Hybrid Oriented Sustainable Urban Development: A Pattern of Low-Carbon Access to Schools in the City of Potenza

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Abstract. This study analyzes urban street network of the city of Potenza in Basilicata region to provide input for a sustainable urban mobility-based strategy enabling students to reach schools through the use of low-carbon transport modes' share. The analyses have been carried out by using Place Syntax Analysis in order to identify a network of paths which guarantees pedestrian and bicycle access to schools located in the urban area of Potenza. Within urban space morphology research, combining Space Syntax and GIS-methods, Place Syntax allows to perform analyses of the spatial configuration of streets taking into account both street network layout and the location of spatial opportunities. Urban form (in our analysis, in terms of configurational characteristics) and accessibility to destinations (schools in this study) are essential to increase the share of walking and bicycling as the preferred modes of people's daily travel. The paper shows the potential integration between active transport modes and public transport in the city of Potenza. Ensuring an easy transition between walking, cycling and public transport (e.g. by designing a widespread and direct network of cycle-pedestrian paths to and from the stations) contributes to create a "Hybrid Oriented Sustainable Urban Development" towards low-carbon settlements characterized by a significant reduction in congestion, air pollution and carbon emissions.

Keywords: Urban space morphology · Place syntax analysis · Sustainable urban development · Sustainable urban mobility · Liveable city

1 Introduction

A Sustainable Urban Transport System (SUTS) has three components whose interaction is necessary to ensure sustainable urban development processes: public transport, walking and cycling [1]. A SUTS contributes to create people- and environmental-friendly cities and communities reducing traffic congestion, air pollution and greenhouse gas (GHG) emissions. The United Nations Sustainable Development Goals (SDGs) of the 2030 Agenda recognise that it is possible to improve the cities' quality of life and strengthen their economy by making these mobility modes attractive and

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competitive [2]. In the next decade, the SDG target 11.2 foresees the need to: "*provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety*" [2]. Moreover, the New Urban Agenda (NUA) undertakes to promote the realization of: "*safe, sufficient and adequate pedestrian and cycling infrastructure and technology-based innovations in transport and transit systems*" which contributes "*to reduce congestion and pollution while improving efficiency, connectivity, accessibility, health and quality of life*" [3]. Public transport, walking and cycling contribute to achieving liveability, sustainability [4, 5] and health goals in the current difficult context: the urban population will continue to grow [6] and tackling climate change is a relevant concern in the coming years [7].

Within low-carbon city development strategies [8], many cities promote soft transportation modes such as walking and bicycling both as an alternative to the exclusive use of motorized vehicles and as an opportunity for urban space regeneration. Facilitating sustainable urban mobility frees up space in order to create green and public spaces for people. In fact, with an increasing proportion of people living and working in cities, there will be increasing competition for a limited amount of public space [9].

Facilitating sustainable urban mobility also relies on the provision of efficient public transport services. Active and clean mobility modes are well suited for short-distance trips within cities. They can be fostered in association with public transport thus increasing their reach and use on longer journeys according to an intermodal approach. So, it is possible to introduce the concept of "chain mobility". To make active mobility modes competitive transport options, urban development should be based on the location of public transport nodes, so that people can walk and/or cycle to the station [10–12]. Planning for the bicycle further increases the catchment area of the stations.

Better and coordinated transport and urban planning leads to a SUTS where the promotion of bicycling and walking in association with public transport extends the "Transit Oriented Development" (TOD) [13] into a "Hybrid Oriented Sustainable Urban Development" (HOSUD). The latter ensures widespread and sustainable accessibility, guaranteeing adequate levels of usability of urban opportunities to the greatest number of people regardless of origin, income, age and physical ability. As established by the NUA, a sustainable urban mobility-based model should be implemented [3].

Our study focuses on configurational analysis of the street network of the urban area of city of Potenza by using Place Syntax Analysis (PSA), a field of space-morphology research [14]. The city of Potenza is the county seat of the Basilicata region, located in southern Italy with more than 65,000 inhabitants. Several studies show that the city is characterized by urban fragmentation phenomena [9, 15–19].

In particular, this paper shows how it is possible to introduce an urban mobility scheme based on modal integration between the three components of SUTS at the service of schools and students in the Potenza's urban area.

2 Methodology

This study applies Place Syntax theory, its techniques and measures in order to perform a space-morphological analysis. In particular, we use PSA for analyzing syntactic properties of the street network (revealing its structure and hierarchy) of the city of

Potenza as the case study, while taking into account the location of schools as "attraction objects". The street network is the primary spatial structure able to determine the spatial distribution of people's movement potentials and land use. Within urban morphology research, PSA is a quantitative and configurational method which allows to analyze spatial relationships existing between the elements of the built form and to simulate the potential effects both on the single spatial unit (such as street segment) and on the whole system. PSA enriches spatial configuration analysis based on Space Syntax Analysis (SSA) taking into account the location of urban attractions/spatial opportunities within attraction-based network analyses. The use of PSA is motivated by the fact that accessibility connects the two main components of the urban structure: the space-functional component (urban activities, land use) and the space-morphological component (transport network, transportation).

2.1 Place Syntax Analysis (PSA)

Within space morphology research, PSA is a theory which takes into account 'distance' and 'attraction' in urban space modelling [20], including theoretical principles of SSA [21]. "*Space syntax … is a set of techniques for the representation, quantification, and interpretation of spatial configuration in buildings and settlements*" [22]. The built environment and the mutual relationship between spatial units are analyzed according to a quantitative and configurational method, representing the use of space from a cognitive point of view [23–26].

Unlike the concept of "space" [27], "*'place' simply means a geographically specific space, a location, or a space with a specific content*" [28]. Based on loading "*geographical data for improved predictions of pedestrian movement within space syntax*", PSA is "*an improved tool for accessibility analysis in general*" [28]. In urban modeling, this allows to enrich the knowledge deriving from the syntactic analysis based on how one space is topologically and geometrically connected to all the other spaces of the system. In particular, PSA provides a relevant theoretical and methodological contribution in analysing, understanding and interpreting the relationship between urban space-morphology and the distribution of people's movement in cities [29–32]. In addition, unlike the SSA which only allows the analysis of spatial accessibility of urban spaces, location/attraction-based "*Place syntax analysis can […] be said to deal with specific spatial accessibility, such as accessibility to different attractions*" [33].

Attraction Betweenness of a node *i*, $AB(i)^r$ represents the potential "through-movement" of each street network's space unit (node). Using graph theory [34], network Betweenness calculates how often a space unit (street segment) falls on the shortest path between all pairs of spatial units in a system [35]. It is a street network's centrality measure highlighting how important a segment is as a through-road for the network. The AB value depends on location and attributes of the attractions ('spatial opportunities').

$AB(i)^r$ is calculated as follows:

$$AB(i)^r = \sum_{j,k \in G-\{i\}; d[j;k] \leq r} \frac{n_{jk}[i]}{n_{jk}} \cdot W[j] \quad (1)$$

where $n_{jk}[i]$ is the subset of paths which pass through i, with nodes j and k falling within the network radius r (threshold distance) from the node i, n_{jk} is the number of shortest paths from j to k in graph G, $W[j]$ is the weight/attribute characterizing the destination-node j.

Therefore, combining SSA and Geographical Information Systems-GIS (providing spatial analyses and the visualisation of results), the outputs of the AB network centrality analysis depend on the attractiveness of urban destinations (based on their attributes), the number and location of attractions and street network layout (spatial input data). Street segments, with high scores based on attraction points' weights, that control and mediate movement and connections between many other segments have a high AB value.

2.2 Modelling the Place Syntax-Based Street Network's Graph

In our study, we have measured AB value for each of street segments within the urban area of Potenza taking into account the location of schools, i.e. spatial opportunities-attraction objects of the location-based analysis. This quantitative measure makes it possible to identify and classify street segments according to their AB values and to define paths that enable schools to be reached in a sustainable way (walking and bicycling) in Potenza's urban area. Network accessibility to schools is a relevant infrastructure planning parameter for achieving a high rate of sustainable active urban travel modes, such as cycling and walking [36]. To promote them, the AB measure captures the potential distribution of people's movement patterns [37], providing information to be used in the design phase. To perform AB analysis, we have used QGIS-PST tool and chosen different options for "distance mode" and "radius". In particular, we have chosen "angular distance" in the "distance mode" options and set the "radius" based on network "walking distance". Angular distance (measured in degrees) takes into account accumulated angular turns needed to get from origin-point to destination-point in the network. The angular distance of all possible paths between origin-point and destination-point are calculated and the one with the least angular distance is selected as the shortest path [26]. So, paths' angular minimization is a morphological-geometric feature which makes walking and cycling more attractive. "Walking distance" is the metric network distance of the shortest 'walking' path that connects two points through the network. To compute urban street network's syntactic measures and capture "walkable" and "cyclable" centralities, we have set two threshold distances for the analysis: 1,500 m and 3,000 m. These values are compatible with walking and cycling respectively [38]. In our study, we have mapped schools (primary schools, elementary schools, middle schools, high schools) which are in the Potenza's urban area [39, 40]. They are "attraction points", i.e. relevant generators/destinations of systematic daily trips involving a large number of street users. To georeference schools,

we used data downloaded from the website of the Italian Ministry of Education[1]. The schools have been weighed up taking into account the number of students.

To capture urban space's configurational properties (focusing on mutual position of the network elements), we have created street network's segment map from the street-centerline map, as GIS vector layer representing the street network. Segment map can be used as spatial network input for the PSA-based analyses revealing urban space's performance. To create a detailed segment map, the GIS-representation of the street network of Potenza has been enriched by using high resolution orthophotos and site-specific surveys. A correct and thorough urban space modelling has a significant impact on the results obtained from the syntactic analysis. Using PST tool, we have considered three geometric features: street-segments, unlinks and attractions. Unlinks represents the intersection points between street segments which should be ignored during the analyses, i.e. bridges, tunnels. With reference to graph theory, PST creates a network graph representation from the segment lines for analysis, where every street segment (the main spatial unit of analysis) is a node and every crossing point provides an edge.

Then, we have post-processed the results by classifying them into classes and producing attraction-based configuration maps (differentiating the network street segments) in order to highlight the spatial distribution of street network's syntactic properties within the urban area of Potenza.

3 Results

In the urban area of the city of Potenza, there are 47 schools with a total number of students equal to 13,232. Specifically, the highest number of students in a school is 1,067 (an high school) while the lowest value is 17 students (a primary school). 80% of schools have less than 435 students while about 4% of them have a student population of more than 800. Most of the schools are located North-West of the Historic Centre (a, Fig. 1) of Potenza, in an area including three districts: "Poggio Tre Galli" (b, Fig. 1), "G Area" and "Study-Centre". They were built between the 1970s and 1980s, have a population of over 6,000 inhabitants (according to Italian National Institute of Statistics (ISTAT) demographic data of 2011) and are characterized by the presence of public services of territorial interest such as the offices of the Basilicata Region. In this area, an experimentation of a bottom–up approach-based participatory process aimed at defining a neighbourhood scale-based regeneration project focused on the promotion of active transport modes have been developed [41–46].

In this area, there is a large part of the city's high schools which also have the highest number of students. The "Verderuolo" district (c, Fig. 1), located North of the Historic Centre, is characterized by the presence of a good number of schools and students. It is served by two railway stations located along the RFI national railway network and the FAL railway network (connecting the Basilicata region and the Puglia region). It is therefore an important interchange railway node in the urban area of

[1] Cercalatuascuola.istruzione.it. Available online: http://cercalatuascuola.istruzione.it/cercalatuascuola/ (accessed on 19 April 2020).

Potenza. Moreover, the "Macchia Romana" district (d, Fig. 1), more recently built and mainly residential (in the North-East), the South-East area including the district of "Bucaletto" (e, Fig. 1) and the South-West area are the most lacking in schools and students.

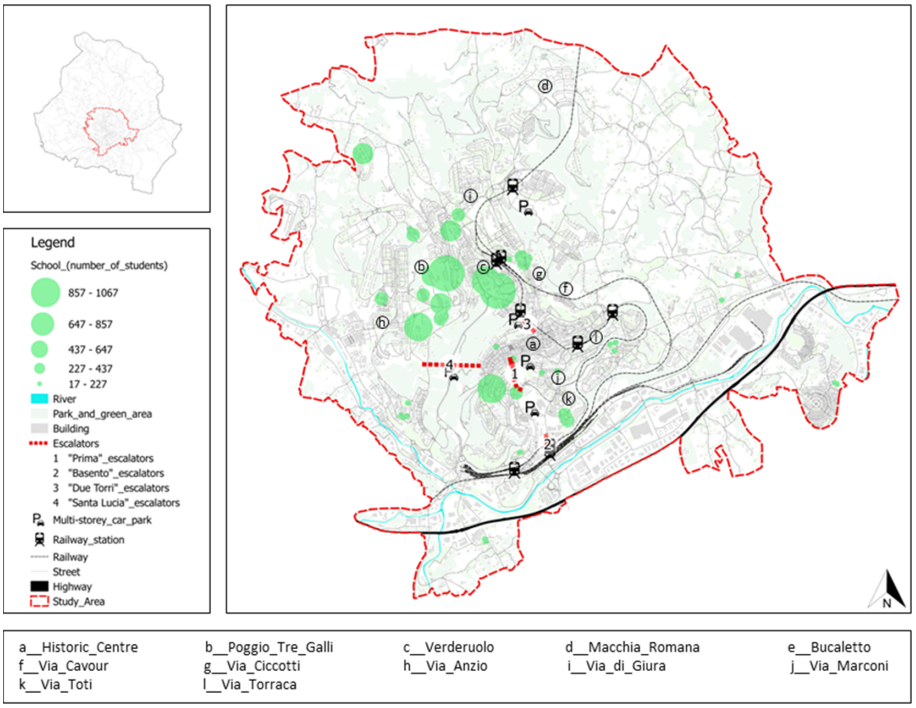

Fig. 1. Potenza's urban area: the location of schools and mobility network infrastructures.

GIS-mapping of schools captures the spatial distribution of schools within the urban area showing the well supplied districts of the city of Potenza. Moreover, in this section, we report the results obtained by applying the AB analyses, where the schools are the "attraction objects" weighed by the number of students. Since all destinations are not counted equally, the attraction analyses provide results depending not only on the location but also on specific quantitative "attractiveness capacity" of schools based on the number of students (Fig. 2).

Considering both the route directness (angular minimization) and the weighed location of schools, streets crossing the "Verderuolo" district (c, Fig. 2) have high AB values setting a threshold radius of 1,500 m as "walking distance" to perform a configurational analysis of the street network compatible with walking. The spatial network analysis at a certain distance highlights the most chosen paths inside the network in dark blue and the least chosen paths in white. The thematic map shows how most of the schools in Potenza, located North of the Historic Centre, are connected by street segments with a high attraction-based network centrality value, i.e. a relevant potential

"through-movement". South and near the Historic Centre, it is possible to identify a continuous path connecting the schools in this area (i, Fig. 2) even if the AB value is lower than that of the streets located in the "Poggio Tre Galli" (b, Fig. 2) and "Verderuolo" (c, Fig. 2) districts.

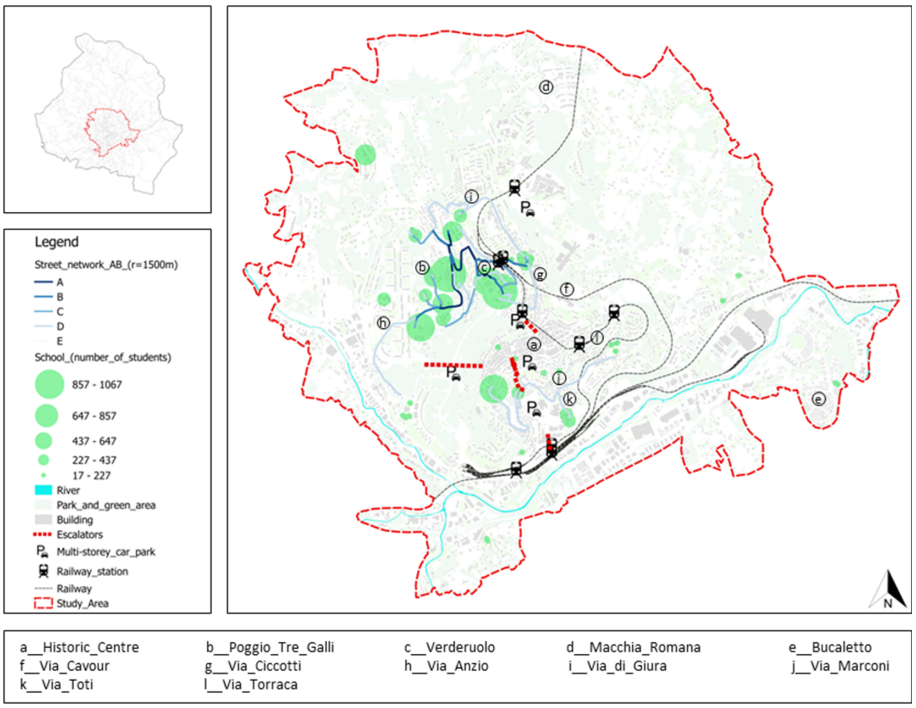

Fig. 2. Potenza's urban area: Attraction Betweenness(AB)-based analysis of urban street network (r = 1,500 m).

The AB analysis of the urban street network, whose "walking distance" radius is equal to 3,000 m, shows how there are streets which acquire a greater centrality than the scenario described above: Via Cavour (f, Fig. 3), Via Ciccotti (g, Fig. 3), Via Anzio (h, Fig. 3), Via di Giura (i, Fig. 3), Via Marconi (j, Fig. 3), via Toti (k, Fig. 3), Via Torraca (l, Fig. 3). By increasing the radius distance (from 1,500 m to 3,000 m), the network analysis shows the most convenient routes for bicycles and other small electric vehicles, while identifying strategic corridors to sustainably connect adjacent districts [47–54]. As in the previous analysis, a set of streets with a higher potential to be relevant intermediate points (characterized by a greater potential of being used in shortest path within the system) emerges. In this case, the thematic map makes it possible to identify a ring characterized by the street segments with the highest AB values, connecting most of the schools in the urban area of the city of Potenza.

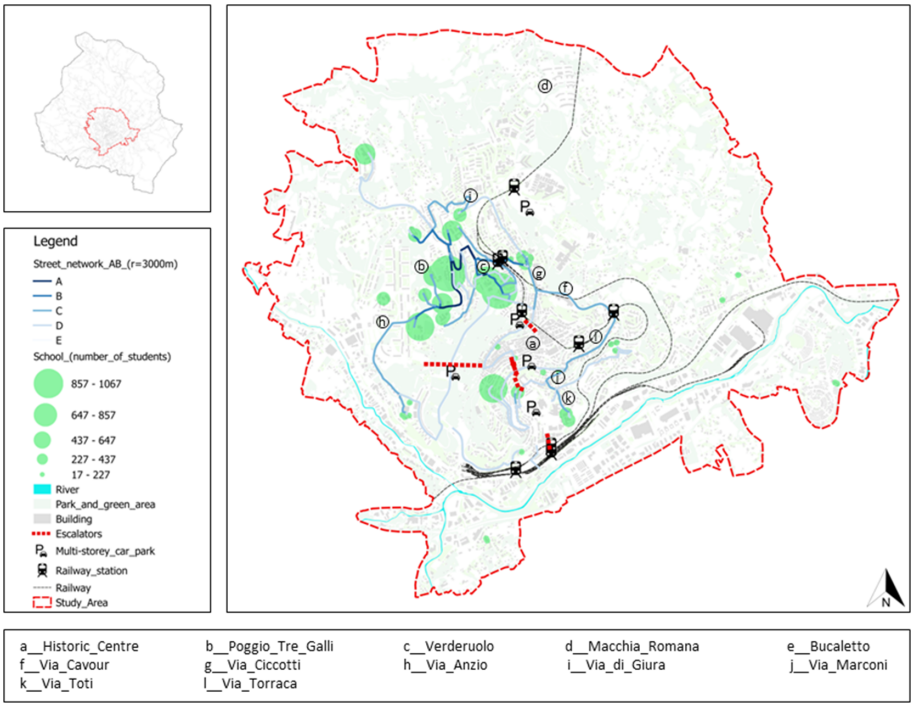

Fig. 3. Potenza's urban area: Attraction Betweenness(AB)-based analysis of urban street network (r = 3,000 m).

4 Conclusions

Results obtained from the attraction-based analyses show how it is possible to promote sustainable (walkable and cyclable) access to schools in the city of Potenza, characterized by a private car-dependant mobility culture. By aiming at the creation of low-carbon settlements, this could be an important incentive for the definition of a new mobility scheme for the whole city, alternative to the current one based almost exclusively on the use of motorized vehicles, in particular the private car. From the thematic maps (providing visualization of spatial distribution of AB analyses' outputs within Potenza's urban street network), it emerges that the concentration of schools in the area North of the Historic Centre of Potenza represents an incentive to promote multimodality for commuting (while reducing private car use). In fact, the streets with the highest AB values (a hierarchy of street network's "walkable" and "cyclable" centralities from space-morphological point of view emerges) are located near a very important railway interchange between the national (RFI) and interregional (FAL) railway lines (Fig. 4). So, project interventions could be defined in order to promote/improve pedestrian and bicycle mobility on the streets leading from the station to schools, covering the first/last parts, i.e. the "last mile", of the daily journey in a sustainable way. Moreover, our methodological approach allow to evaluate the

sustainable mobility potential of neighborhoods in the urban area. A spatially integrated routes' network is important for making walking and biking attractive and competitive both for shorter and longer daily trips (in the last case in association with public transit).

Results obtained from the attraction-based syntactic analyses allow to classify the streets segments and select those considered as priority and to be included in a network of urban pedestrian-cycling routes. The two railway lines cross the city of Potenza along the North-South axis: the construction/expansion of interchange car-bus parks near the main vehicular entrances to Potenza, located in the North and especially in the South, and the upgrading of a city rail could contribute to the reduction of motorized vehicle traffic crossing the urban area of Potenza. So, the students coming from the other towns of Basilicata region could take advantage of an intermodal solution (train + walking-bicycling) to reach schools.

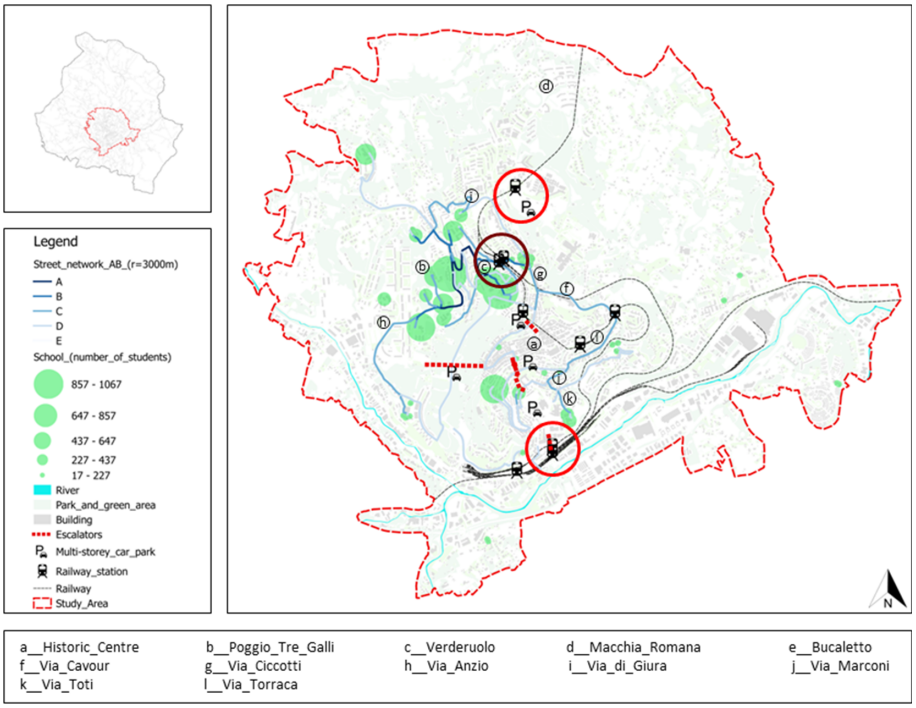

Fig. 4. Potenza's urban area: Attraction Betweenness(AB)-based analysis of urban street network (r = 3,000 m). The car-bus interchange parks are in red circle and railway interchange between the national (RFI) and interregional (FAL) railway lines is in dark red circle. (Color figure online)

The analyses carried out considering as walking distance 3,000 m (Fig. 4) shows how schools and students could benefit from this intermodal solution. In this case, the

use of bicycles and, above all, of pedelecs, ebikes would make it easy to cover this distance. Furthermore, the city of Potenza is equipped with 4 mechanized pedestrian mobility systems, escalators and elevators, which allows to implement a sustainable reorganization of urban mobility with advantages for residents and commuters. In fact, the results of attraction-based syntactic analyses could influence policy-makers in the definition of strategies that favour a rational management of urban mobility and sustainable urban development. As a computer techniques-based formal model, the space-morphological analysis (syntactic analysis is a graph theory-based mathematical calculation of configurational properties of street network) should be integrated by detailed traditional site-specific surveys focused on other morphological features for a comprehensive and detailed assessment of the street network.

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