and tracing the total time as a strategy to exit the recursive procedure.
The elementary recursive procedure is reported in the following script. The series of four recursive controls indicates the order of possible links for each cell (figure 2). However the links can be applied also using other processes, e.g. by implementing a base matrix for the links made by 9 cells, and using a penalized time of √2 along the diagonals.

```
procedure TryNext(i,j:integer;TotalTime:real);
begin
  if Matrix[i,j].time> TotalTime then
    begin
      Matrix[i,j].tempo:= TotalTime;
      if i>1  then TryNext(i-1,j,TotalTime+Matrix[i,j].CrossingTime);
      if j<ny then TryNext(i,j+1,TotalTime+Matrix[i,j].CrossingTime);
      if i<nx then TryNext(i+1,j,TotalTime+Matrix[i,j].CrossingTime);
      if j>1  then TryNext(i,j-1,TotalTime+Matrix[i,j].CrossingTime);
    end;
end;
```

Furthermore, the algorithm can be generalized by the creation of 'virtual links' among two different cells outside the base matrix, even far from each other. Those virtual links can be applied to model public transport links between two cells, as shown in figure 4.

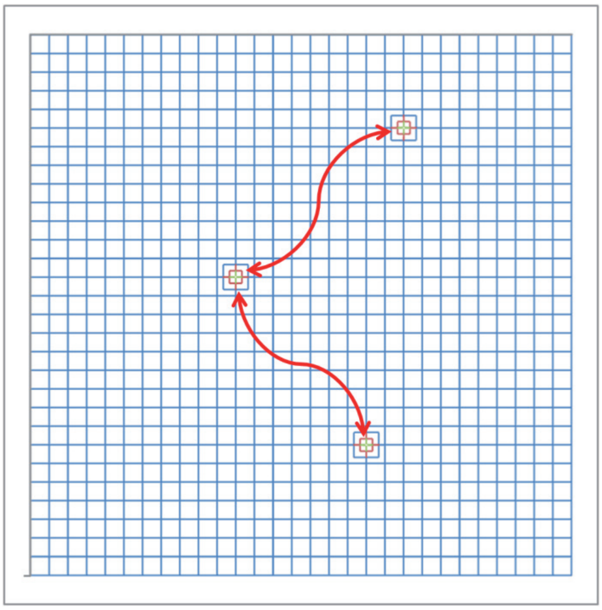

Figure 4 – How 'virtual links' among cells work.

Grid dimensions can be theoretically unlimited, but maximum dimensions of 2000x2000 cells are recommended. In this latter case, computation times are approximately 15 minutes.
The firsts simulations of the model were run on a 20x20 grid, and led to the results shown in the following figures (figures 5, 6, 7), in which the red dot indicates the starting point of the computation and the numbers express the travel time to reach the dot in minutes.

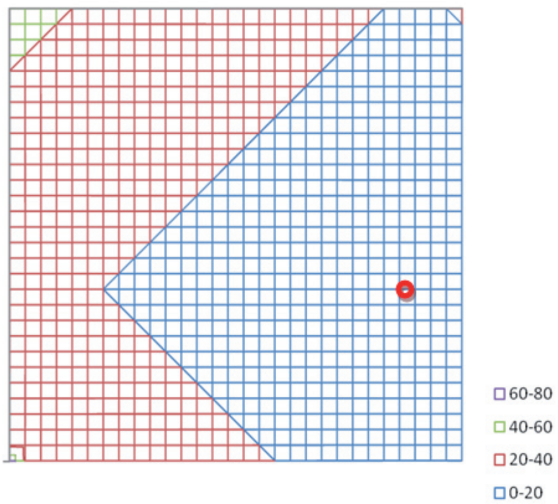

Figure 5 – First simulation. Uniform matrix (with no obstacles).

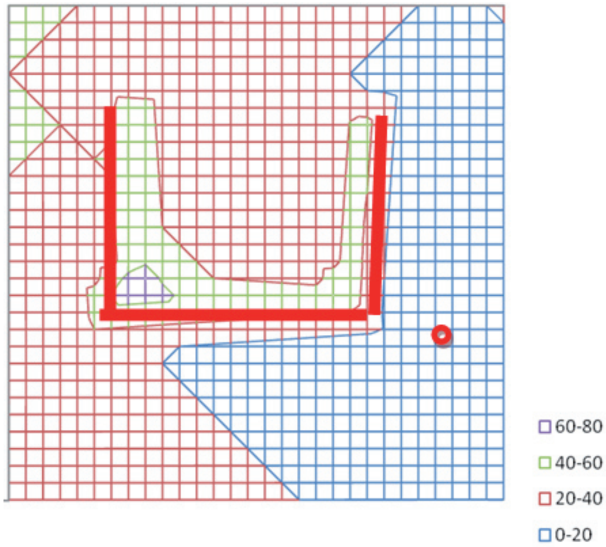

Figure 6 – Second simulation. The matrix has a U-shaped obstacle (e.g. a building), without permeability at all.

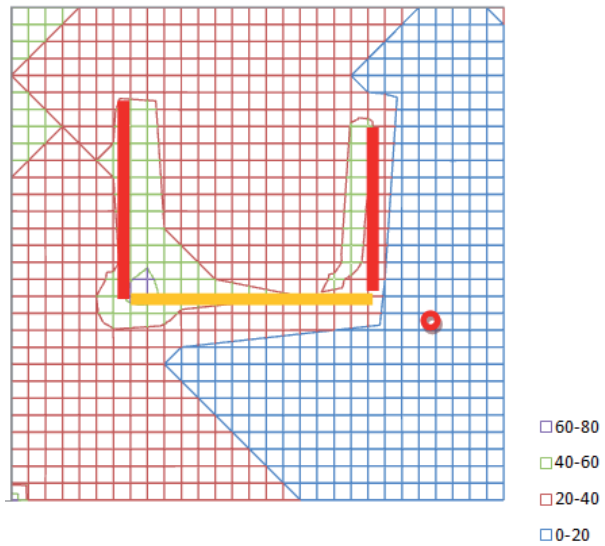

Figure 7 – Third simulation. The matrix has a U-shaped obstacle (e.g. a building), with a reduced permeability.

4. A pilot application of the methodology: the case study of San Polo district in Brescia

To test the proposed methodology, a first application on a real case study was performed. The chosen pilot area is the neighborhood of San Polo, in the outskirts of Brescia, a middle-sized city in the North of Italy. San Polo is a district that was built in the '80s on a design by the architect Leonardo Benevolo. The whole district today counts approximately 20,000 inhabitants, and is composed by medium to high-density buildings, mainly subsidized housing.
First of all, georeferenced data for the district were collected.

Those mainly include the boundaries of the neighborhood as defined by the municipality, the topographical database and a land use shapefile (figure 8).

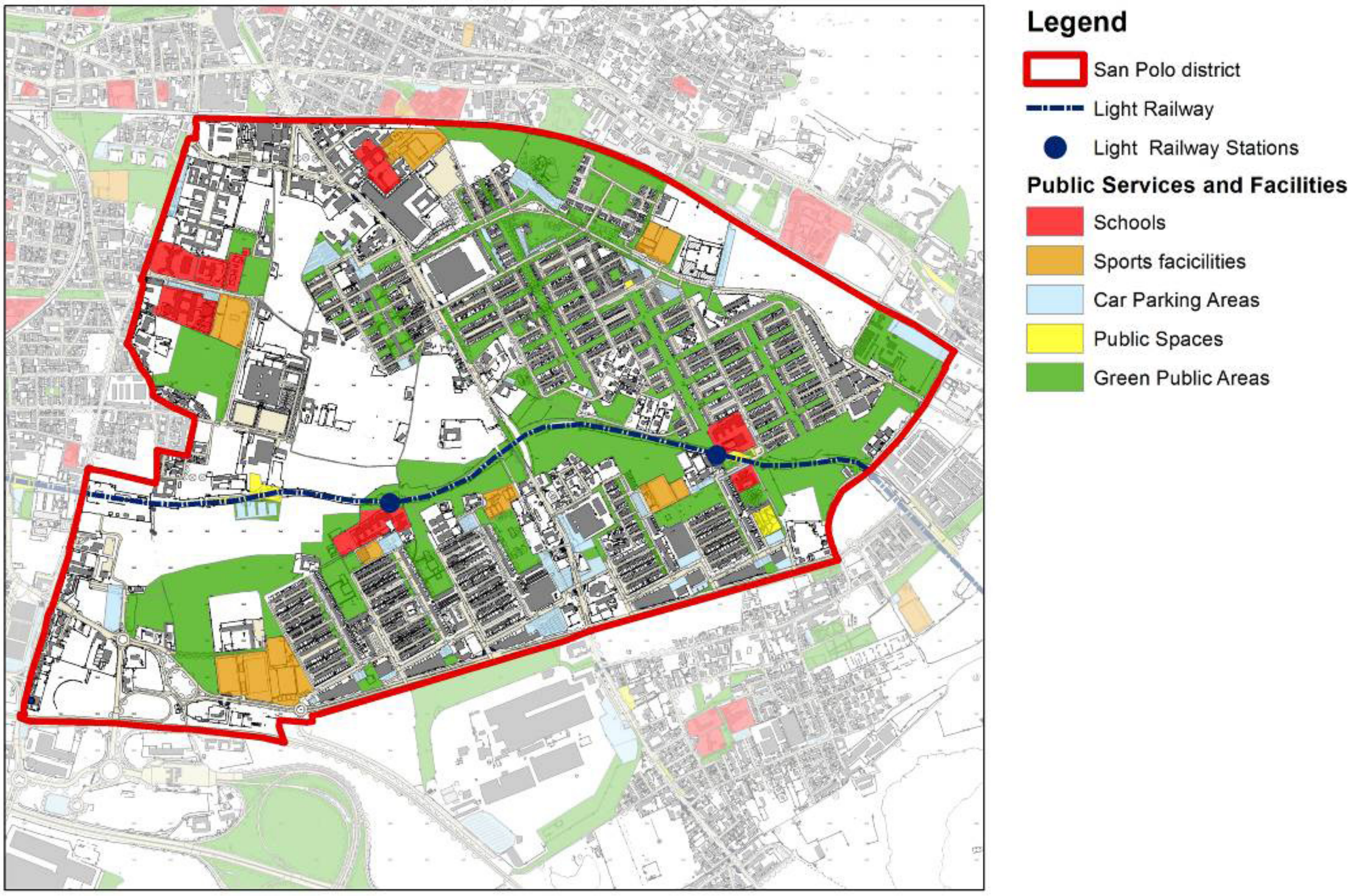

Figure 8 – A map of San Polo district containing the topographical database and the land uses.

Then, a discretization of the territory was built through a uniform matrix of cell. The grid for San Polo was created using the ET-Geowizard tool, a free extension of the ArcGIS software. The Vector grid tool of the ET-Geowizard automatically creates a polyline or polygon vector grid using user defined extents and cell size. In this case, a polygonal shapefile was created, using the boundaries of San Polo district as extents and a cell size of 10x10 m. The result consists in a rectangular grid of 74,259 cells, covering an area of 742.59 hectares of land. In the attribute table of the vector grid, the ET-Geowizard tool creates two types of Identifiers for each record: a field named 'ET_ID' containing the identification number of each cell, and a field named 'ET_Index' that contains the field and the record of the cell in the matrix. This is a crucial field, because it makes possible the link between the shapefile and the computation algorithm.

To each cell of the grid a crossing time was assigned according to the following table (table 1), that consider the possible land uses of each cell. Crossing speeds were chosen considering an average walking speed of 3 km/h (the speed that a child usually walks). A slower speed was chosen for parks and green areas due to curvier paths. However, those speeds can be changed and chosen in cooperation with decision makers.

With reference to table 1, a field was added to the attribute table of the matrix and filled in with the crossing time assigned to each cell. Then, the table was exported in ASCII format to run the algorithm.

For this case study, two destination points were chosen: the two light metro stations that are located in San Polo (*San Polo* and *San Polo Parco* stations). The two cells in the grid that are located on the stations were detected and chosen as starting points to run the algorithm. The results of the algorithm, e.g. the attribute table of the grid with a new field containing travel times from every cell to the destination point, were then reconverted to a shapefile, by joining the resulting table in ASCII format with the vector grid using as common field the ET_index.

The algorithm was run twice: the first time using as starting point *San Polo Parco* light metro station, and the second time using *San Polo* metro station. The results are shown in the following figures (figure 10 and figure 11), where travel times are expressed in minutes.

Table 1 – Pedestrian crossing speed and times assigned to each cell of the district with reference to the land use of the cell.

Land use	Crossing speed	Crossing time
Roads	3 km/h	Cell size/crossing speed
Public spaces	3 km/h	Cell size/crossing speed
Parks and Green areas	2 km/h	Cell size/crossing speed
Obstacles (buildings, railways, water surfaces, …)	0 km/h	Very long (endless)

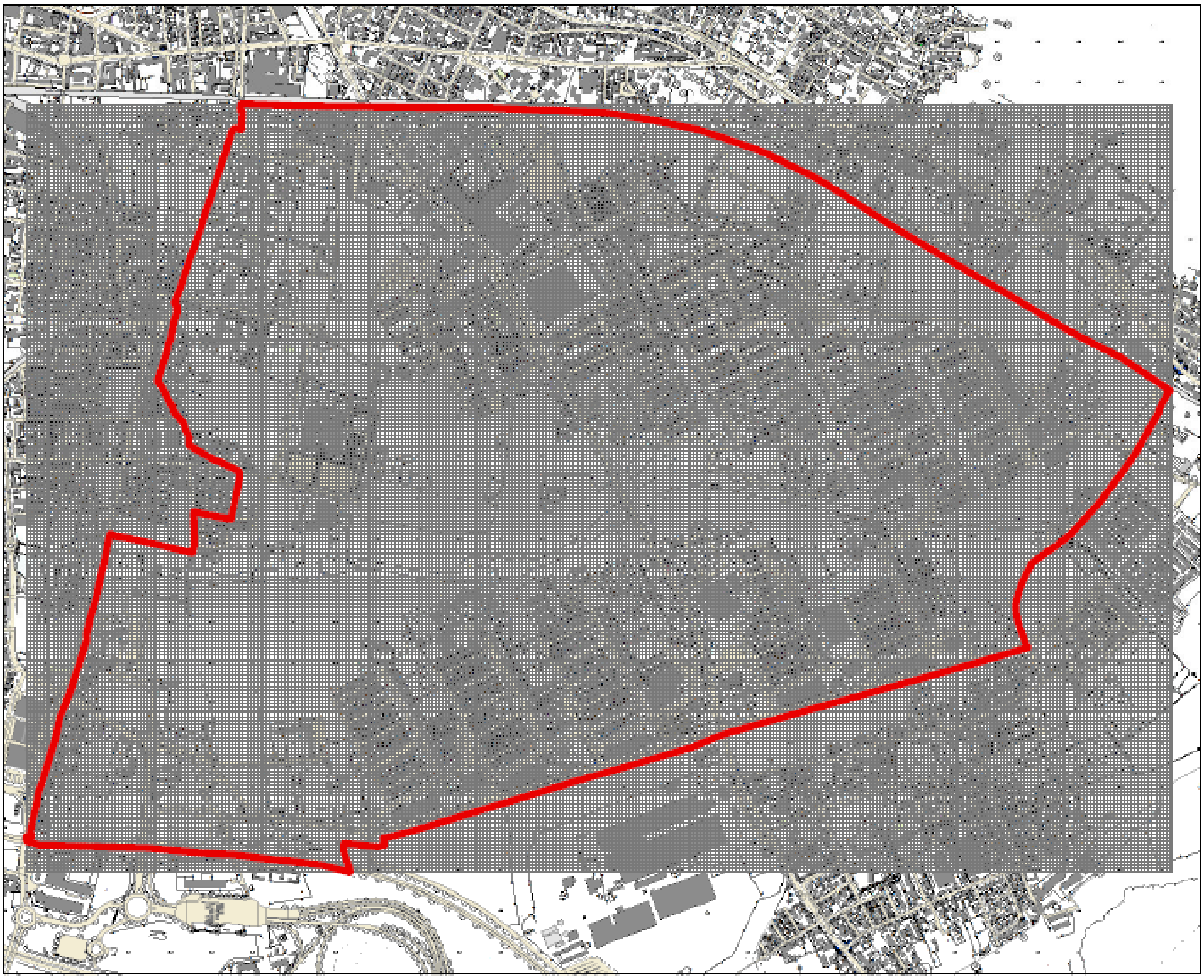

Figure 9 – The vector grid created for San Polo.

Finally, for each cell of the grid, the minimum between the two travel times to reach the stations was calculated, and the results are shown in figure 12. Therefore, figure 12 highlights travel times from each point of San Polo district to the closest light metro station.

5. Further developments and final remarks

The paper presented a tool to assess the pedestrian travel times to public services and facilities. Those times, according to the Organic Urban Planning vision, plays a crucial role at the scale of the neighbourhood, where pedestrian mobility should be encouraged and access to services and facilities should take place preferably by foot.

At the moment, an improvement of the tool is under development, with the aim to consider the public transport use as complementary to pedestrian movement. Therefore, the computation algorithm can include space-temporal tunnels at public transport nodes (metro stations, bus stops...). Those tunnels work as virtual links among cells that are far from each other, and are characterized by a travel time equal to

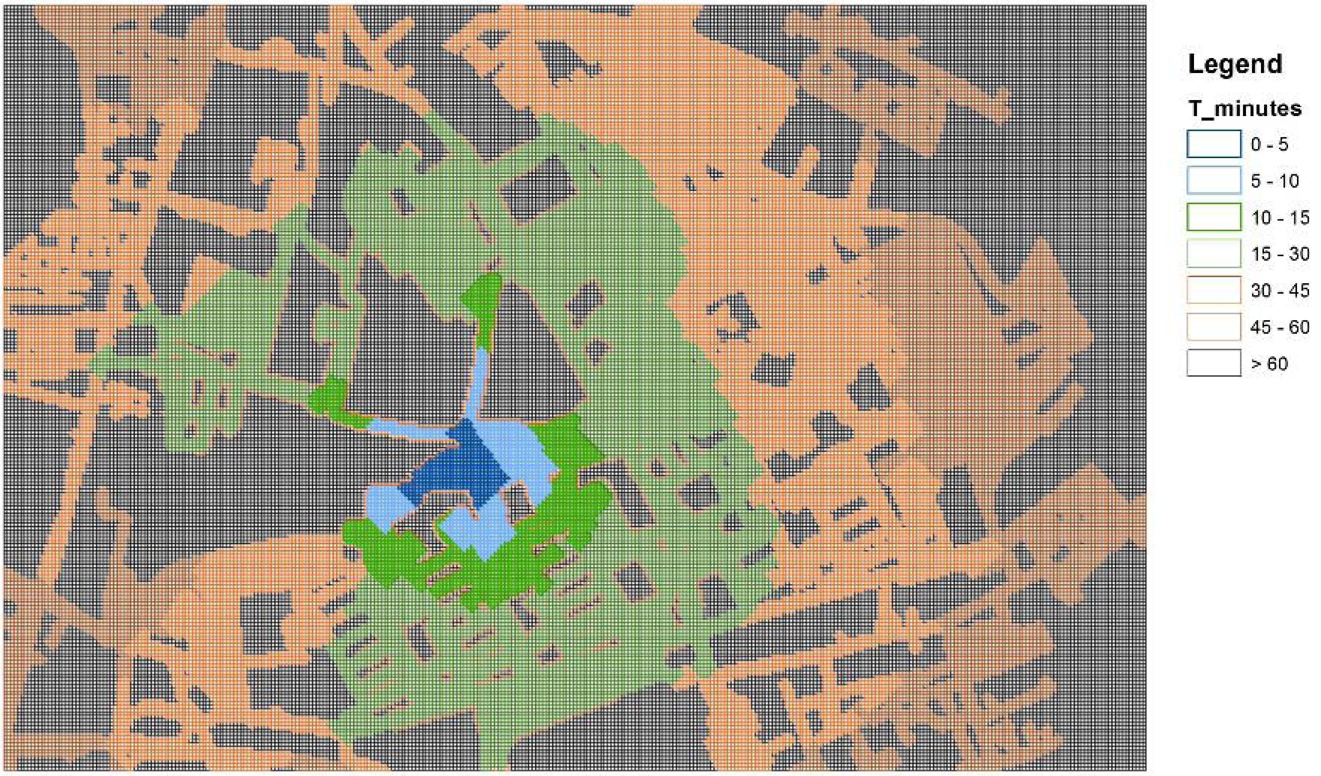

Figure 10 – Pedestrian travel times [minutes] to reach San Polo Parco light metro station.

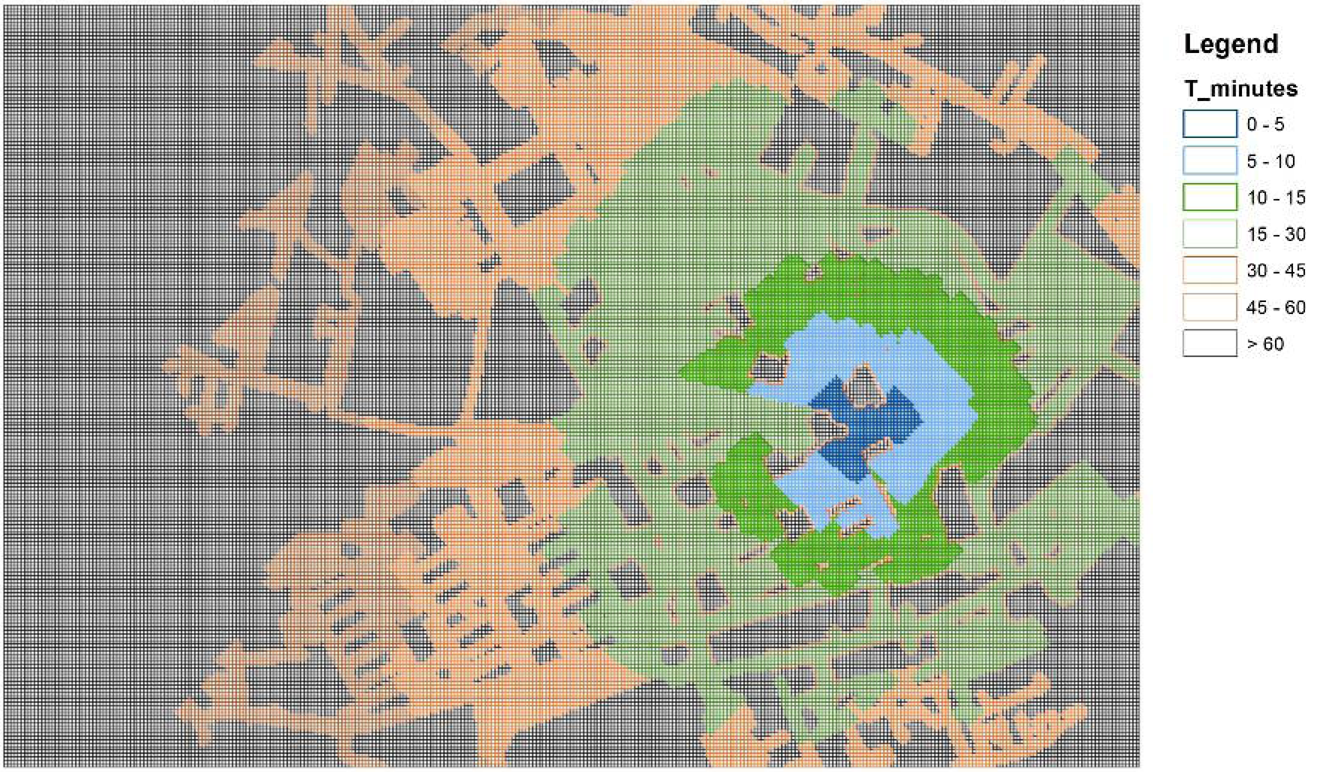

Figure 11 – Pedestrian travel times [minutes] to reach San Polo light metro station.

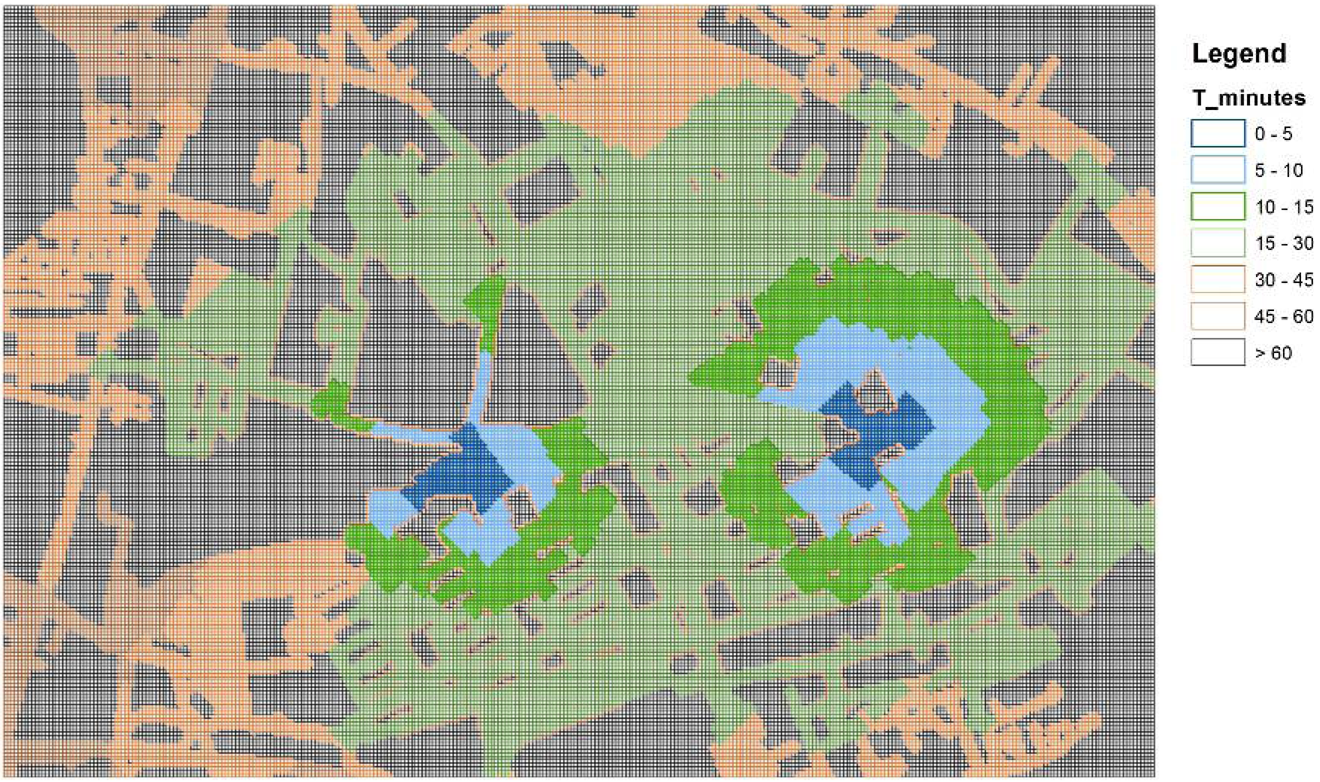

Figure 12 – Minimum pedestrian travel times [minutes] to reach one of the two light metro stations.

public transport travel times, including average waiting times at the public transport stops. The methodology can be used to study ex-ante the accessibility improvements that the introduction of new public transport lines, or their modification, can have on the territory.

Furthermore, a further development of the tool can also take into account the spatial distribution of the population. If the population is georeferenced, the attribute 'population density' or 'number of residents' could be assigned to each cell, and could be used as a weight in the computation process.

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