Accessibility and Mobility in the Small Mountain Municipality of Zafferana Etnea (Sicily): Coupling of Walkability Assessment and Space Syntax

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Abstract. The new mobility paradigm, the spread of new city models and the recent pandemic have highlighted the variability and complexity of people's mobility. There is a widespread need for dynamic urban planning strategies to adapt to circumstances and mitigate the risk of dangerous events such as natural disasters and pandemics. The last decade has been characterised by urban transformation processes that have often led to inequalities in spatial and infrastructural distribution and services. To reduce this criticality, it is necessary to investigate the reciprocal influence between the spatial configuration of the built environment and the way everyday mobility is implemented and becomes habitual, and its relationship with the inequalities mentioned above (e.g. suburbs, degraded areas, urban voids). This research focuses on studying the evolution of the accessibility of the small mountainous urban centre of Zafferana Etnea, which seismic phenomena have hit several times. In the first instance, the work identified and characterised the case study by estimating the mobility demand based on access and the analysis of the spatial configuration (buildings, infrastructures and services). Similarly, the research proposes the definition of the primary attractive nodes of the city, zoning and the purpose of key factors for the definition of mobility indicators that allow the realisation of a quantitative analysis of transport demand and supply based on indicators rather than on the configuration of the urban fabric, which will be addressed with theoretical and methodological tools provided by the spatial syntax.

Keywords: Urban mobility · Walkability · Spatial analysis · Space syntax

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1 Introduction

The worldwide pandemic problem triggered by Covid19 has led to reassessing cities' development, especially how modern cities are created and constructed. A reflection on the principles of understanding these issues with cities and the construction of spaces for human living, as well as fields such as social sciences and civil and transport engineering [1].

UN-Habitat report [2] notes that in the pandemic around 120 million people would become impoverished and their standard of living will fall by 23%. In cities, a new reality might develop if housing, services and security are prioritised. Since Covid-19, urban areas have been at the forefront of the crisis. Governments and local communities have been compelled to take swift and decisive action to prevent the virus's spread.

Most countries and cities were unprepared for the spread of SARS-CoV-2, officially declared a pandemic in March 2020. During the second phase, governments attempted to adapt to Covid-19 and started studying ways to mitigate its negative social and economic consequences. The second phase is rebuilding and recovery, which some governments started working on right away in the first months of the pandemic, but others (mostly low-income countries with less resources) have yet to start as they continue to suffer the effects of the virus.

Several literature studies highlighted the need of acquiring higher knowledge of road users' changing travel habits, their attitudes toward public transport, and their perceptions of sustainable urban mobility modes in order to enhance post-pandemic urban and transport planning [3–5].

Political leaders need to reorganise cities by emphasising neighbourhood planning, how people move in urban centres, and ensuring multifunctional and inclusive settlements. Well-planned cities combine residential, commercial, public spaces and affordable housing to foster a sense of community [6–8].

Indeed, cities capable of ensuring the health, housing and safety of the most vulnerable populations may contribute to the "new reality". Local governments must prioritise measures that safeguard land rights, increase access to water, sanitation, public transport, electricity, health, education, and ensure inclusive digital connectivity.

The four key pillars for reviving cities are as follows:

- rethink the shape and function of the city;
- tackle poverty and inequalities;
- rebuild an urban economy;
- clarify urban legislation and urban governance.

New, more sustainable and productive urban systems characterised by compact form, accessible mobility and diversified land use may help create safer and more liveable urban environments [9, 10]. Several actions have been undertaken on a worldwide scale in recent months, from metropolitan cities to small towns.

For instance, Montréal established a network of accessible corridors for pedestrians and cyclists in response to the pandemic, consisting of 112 km of bike and walking lines that connect city residents to parks, schools, essential services and businesses. Additionally, cities around Europe are restructuring their highways to support a larger reliance

on non-motorised transport. Milan's city centre will be renovated to offer approximately 35km of road space for bikes and pedestrians. In Brussels, where an extensive pedestrianisation plan was already underway prior the pandemic, the whole city centre was changed into a priority pedestrian and cycling zone. London recognised the need of providing secure accommodation for the city's vast homeless population in order to protect them from illness and prevent viral spread. Vacant hotels and workplaces were swiftly turned into safe spaces.

Following an analysis of the literature related to the concept of accessibility [11, 12], the need to investigate the mutual influence of the built environment's spatial configuration and mobility emerged. This was accomplished by defining the network graphs of a city and estimating access-based mobility demand, both through the analysis of spatial configuration (buildings, infrastructures and services).

The next paragraphs provide an overview of the literature on the notion of city accessibility at different sizes and emphasise crucial challenges pertaining to small mountain urban centres. Subsequently, the case study's features are detailed, emphasising the rationale for selecting the city for analysis and outlining the city's major centroid nodes, zoning, and network graphs, with a special emphasis on pedestrian mobility. Finally, components of the spaces are identified via the use of space syntax analysis through maps and images that depict the relative connectedness and integration of those spaces.

2 Literature Review: Accessibility and Mobility and the Combination of Walkability and Space Syntax

Making the city more inclusive is a worthwhile, achievable, and productive goal. It is vital for everyone's quality of life, but particularly for the most vulnerable people because it improves access to communities, services, and public places by providing safer and more accessible roadways and sidewalks [13–17]. Additionally, it benefits everyone's health by reducing pollution and accidents and enabling better lives. It is beneficial for encouraging social participation [18–20] and increasing the autonomy of disabled individuals [21, 22]. It is also practicable because it may be accomplished with low-cost treatments that have instant results. It is successful since it entails additional advantages for the city's growth.

Moreover, the vitality potential of public space is determined by the spaces' intrinsic qualities, most notably its configurational properties. Configuration may be described as the relationship of access and visibility between interdependent spatial elements that compose an overall structure.

Spatial relations define conditions of the centrality of spatial elements and influence the distribution of natural movement and, consequently, the patterns of co-presence across spaces. Natural movement patterns have an effect on land use patterns, favouring the concentration of functions in integrated and central places and dictating the creation of lively local and supralocal centres as well as quieter monofunctional zones. This, in turn, activates local adaptations of the spatial structure, resulting in the intensification of the urban grid and the densification of built-up areas, resulting in a multiplier effect on the distribution of movements and space use, as well as the location of land uses, resulting in a recursive socio-spatial process denominated as movement economy. As a

consequence, the interaction between space and social activities, as well as the effect of space configurations on people's structures, are understood at the configuration level. Indeed, it is centrality that is emerging as the spatial characteristic that reflects and reproduces social norms, connections, and behaviours.

3 Methodology

3.1 Space Syntax Analysis

Space syntax refers to approaches, theories and techniques for analysing spatial configurations. Bill Hillier and colleagues from The Bartlett, University College London devised it in the late 1970s to assist urban planners in simulating the likely social implications of their projects [23].

The underlying concept is that spatial structures can be formalised as a set of spatial components and characterised in terms of topological relations among elements interdependent in a global network. Recent studies on urban spaces, in particular, are focused on lines of movement, and formalised spatial structures as segment maps; segment maps represent spatial structures as a set of segments delimited by consecutive intersections. Afterwards, maps are turned into graphs in which nodes represent spatial components and arcs indicate intersections among spaces. Segment map analysis is characterised by three distinct aspects of centrality of spaces: degree centrality, closeness centrality, and betweenness centrality. Degree centrality is a local configurational property that refers to the number of spatial elements that are contiguously related to a space. Closeness centrality is determined by the distance between a space and all other elements in a spatial layout. As a result, the importance of a space as a destination is defined by its closeness centrality. Finally, betweenness centrality is a configurational attribute that is determined by the likelihood that a space is included inside the shortest paths connecting any origin space to any destination space contained within a spatial layout. As a result, betweenness centrality refers to the through-movement potential of a spatial element. These centrality properties are influenced by the distance among spaces. Distance is conceptualised in three ways in space syntactic theory: metric, topological, and geometric ones.

Geometric distance is defined as the sum of angular deviations along a route from an origin space to a destination space. The proposed research considers the geometric conceptualisation of distance and measures the aspects of centrality via the indicators Normalised Segment angular Integration (NAIN) and Normalised segment angular Choice (NACH). Normalisation of measures of integration and choice aims to enable the comparison of spatial structures of different sizes, and in the case of normalised angular choice, to solve the paradox that segregated structures determine an increase in total and average choice values compared to integrated structures [24]. Moreover, NAIN and NACH are computed at the global scale, and within a radius of 800 m and 300 m of each origin space, respectively, to identify global and local centers and to account for the influence of the configuration of the spatial layout on the distribution local scale pedestrian movements and global motorised travel. Lastly, values of Normalised Choice at the local (at radius 300 m) and global scale are compared to identify spaces intersected by main itineraries and local itineraries that emerge as suitable locations for diversified

services and urban functions. Thus, configurational metrics are used to assess the extrinsic properties of the urban structure that connect the system of mobility and circulation to the distribution of natural movement and co-presence, consequently impacting the intensity of individual and social practices across public spaces. This configurational description of the urban structure is central for generating the knowledge base needed for urban regeneration interventions aimed at promoting the vitality and inclusivity of urban spaces [14, 25].

3.2 The Development of the Correlation Between Mobility and Urban Spaces in the Post-pandemic Phase

Mobility is crucial to a region's attractiveness. In particular, the development of infrastructures and transport services facilitates travel, work and leisure activities.

The recent pandemic has highlighted these gaps but has also shown potential opportunities in mountain areas and villages [26]. However, it also stimulated the transport of goods as a result of the growth in e-commerce purchases [27]. In many rural and mountain areas, a traditional dependence on cars prevails, and the lack of adequate collective transport alternatives forces some typologies of rural residents to live in social and geographical exclusion. In such contexts, accessibility is crucial to the success of development initiatives, and the lack of adequate accessibility affects any development strategy implemented in rural areas [28–30].

International and local research demonstrates that such mountainous areas are interchangeable with low demand transport areas, which may reflect negatively on the economic feasibility of public transport lines. Furthermore, they are often characterised by a high number of elderly people, sometimes a high poverty rate and a relative remoteness from the main airports/railways /road connections.

Mountain locations also have specific topographical characteristics, such as slopes, altitude and protected areas, which complicate and increase the cost of road and railway development [31]. The literature highlights the need of considering complementary solutions of transport beyond traditional urban and extra-urban public transport, such as micro-mobility and pedal-assisted bike solutions for short-distance travel, and DRT services for medium and long-distance travel [32, 33]. The evaluation of strategies for optimizing mobility will also have to start from the simplest form, namely walkability.

From these considerations, this paper establishes the framework for a research project aimed at identifying how space syntax analyses at various levels of scale can be used to identify and describe the spatial characteristics of a mountain city and improve its walkability, starting from the case study of Zafferana Etnea in Sicily, Italy.

3.3 The Case Study of Zafferana Etnea in Sicily

This case study was chosen because in mountain areas, the limits imposed by the morphology of the territory, the slow but widespread ageing of the population and the contraction of resources pose the problem of accessibility to basic services. Schools, as well as local health services and community centres (associations, theatres, squares, etc..), are the main sectors with which those who live in areas far from the main urban centres are confronted on a daily basis. Zafferana Etnea, situated on the south-eastern side of

Etna, has 9,262 inhabitants (ISTAT, 2021) and covers an area of 76.67 square kilometres, making it the largest municipality on the south-eastern side. Around 80% of the territory is covered by Etna Park, which is subject to naturalistic restrictions. The territory has a high level of tourism, for the volcano's proximity and the food and wine events (Fig. 1).

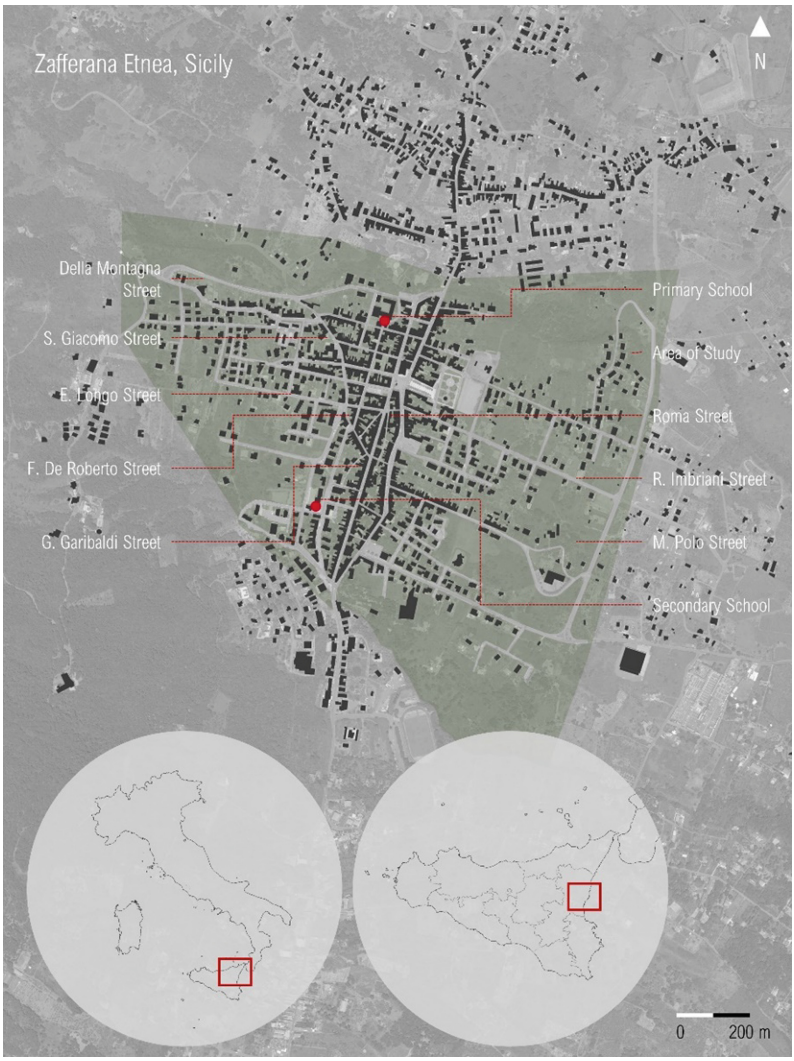

Fig. 1. Zafferana Etnea in Sicily (authors' elaboration).

Zafferana Etnea is located in a highly critical setting, both volcanically and seismically, because it is perched on the slopes of Mount Etna and is susceptible to the danger of periodic volcanic eruptions. The historic centre of the city is characterised by a strong concentration of inhabited areas and hence resident population, as well as characterised

by the location of most of the public services (schools, town hall) and private ones. The main road axes are parallel to the contour lines in the NE-SW direction, with a system of crossways in the NW-SE direction acting as linkages. This has resulted in a significant pedestrianisation of the Zafferana's principal axes, which do not have extremely steep slopes despite the orography of the territory. Instead, the crossways are characterised by high slopes. At the urban planning level, the town begins to assume its current configuration in the early 1900s, with the formation of the historic centre's original core around Roma Street (Fig. 2).

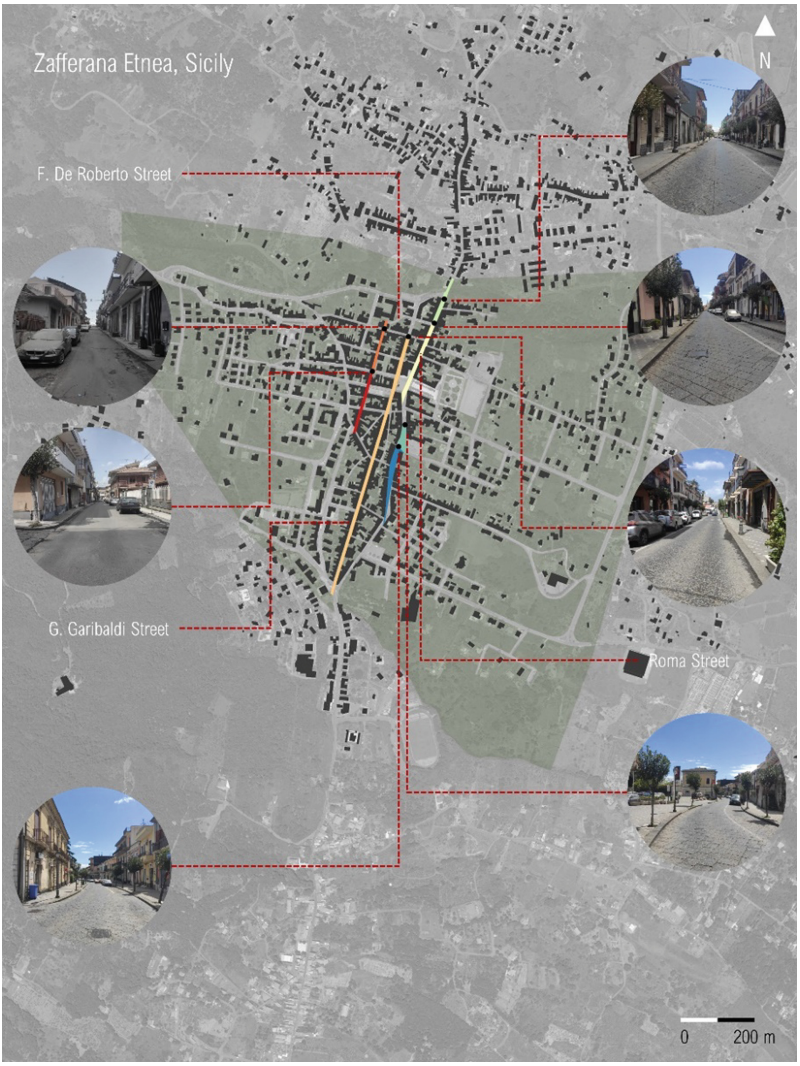

Fig. 2. The significant major routes across Zafferana (authors' elaboration).

The later-created perpendicular "Della Montagna" Street, together with "San Giacomo" Street form a triangle marking the town's original urban core. The expansions to the south and east, which began in the 1970s, represent a continuation of this period. The current urban configuration is bounded to the west by the Etna Park limited by the landscape constraint to the West, due to the presence of the Etna Park; new residential areas are mostly located east of the urban core. The triangle formed by Roma Street, Della Montagna Street and S. Giacomo Street is the historical urban area of Zafferana Etnea, with the surrounding territories mostly used for agricultural, residential, and productive purposes. Its primary attractions include the schools positioned on each side of the major road axis, as well as the offices and banks located around the main square.

4 Results

The segment angular analysis of Zafferana (Table 1) underlines the emerging spatial structures, at distinct levels of scale. In particular, the analysis of configurational properties, at the local scale (r = 300 m), describes the structure of the most relevant destination spaces and routes in relation to pedestrian movements.

Table 1. Results of the angular segment analysis of the system of roads and public spaces in Zafferana

Zafferana	NACH 300	NACH 800	NACH N	NAIN 300	NAIN 800	NAIN N
Min	0.301	0.301	0.301	0.793	1.056	1.604
Max	2.501	3.537	3.814	1.756	2.016	2.057
Mean	1.482	2.367	2.498	1.329	1.745	1.902
Standard deviation	0.642	0.862	0.989	0.239	0.221	0.098
Variation Coefficient	0.433	0.364	0.395	0.180	0.126	0.051

The distribution of normalised angular integration, in a 300 m radius, underlines the emergence of a reticular structure of integrated spaces (Fig. 3), comprising part of the centre of the ancient formation and the segments, contiguous to the Cardinal Pappalardo Square, of the system of longitudinal streets, including G. Garibaldi Street, F. De Roberto Street, and Roma Street. A set of segregated spaces are located along the edges of the area of study (Fig. 3). The distribution of choice, at the local scale, underlines a centripetal structure of spaces relevant for pedestrian trips, that intersect the central compact area and includes segments of the longitudinal streets F. de Roberto, San Giacomo and G. Garibaldi streets. Moreover, the distribution of integration and centrality in an 800 m radius, identifies a grid structure of accessible spaces for pedestrians and cyclists, relevant as destination spaces and a radio-centric structure of circulation spaces (Fig. 4).

Lastly, at the global scale, the distribution of centrality underlines the emergence of distinct sub-systems of routes relevant for urban-scale movements: the ring route comprising Marco Polo, R. Imbriani and A. De Gasperi streets; a reticular sub-system

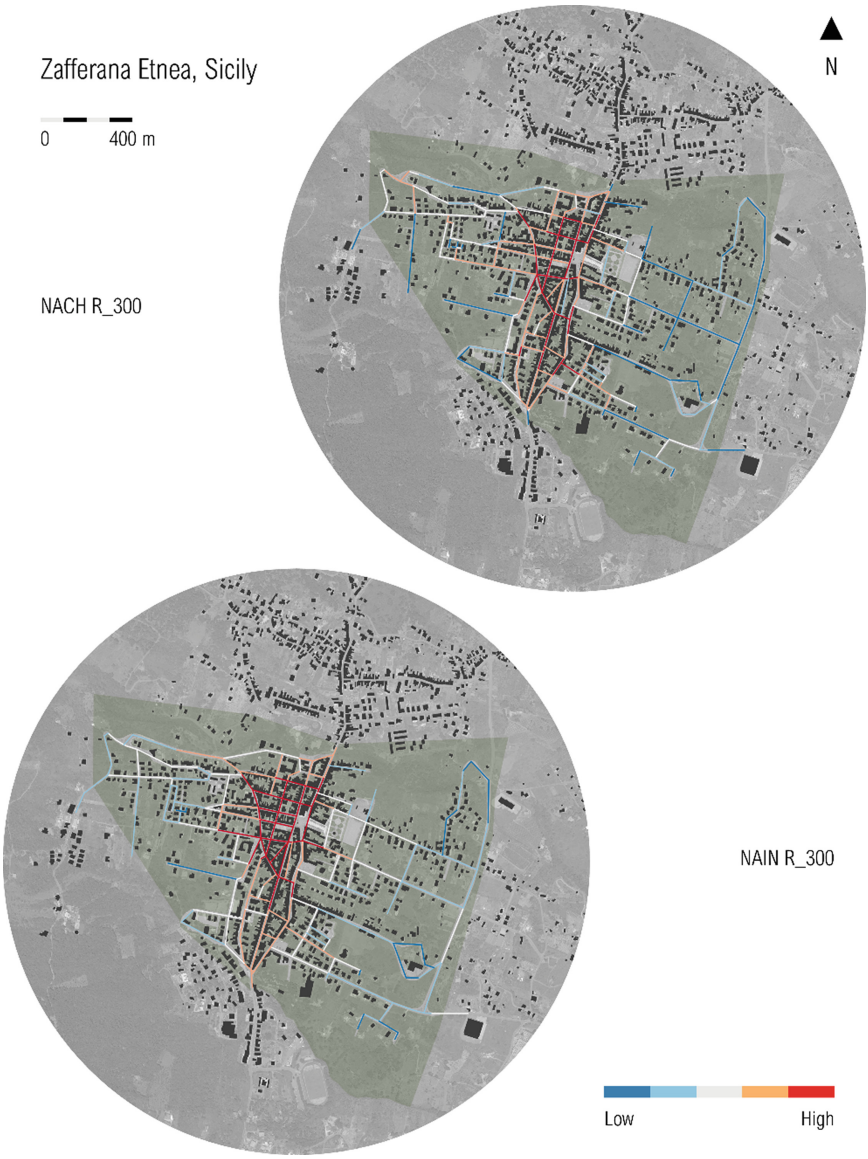

Fig. 3. Distribution of NACH and NAIN at radius 300 m (authors' elaboration).

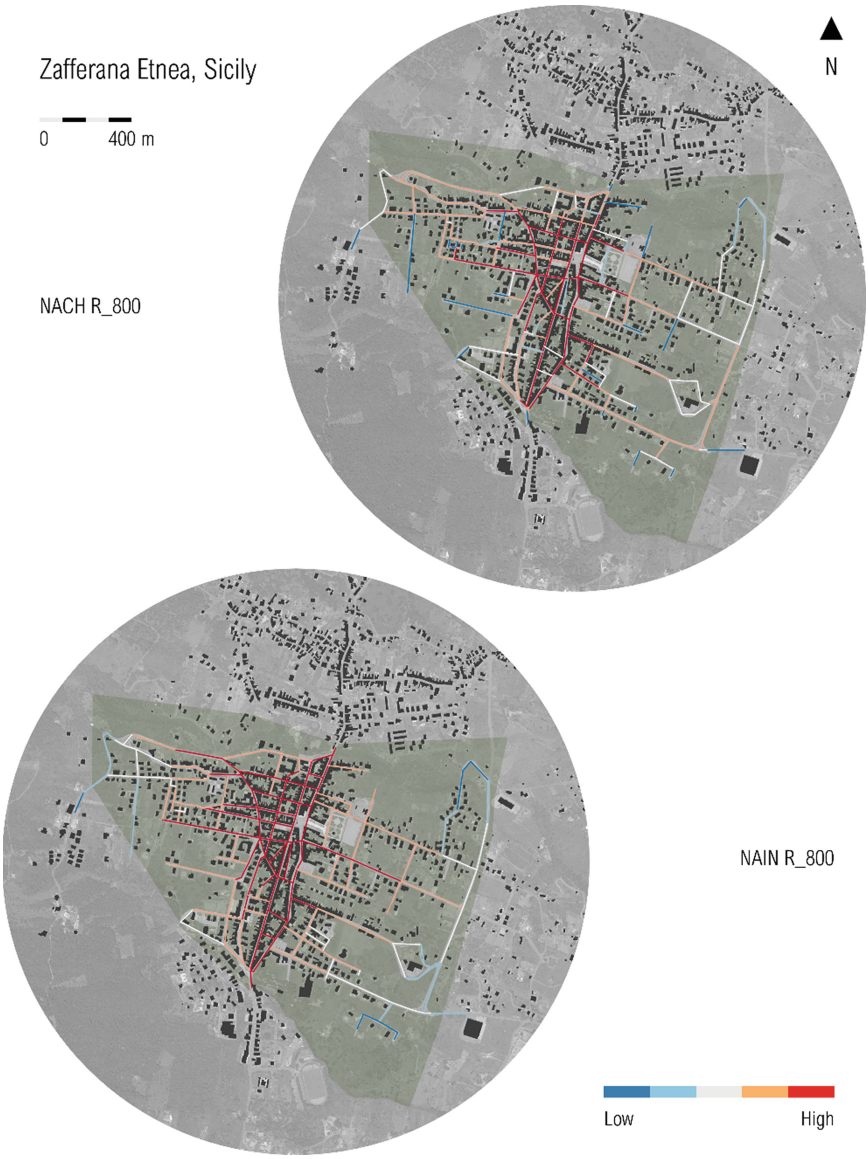

Fig. 4. Distribution of NACH and NAIN at a radius 800 m (authors' elaboration).

comprising the central compact area, including Roma, G. Garibaldi, F. de Roberto, S. Giacomo streets, and a sub-system of radial routes oriented from the central area to the edge of the urbanised area, and including E. Longo and Cassone Streets (Fig. 5), and resembling a deformed wheel structure [23].

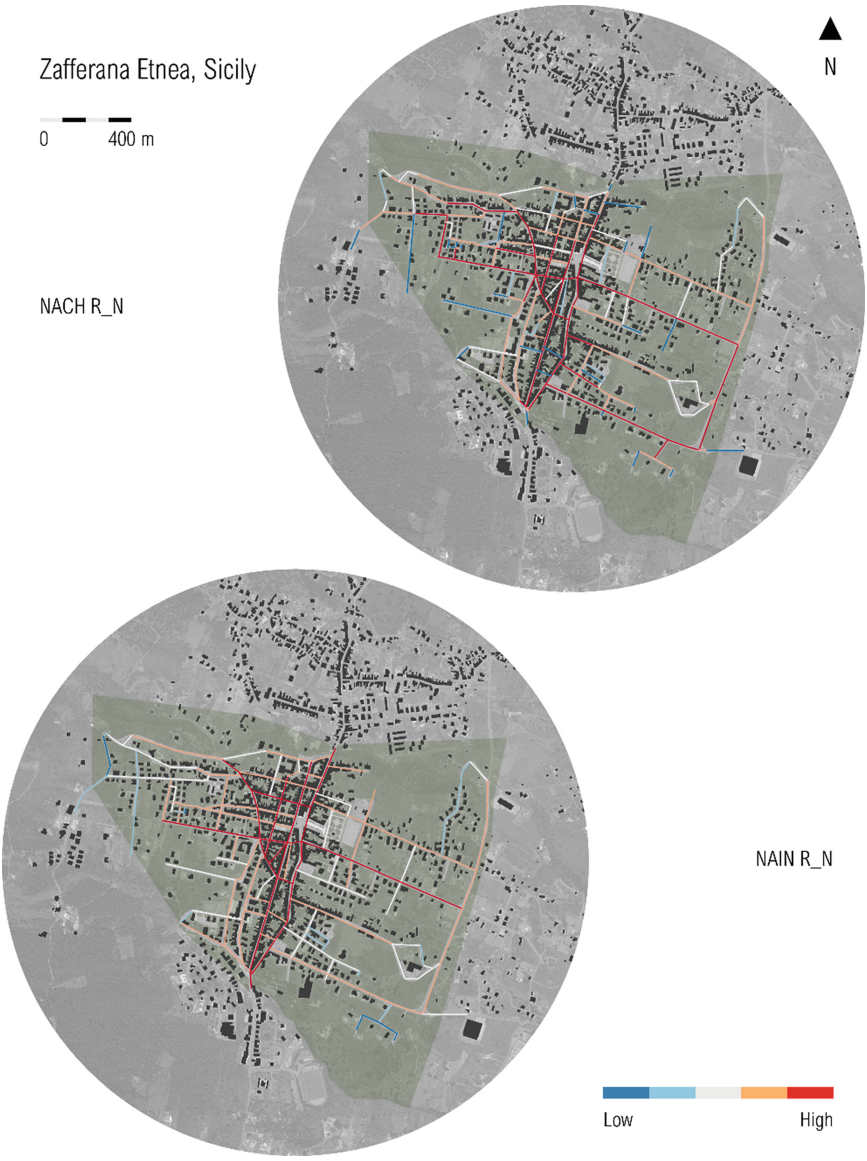

Fig. 5. Distribution of NACH and NAIN at radius n (authors' elaboration).

Moreover, the distribution of integration underlines a reticular structure of routes intersecting the central compact area and a radial structure of routes, including Roma, G. Garibaldi and S. Giacomo streets, connecting the central compact area to the edge of the urbanised area.

Lastly, the comparison of NACH at the local scale, calculated in a 300 m radius, and global scale underlines a centripetal structure of main routes at the local and urban

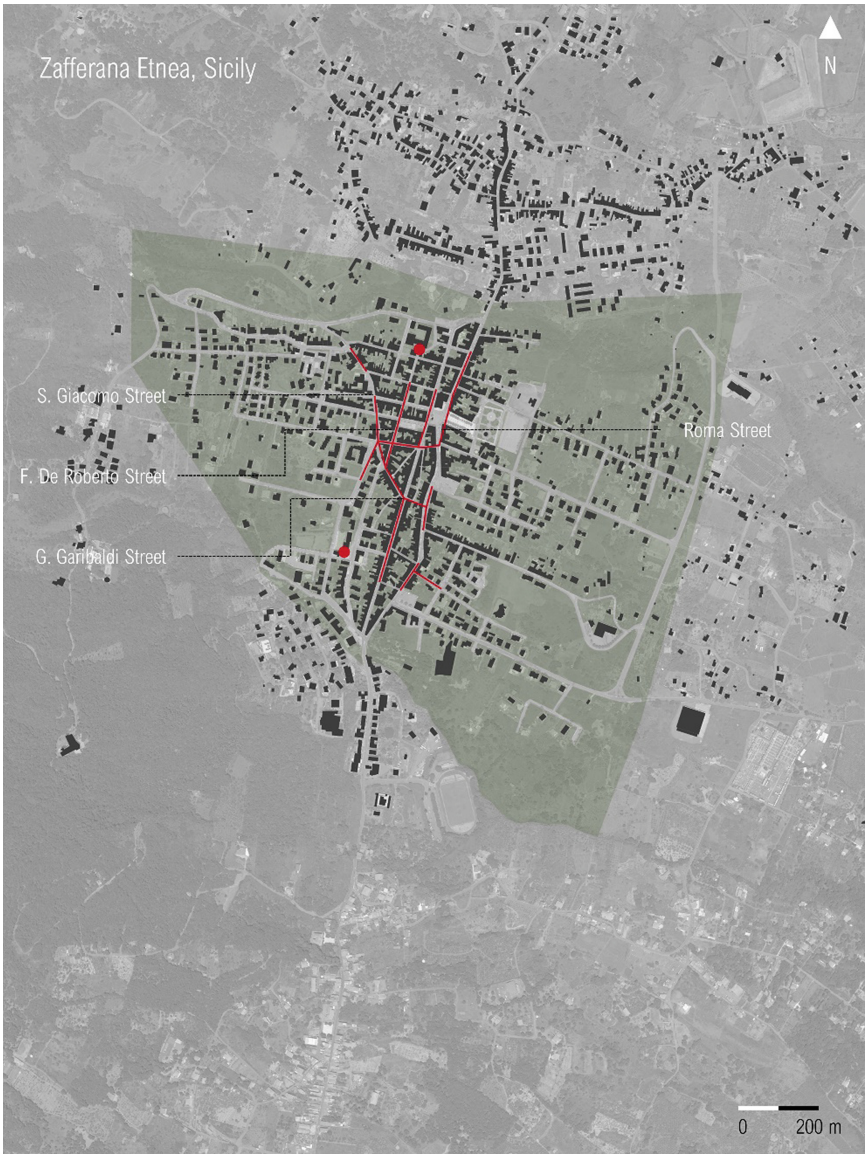

Fig. 6. Segments constituting a potential vibrant urban centre (authors' elaboration).

scale (Fig. 6) that present a significant spatial pre-condition for the emergence of vibrant central areas.

5 Discussion and Conclusions

Considering the territory's conditions and the exposure to seismic and volcanic activity. Zafferana Etnea requires particular attention in terms of urban planning and mobility. This small mountain municipality is an area to be re-evaluated in light of the recent Sustainable Development Goals of Agenda 2030, but especially in light of the organic measures aimed at promoting economic development and the recovery of territories for reversing the depopulation of the Italian mountain regions.

The urban layout, which twists down the slopes near the woodlands surrounding the volcano Etna, has been subjected to multiple powerful seismic events (1952, 1984, 2002) some of which caused irreversible damage, particularly in the city's hamlets. Despite this, the historical centre attracts many visitors from all over Italy also for a variety of religious and gastronomic events. These peculiarities motivate the spatial syntax analysis of this small urban centre, ensuring the understanding of the organisation's socio-spatial of built environments.

By assuming that space syntax is a theory of space and a set of analytical, quantitative and descriptive tools to analyse the arrangement of space in buildings and cities, the authors highlight its significant utility for the urban areas at risk, such as Zafferana Etnea. Not only does this enable the spatial configuration to be defined as relationships between spaces that take other relationships into account, and thus as relationships between all the various spaces in a system, but it also contributes to a more comprehensive vision for urban planning, mobility, and emergency planning.

This first step of research identifies the urban structure's features, namely finding a "vibrant historical centre" and a radial structure linking to the surrounding areas.

The normalised angular integration and normalised angular choice measures allow the recognition of a deformed wheel structure with central spaces for circulation and co-presence. Moreover, the emerging centripetal structure of central spaces at the local and global scale presents the spatial conditions favourable to the location of services and functions. Thus, these spaces become the focus of future studies, which will examine the underlying geometric and spatial conditions that influence pedestrian activities, and the interactions among the public open space and the enclosed private space of buildings.

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