

Linking Urban Railways, People and Places: A Spatial Multicriteria Decision Analysis in the City of Catania



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Abstract The interconnection of urban contexts represents the baseline for the quality of life within them. An efficient urban mobility system ensures environmental, economic and social sustainability. It promotes inclusivity by fostering access to urban facilities and services. Moreover, it enables improvement to the organisation of urban space by allowing better allocation of city facilities. Urban railways connect the areas they cross by triggering relationships between these places, fostering the emergence of new centralities, urban regeneration practices and sustainable and inclusive mobility behaviour. This research proposes a model to study urban centrality through spatial data and multicriteria decision analysis. It shows a method to achieve a degree of centrality of station service areas according to different types of urban populations.

Keywords Centrality · Accessibility · Urban populations · Urban railway · GIS

1 Introduction

1.1 Urban Centrality, Mobility and Social Inclusion

Goal 11 of the 2030 UN Agenda focuses on “Sustainable cities and communities”. In this framework, sustainable mobility is achieved by providing a safe, affordable, accessible and sustainable transportation system for all citizens [30]. Cities represent the human context in which opportunities are concentrated and where the mobility system has been strongly implemented. Hence, mobility becomes almost a synonym for the city itself [20]. Enhancing public transportation services is considered crucial, particularly in relation to the most vulnerable social groups [7, 19].

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Improving accessibility to places and services is an aspect of social equity [24]. An effective and inclusive mobility system influences the degree of sustainability of cities from environmental, social and economic points of view.

The concept of accessibility [1, 2] is presently included within citizenship rights because it can affect levels of social inclusion, equity and quality of life: it is “a matter of overcoming constraints of space at particular moments of time so as to gain access to the informal networks of work, leisure, friendship and family” [4: 548]. In other words, accessibility can be defined as the ease of supporting the material or temporal cost of reaching desired places. Constraints in urban movements can fuel inequalities that should be overcome through the implementation of suitable mobility policies. Recalling the concepts of the right to the city [17] and social production of the space [18], improving accessibility can create and strengthen spatial and territorial justice [13].

Facilities include various types of activities available in a city to satisfy people's needs, which are more accessible according to their availability in a space or if they are achievable through mobility practices. From a sociological perspective, the transportation system has to be considered in a study of accessibility [10]. The availability of public transportation services increases accessibility to urban resources, and they also help urban populations to achieve their goals and wishes. Centrality is a concept that summarises the degree of the appeal of a place in comparison to a surrounding periphery. According to Christaller [6], the model of central places depends on the quantity and levels of urban facilities offered. Central places benefit from higher-quality services and availability in larger numbers. The scattering of human settlements hosting activities and functions due to the evolution of transportation technologies and mostly private motorisation has affected the well-defined and highly gravitational spatial pattern [7].

Scientific literature identifies different types of urban populations [23, 27]. Each category has different needs and desires to be satisfied through the resources offered by a city. The intersection of urban populations and facilities shapes multiple scenarios of resource accessibility and the centrality of places. Mobility behaviour depends on the locations of different facilities, corresponding to the needs expressed by the inhabitants and all those who experience the city. Improving accessibility involves better distribution of facilities and improvements to public transportation services. A study of mobility necessarily requires the collection and analysis of spatially explicit data to investigate and understand the complexity of the phenomenon. Through an interdisciplinary and territorial approach, Geographic Information Science (GIS) supports a cognitive framework to provide a more successful use of urban space. Deeper and spatially explicit knowledge is necessary to support inclusive decision-making that is useful to foster sustainable mobility, reducing inequalities in access to facilities and services [31]. The construction of new transportation infrastructures, such as urban railways (i.e. metro lines or rail loops), represents an opportunity to improve the sustainability of cities, rethinking the organisation and centrality of urban areas. New relationships between the nodes of a transport network make it possible to change the conditions of centrality or

peripherality that characterise the areas concerned, triggering potential changes in the social and economic fabric.

1.2 Study Area: The Geographical Framework of Urban Mobility

This study frames a representative case study of centrality and facilities by analysing the mobility dimension in the city of Catania, in Italy (Fig. 1). The city has a population of 301,104 people (ISTAT, as of 1 January 2022). It is home to an ancient university and has numerous services and activities. Moreover, it is a daily destination for commuters, students, tourists and more.

Since the 1970s, the city has been affected by a significant dispersion of residential settlements outside the historical city core, with the creation of neighbourhoods in the northwest and in the south [8]. Intense urban sprawl has led to congestion and pollution in the city centre [16].

Since 1986 [25], the city has been involved in the expansion of two urban railways: the subway and the rail loop. These projects could greatly contribute to solving the serious quality-of-life problems caused by excessive use of private vehicles. For example, in 2018, there were almost 72 vehicles per 100 inhabitants [15]. Since 2023, only one line and 10 subway stations have been working. By completing the infrastructural lines and their integrating service, the two urban railways could provide accessibility to important areas of the city through a single network. By exploring and investigating such urban development dimensions, this study provides the first insight into the contribution of railways to the potential of new urban centralities. Possible projects, if properly planned, could mix areas of the city that are not entirely coherent with one another and support urban regeneration processes. The relocation

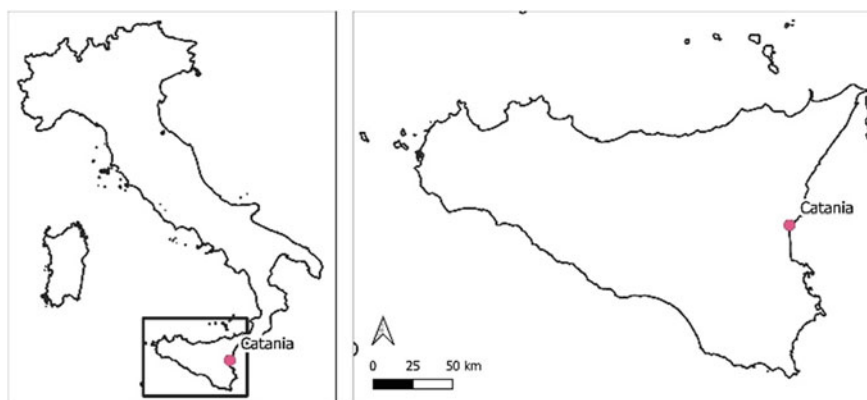


Fig. 1 Geographical location of the study area

of services to different neighbourhoods could lead to the creation of new centralities and improved quality of life.

1.3 Aims of the Study

The general aim of this study is to explore and reflect on the concept of urban centrality applied to the areas served by stations (service areas) regarding urban populations.

The specific aims are as follows: (i) testing a replicable way to measure the degree of centrality of each station's service area; (ii) identifying which type of urban railway user profile more frequently uses each station; and (iii) assessing future scenarios of urban centrality after the completion of a railway network in the city and its integration with a unified service.

2 Data and Methods

This study combined urban facilities and the profile types of populations by using spatially explicit data from OpenStreetMap (OSM) and other sources. Multicriteria Decision Analysis (MCDA) [21] was adopted to assess and quantify the degree of centrality of areas served by railway stations according to multiple urban facilities and user type profiles. MCDA encompasses numerous techniques for evaluating complex processes in which the heterogeneous elements involved affect them differently [12]. This approach is particularly useful to support decision-making in the public or private sector by involving stakeholders or citizens in participatory processes [11]. Data management and analyses were performed in a complete open-source GIS environment using QGIS software and different integrated plugins.

In the first phase of the spatial analyses, all the data were collected and geovisualised; then the two rail lines, the location of stations and the road network were extracted from OSM (as of 19 February 2021). The locations of railways and stations in progress or under construction were also obtained from municipality infrastructure plans [25, 26]. Spatial analyses were developed by performing two different territorial scenarios: (i) the present infrastructure dimension and (ii) the possible future layout, with infrastructure implementation and the integration of the two lines into a unified network.

The spatial units of analysis, or isochrony areas [28], were based on the locations of the stations (service area). Each of these corresponds to an area accessible through one of the railway stations, which is more or less equipped with facilities and is thus characterised by a different level of centrality. These areas represent the part of the city served by each station and its accessibility in terms of a set threshold of a 10-min walking time (5 km/h), considering the road network [3, 29].

Subsequently, 16 criteria were set to perform the MCDA analysis, corresponding to different selected urban facilities (Table 1).

Table 1 Selected criteria for Multicriteria Decision Analysis (MCDA), cartographic resources and supplementary information (OSM = OpenStreetMap)

MCDA criteria (facilities and services)	Source	Supplementary information
Grocery shops	OSM	<i>Shop: Bakery, butcher, convenience, deli, greengrocer, seafood, superm</i>
Bars/Kiosks	OSM	<i>Amenity: Bar + Shop: Beverages</i>
Cinemas	OSM	<i>Amenity: Cinema</i>
Libraries	OSM	<i>Amenity: Library</i>
Pharmacies	OSM	<i>Amenity: Pharmacy</i>
Places of worship	OSM	<i>Amenity: Place_of_worship</i>
Schools	OSM	<i>Amenity: School</i>
Services	OSM	<i>Amenity: Arts_centre, Bank, Clinic, Hospital, Police, Post_office</i>
Sport facilities	OSM	<i>Sport: (all the values)</i>
Shops	OSM	<i>All values except those considered in other categories</i>
Theatres	OSM	<i>Amenity: Theatre</i>
Tourism sites	OSM	<i>Tourism: All values</i>
Universities	OSM	<i>Amenity: University</i>
Urban intermodality	Metropolitan Transportation Company (AMT)	Bus line shapefile data are extracted; then the number of lines passing through each iso-area is calculated
Suburban intermodality	OSM	Railway stations, suburban terminals and the airport are considered (whose placement was forced from original in OSM data)
Public green spaces	Territorial Information System (Catania Municipality)	Categories of public green spaces considered: children's playgrounds, historic gardens, equipped green space

The majority of the spatially explicit data were derived from OSM, which allows for the extraction of information based on a pair of key value attributes corresponding to the data of interest. The data were obtained directly in QGIS through the QuickOSM plugin; hence, data corresponding to many different services, amenities, stores and facilities were extracted. Public green space data were obtained from the Territorial Information System of Catania Municipality (as of 15 March 2021), whereas bus lines were extracted from open-access General Transit Feed Specification (GTFS) data by the Catania Metropolitan Transportation Company (as of 17

March 2021). Hence, a count of each type of facility in each area was performed for point data from OSM and bus routes. For public green space areas, the percentage of occupied areas compared to the station service area was calculated. Moreover, the collected data were merged into a single attribute table of the layer containing polygons corresponding to the service areas.

The VectorMCDA plugin [22] was used for MCDA analysis, performed using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology, that “rates the decision alternatives under consideration according to their multidimensional distance to the ideal point using the distance metric” [21: 102]. Weights are set to evaluate decision alternatives that can have a positive or negative contribution. The best alternative is placed at the shortest Euclidean distance from the ideal situation and at the greatest distance from the worst one. In this study, urban facilities are the decision alternatives, considered with a positive contribution. The decision table, with the decision criteria (Table 2), was established by rating each urban facility from 1 to 10 (from the least to the most important), according to each user profile considered (student, city user, commuter, inhabitant, tourist, city leisure user). The table was elaborated by the Members of the research group “Climate Change, Territories, Diversity” of ICEA Department, University of Padua (Italy) by prioritising and weighting the selected criteria. The weight assigned was identified by dividing each rating by its sum, with the values derived having a sum equal to 1. Weights were assigned according to the importance of the relative profile.

In VectorMCDA’s GeoTOPSIS procedure, all weights were added considering gain. Consequently, each element increased the level of centrality obtained. In MCDA, the data included in the table were all normalised. The assigned weights, structured in a spreadsheet, were then reported in the plugin interface. Based on these weighted criteria and the distance calculation, normalised values in a range from 0 to 1 were derived as the degree of urban centrality. This procedure was recursive for each identified user profile. A differentiated station centrality value was therefore obtained according to each urban population profile.

3 Results and Discussion

Using a kernel density map, initial spatial analysis highlights all urban facilities (Fig. 2). The cartographic representation makes the intensity of resources near some already operating stations visible (e.g., Stesicoro, Italia, Giuffrida and Borgo). Other densely populated and suburban neighbourhoods near the Verrazzano and Librino stations, which will be reached in the future by the subway, are poorly equipped.

Moreover, it is possible to discriminate differences in the representation of centrality by the identified values based on MCDA analysis. For each profile chosen, the centrality values are represented in a single map. According to the highest centrality values achieved in different service areas, one or more characterising labels can be assigned to the corresponding stations depending on the prevailing type of potential users. Giovanni XXIII, Giuffrida and Borgo are commuter stations at which

Table 2 Ratings and weights for each user profile and urban facilities

	University students		City user		Commuters		Inhabitants		Tourists		City leisure user	
Grocery shops	7	0.07	5	0.06	5	0.08	10	0.09	5	0.06	5	0.05
Bar/kiosks	8	0.08	8	0.10	8	0.12	8	0.07	8	0.10	8	0.09
Cinemas	5	0.05	3	0.04	3	0.05	8	0.07	2	0.02	9	0.10
Libraries	6	0.06	5	0.06	3	0.05	6	0.05	2	0.02	4	0.04
Pharmacies	6	0.06	5	0.06	3	0.05	7	0.06	5	0.06	5	0.05
Places of worship	4	0.04	4	0.05	3	0.05	7	0.06	4	0.05	4	0.04
Schools	1	0.01	1	0.01	1	0.02	5	0.04	1	0.01	1	0.01
Shops	5	0.05	7	0.09	3	0.05	7	0.06	5	0.06	8	0.09
Sport facilities	5	0.05	4	0.05	3	0.05	8	0.07	2	0.02	5	0.05
Theatres	5	0.05	3	0.04	3	0.05	8	0.07	5	0.06	9	0.10
Tourism	4	0.04	5	0.06	2	0.03	4	0.03	10	0.12	7	0.07
Universities	10	0.10	1	0.01	1	0.02	5	0.04	2	0.02	1	0.01
Urban intermodality	10	0.10	10	0.12	10	0.15	8	0.07	10	0.12	7	0.07
Public green areas	8	0.08	8	0.10	5	0.08	9	0.08	8	0.10	8	0.09
Suburban intermodality	7	0.07	7	0.09	8	0.12	8	0.07	9	0.11	7	0.07
Services	5	0.05	5	0.06	5	0.08	8	0.07	6	0.07	6	0.06
SUM	96	1	81	1	66	1	116	1	84	1	94	1

modal interchange occurs, while university student stations are those that provide access to the most important sites of Catania University or where commuter students perform modal interchange with other systems (i.e., Stesicoro, Giovanni XXIII, Italia, Borgo and Nesima). Notably, due to its proximity to the university campus, the Milo station is particularly frequented by student users. The most central stations for urban dwellers are Italia, Giuffrida and Milo due to the presence of services and commercial activities. The Stesicoro station, thanks to the mix of facilities that it provides, has high values on all profiles, with a particular emphasis on tourists and city leisure users. Some results are presented in Fig. 3a and b.

By adopting a recursive approach to this procedure to obtain the completed infrastructure scenario, it is possible to geovisualise and investigate it on the basis of the current data on urban facilities. The evidence is of low centrality configuration related to some stations that will be built in neighbourhoods currently considered peripheral (e.g., Librino, Verrazzano and San Leone). In fact, there are few available urban facilities in those areas, as shown in Fig. 4, despite being characterised by a high-density

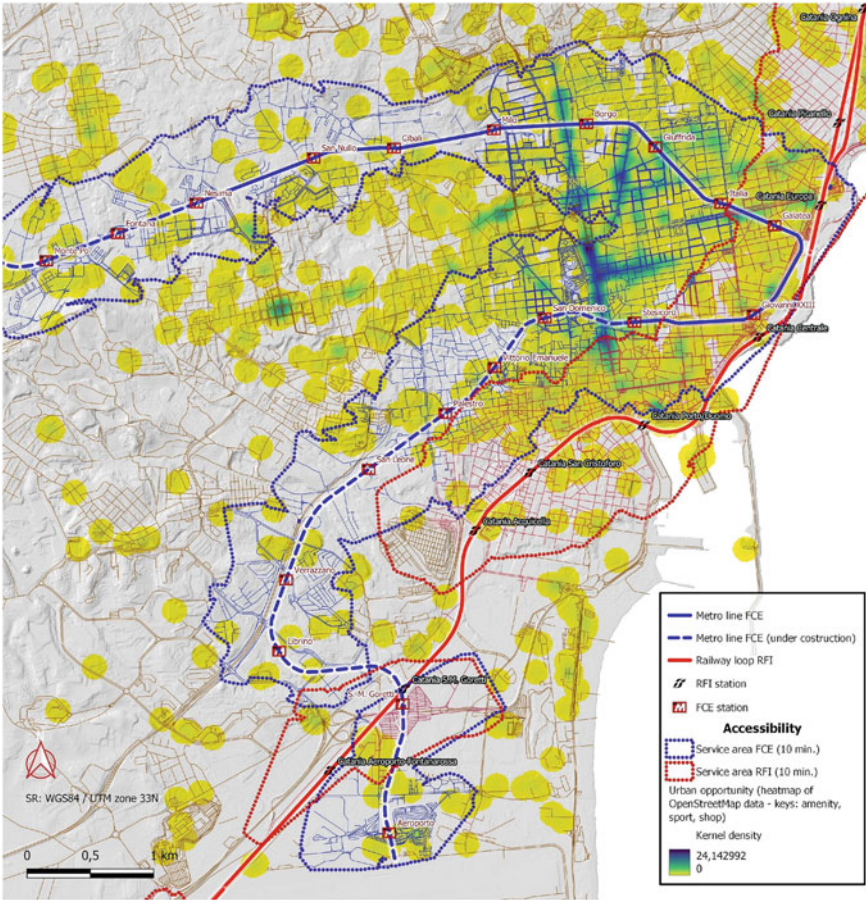


Fig. 2 Kernel density map of urban facilities

population. In this case, the results might have been affected by the few attractive resources and reduced mapped features in the OSM collaborative platform.

The creation of stations might be an essential reason for the placement of new services and the emergence of new activities. During infrastructure implementation over time, changes in opportunity supply may affect the criteria and weights considered to perform simulated scenarios by MCDA analysis.

In general, MCDA analysis highlighted how in future scenarios, new stations and the extension of the railway could provide more centrality to areas that are presently peripheral by creating an opportunity to (i) reconnect the involved urban areas, (ii) change centre/periphery relationships through better urban planning, (iii) relocate services and (iv) create new appeal.

Notably, the entire process is based on and related to data on existing resources. Moreover, the extreme best and worst values employed in the MCDA, related to

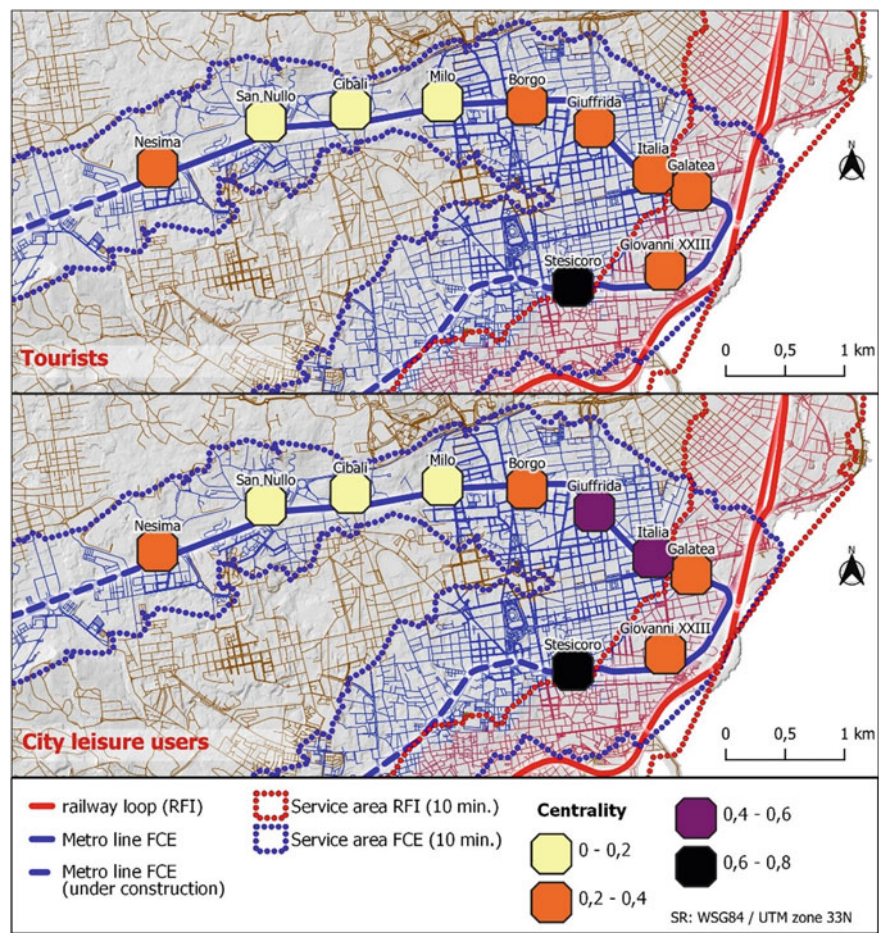


Fig. 3 **a** Urban centrality varies based on two types of urban population: tourists and city leisure users. **b** Urban centrality varies based on three types of urban population: university students, city users, commuters

each decision alternative, correspond to the maximum and minimum levels of urban facilities based on the data collected; therefore, they are related to this case study. They do not represent a valid scale in an absolute sense and thus are not able to confirm the sufficient availability of each resource type. Moreover, in MCDA, the weights could be chosen in a different way by the direct involvement of policymakers and citizens in weighing operations. Further development of this study may also consider elements that can negatively affect centrality, such as degraded places, crime, abandoned urban areas, traffic and pollution. In fact, elements that affect the phenomenon negatively or positively (cost and gain) can be included in the TOPSIS

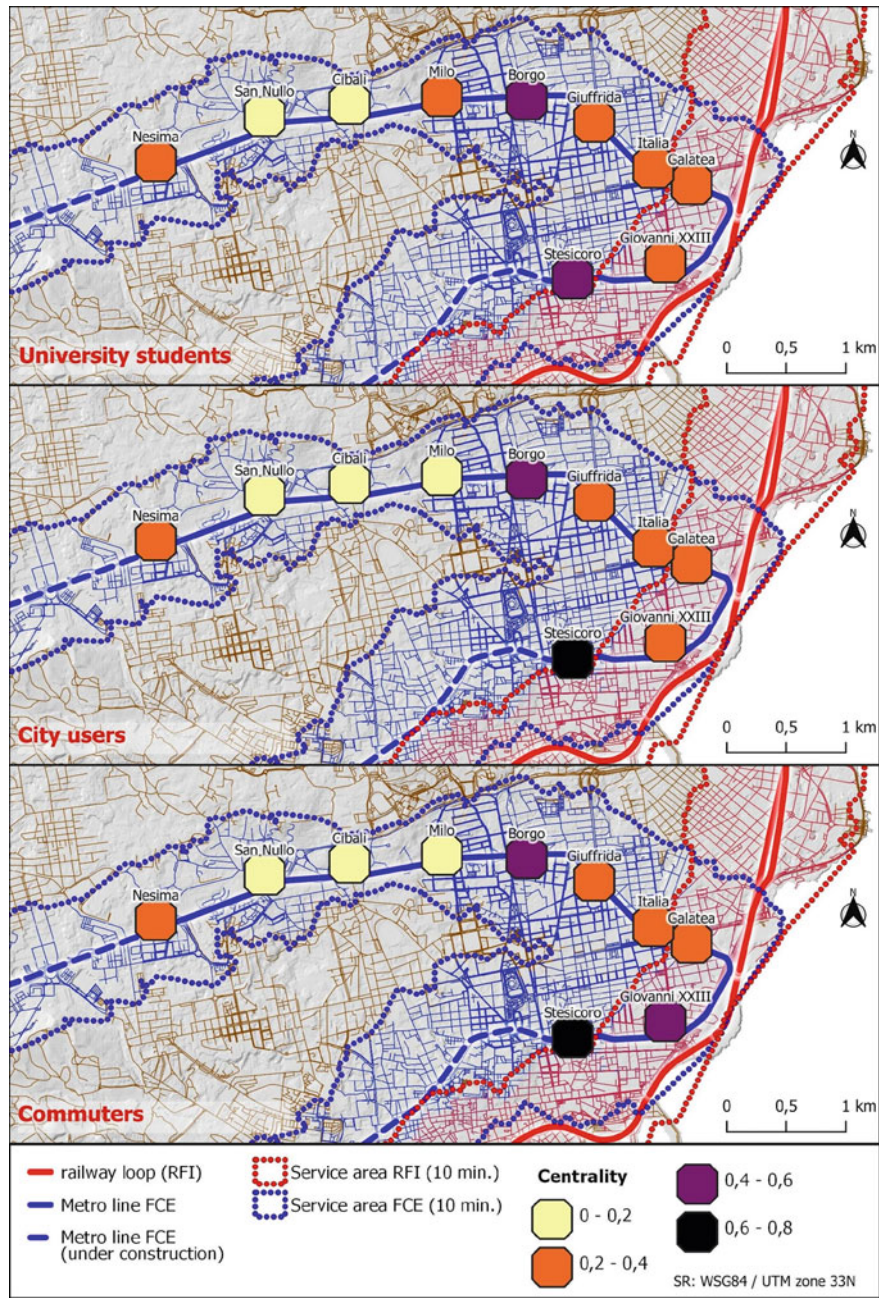


Fig. 3 (continued)

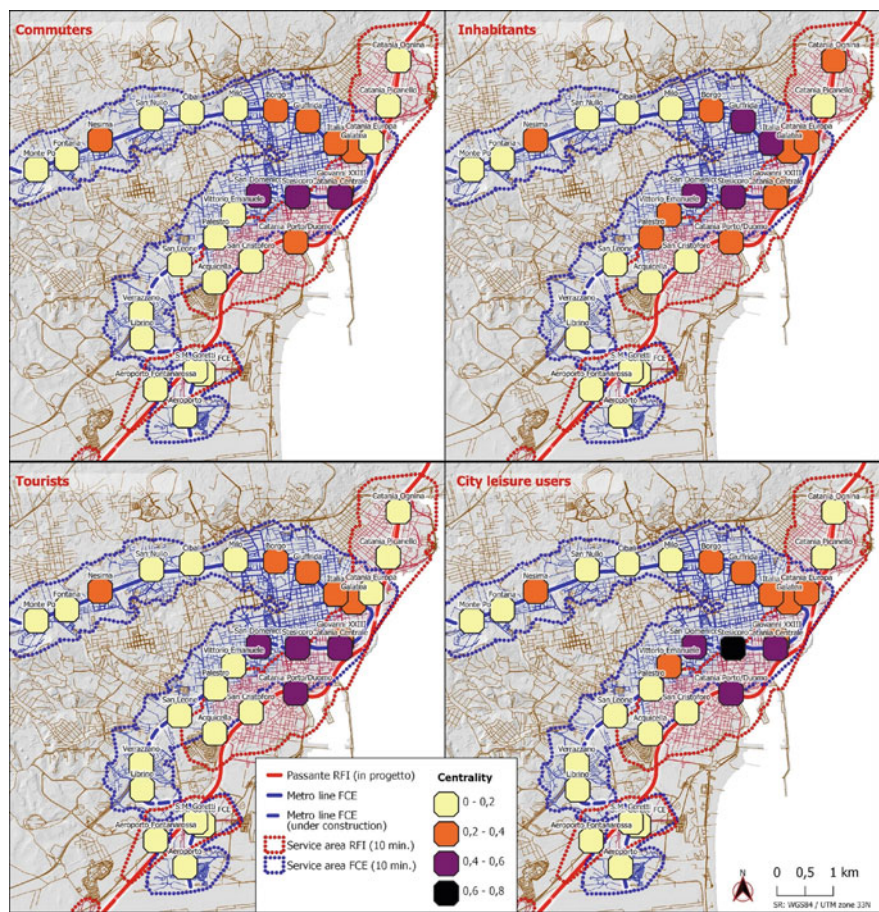


Fig. 4 Urban centrality varies in a completed infrastructure scenario, based on four types of urban population: commuters, inhabitants, tourists and city leisure users

procedure. In this study, all features contributed to the degree of centrality, and consequently, were all considered positives (gains).

4 Conclusion

This study shows how an apparently objective and unique concept such as centrality should first be defined, starting from the spatial dimension of different urban populations and the most vulnerable social groups. Therefore, it is necessary to adopt a perspective that considers centrality on the basis of different needs and desires related to the spatial distribution of residents and territorial features and services.

The proposed model provides the possibility to achieve this goal, as it is replicable and scalable to other urban contexts by analysing user profiles as long as data is available. The analysis of phenomena using spatially explicit data and GIS-based tools constitutes an additional important cognitive contribution that cannot be excluded from the urban planning decision-making process.

More detailed availability of data on urban facilities or comparison with actual data on working station users would achieve further cognitive ends and refine the proposed model. For this reason, it is important to highlight the importance of collaborative mapping activities on open-access platforms, such as OSM, and to share open data on mobility with transportation companies and territorial administrations.

Comparing actual situations with future scenarios highlights the risk that areas of centrality will remain restricted to those of today. This projection suggests the importance of secondary actions in the construction of metropolitan railways. There is a need to encourage the reuse of abandoned spaces, the redevelopment of new neighbourhoods with the implementation of services and activities and the restoration of historic suburban neighbourhoods with regeneration measures.

Some of these changes may be generated spontaneously and are consequential to infrastructure development. Coordinated intervention is also necessary to avoid the production of further imbalances and the creation of dynamics that are far removed from sustainability models and the real needs of urban populations.

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