Spatial configuration and the Messina Strait question: a discussion on Reggio-Calabria and Messina road-networks linkage

Abstract: A permanent traverse across the *Messina Strait* connecting Sicily to the Italian mainland at Calabria has been discussed since the 19^{th} century. From this period onwards, several studies addressed aspects that ranged: from its political significance; to project costs and engineering-design feasibility. Interest in the matter declined during the 2010's due to the ever-unstable Italian political scenario. This, associated to an incipient development of instruments and methods to analyze urban networks, has hindered further studies on *Messina* and *Reggio di Calabria* cities' spatial configuration, or the consequential changes that their permanent connection across the Strait would ensure. As the *Messina Strait* question resurfaced in the 2020-2022, exploratory analyses on urban configuration become crucial in providing spatial-knowledge for decision-making process, as Southern Italy's territorial and transport integration are part of the Italian government and European Union agenda regarding post-pandemic recovery. This paper addresses this question from a territorial-configurational standpoint and simulates spatial changes in the advent of a permanent connection amongst *Messina* and *Reggio di Calabria* road-circulation networks. The objective is to compare and discuss these changes within the context of twin-cities, as *Messina* and *Reggio di Calabria* have the potential to be interdependent in geographical and socio-economic terms. Modeled with *Space Syntax* – a quantitative method that estimates centralities and movement patterns in urban road-networks – simulations demonstrate how changes in the Strait cities' urban configuration could alter the twin-cities functional and hierarchical dynamics. Results and discussion present evidence on how the road-circulation networks react to the cross-strait connection, and conclusions point-out lessons to be learned from the simulations and what can be applied in other projects worldwide.

Keywords: Messina Strait; Spatial Configuration; Twin-Cities; Urban Morphology.

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1. Introduction

The rationale that supports a permanent traverse that connects *Sicily* – the largest and most populated Italian island – to the nation's mainland at *Calabria,* across the *Messina Strait*, revolves around accessibility improvements in transportation towards these peripheral regions at local, national, and European scales. Besides this, and the technical, political, and symbolic values associated with this idea (D'Antone, 2001), a traverse is thought as a manner to promote the economic development of Southern Italy. In that context, a permanent connection between the two sides of a *Strait* that is: both the Mediterranean gateway for important Italian productive regions and an entrance path for goods from Asia and the Middle East to European Markets[1]; have the potential to reinforce the importance of Italy's meridional region – which is historically a less developed area (Bagnasco, 1977) within the Italian economy.

Inserted on a rather unique geographical context (Figure 1), *Messina* and *Reggio di Calabria* are the largest urbanized areas set on opposite sides of the *Strait*. Those urban settlements possess intertwined urban dynamics, with their functional and socio-economic interactions

[1]This role is performed, in its most part, by *Gioia Tauro's* Transhipment Seaport, at Calabria. In 2020, *Gioia Tauro* was ranked as the 6^{th} most well-connected seaport in the world in terms of *betweenness* – the shortest path for trade between seaports – and one of the top 50 seaports with the most direct connections (UNCTAD, 2020).

being structured across the *Strait's* geographical barrier through a seafaring transportation system (Musolino, 2018; Musolino & Pellegrino, 2022). This area can be characterized within the twin-cities concept (Garrard & Mikhailova, 2019) as being "embryonic twin-cities" since, despite the absence of a conurbation – owing to the *Strait* divide – *Messina* and *Reggio di Calabria* still exhibit a sufficient spatial proximity, associated to a certain degree of social, economic, and labor interactions, that have the potential to be intensified, as well as a similar size and status in their respective regions' urban hierarchy (Musolino & Pellegrino, 2021).

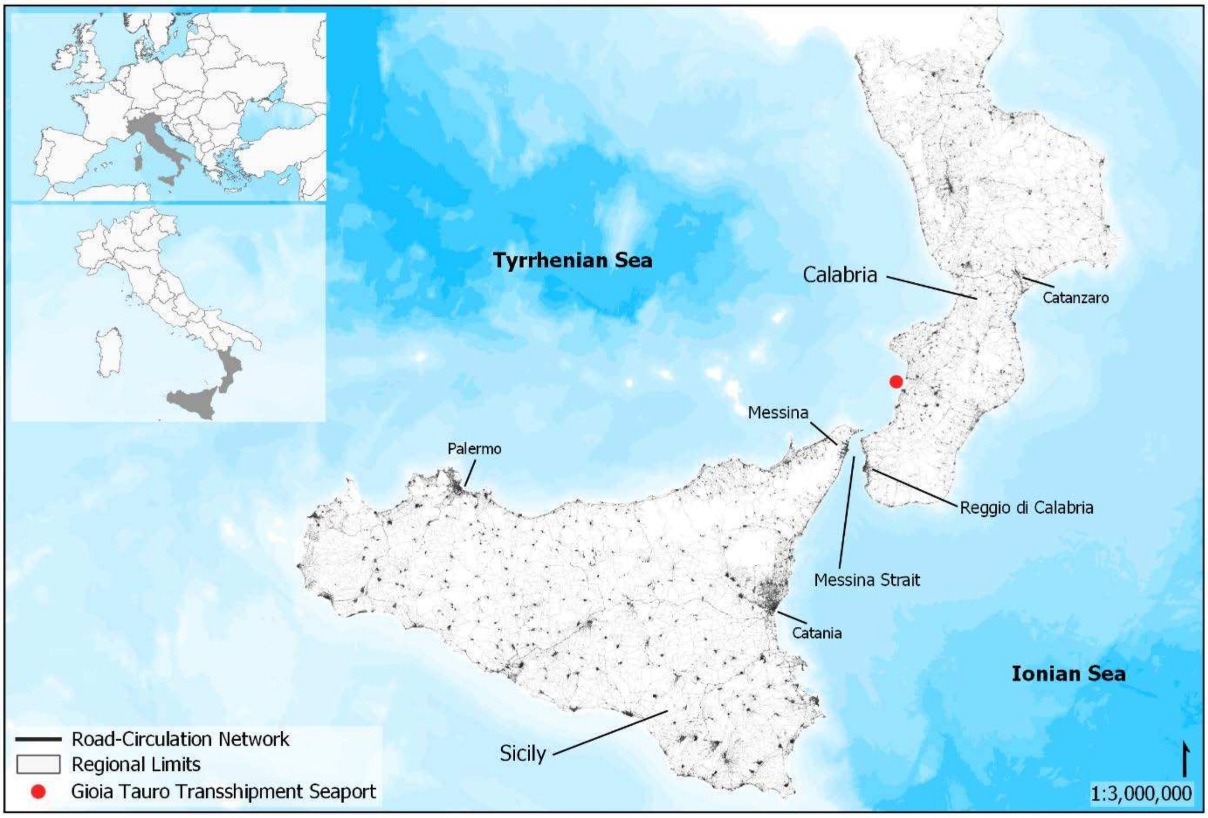

Figure 1. The Strait of Messina geographical context - Sicilian and Calabrian road-circulation networks

In that regard, a permanent traverse across the *Messina Strait* tends to restructure these urban areas' spatial configuration and morphology, creating a point of conurbation, altering land-use patterns and urban expansion tendencies across regional space. Such connection can also shift endogenous and exogenous movement dynamics in both cities (Kolossov & Scott, 2013).

As morphological processes are context-dependent (Kropf, 2011), interventions transcending geographical barriers can also lead to territorial, functional, and socio-economic changes, that can overcome – or increase – systemic unbalances related to spatial discontinuities. Hence, changes in the regional road-infrastructure can, in a positive outcome: enhance the spatial interdependencies and lead to the emergence of a Functional Urban Area (FUA) – minoring functional disparities, improving the regional competitiveness towards economic development (ESPON, 2003; Musolino & Pellegrino, 2022); or, in a negative outcome, lead to a hierarchization between the twin-cities, where one urban area surpasses and suppresses the other in functional and socio-economic relevance, through a process defined by Sohn et al. (2009) as "tunnel effects", where new connections tend to redirect movement away from urban functional centers. While important, aspects were not evaluated in the recent reports regarding the *Messina Strait* question (STM, 2021).

In this paper, the ongoing debate about the technical, political, and symbolic significances of the *Messina Strait* question is set on the background. The focus, instead, is on a rather unexplored topic – the potential morphological transformations of *Messina* and *Reggio di Calabria* urban agglomerates in the advent of a permanent road connection between their road-infrastructures. The main objective is to simulate and analyze *Messina* and *Reggio di Calabria* micro-regional road-circulation networks actual context, delimited by their Local-Labor Areas (ISTAT, 2019), and determine the potential outcomes from different traverse proposals on these cities' spatial configuration and morphology. Analyses are based on *Space Syntax'* methodology (Hillier et.al, 1993; Hillier, 2007), which conceptualizes that movement potentials within urban settlements can be estimated through the analysis of its spatial configuration. The simulations intend: a) to depict movement patterns and *preferential routes* changes for the current setting and each traverse proposal; b) to spatialize commuting nodes and urban hierarchies; c) to provide spatial information about configurational changes that can be related to functional centralities' emergence and possible transformations in the socioeconomic dynamics across the strait. Furthermore, these simulations serve as a baseline to evaluate how spatial configuration changes in each proposal are aligned with intended public policies and sustainable goals for the region, as well as what lessons can be learned and considered in similar connection proposals worldwide.

The paper is structured to provide a contextualization for the *Messina Strait* question, which addresses the political debate (2.1), the functional and socioeconomic characteristics (2.2) and the spatial characteristics of the area, as well as its relationship with national and European road-circulation systems (2.3). Datasets and Methods present a territorialization of the *Strait* in a GIS-environment (QGIS, 2020) (3.1), and present the *Space Syntax* methods and the configuration analyses used for constructing the models and simulations (3.2). Results (4.1) demonstrate morphological changes related to each traverse proposal, their discussion (4.2) ponders if these: enhance or hinder the current functional centralities; and preserve or alter the twin-cities road-circulation network hierarchical equivalences across the micro-region, to indicate the traverse proposal that better fulfills the Italian planning goals for the region. Conclusions then resume the findings and the discussion pointing out the lessons to be learned from the analyses and what can be applied in other connection proposals worldwide.

2. The Political, Socio-economical, and Geographical contexts of the *Messina Strait*.

2.1 – The political background of the Messina Strait question

Discussions about a table traverse across the *Strait* date back to the late 19th century as, from the 1890's onwards, several technical studies addressed the *Strait* undersea geomorphological characteristics. Nevertheless, it was not until the 1970's that the area received its first set of planning regulations, following the 1969 International Design Competition (Brancaleoni et.al, 2010). Debates proceeded throughout the 1970's, resulting in a plethora of essays published during the conference: *L'attraversamento dello stretto di Messina e la sua fattibilità* (1979), that included a cable-stayed bridge proposal for the Strait traverse. Those analyses were later procured by the *Stretto di Messina S.p.A*, a state-owned company created in 1981 to plan and oversee the bridge project and its construction. Several technical studies on costs, environmental impacts and engineering-design feasibility were conducted by the company and supported a detailed project, approved in 1992 by the Italian High Council of Public Works *(Consiglio Superiori dei Lavori Pubblici)*.

The ever-unstable Italian political scenario meant innumerous setbacks for the *Messina Strait* traverse project, as cancelations and reinstatements abounded in the 2000's and 2010's period. In 2003, a reworked proposal, based on the 1992 technical project was presented and then, in 2006 formalized in an executive contract. In the same year, the contract would be suspended by the Italian parliament. The project was then reinstated in 2008, during Silvio Berlusconi's mandate, a period in which it was also evaluated and integrated into the 2011 plans for the Trans-European Transport Corridors (TENT-T) (European Commission, 2013). Nevertheless, the project was indefinitely canceled in 2013 (Musolino et.al 2018), after budget constraints culminating in *Stretto di Messina S.p.A's* liquidation. Another reinstatement was considered in 2016; however, the discussions failed to attain enough public or political support.

In 2020, the *Messina Strait* was again brought into contention, as the Italian government stated the crucial role of a permanent connection between *Calabria* and *Sicily*, in improving transport networks, and promoting economic development in Southern Italy. A technical commission was created in Giuseppe Conte's government to re-evaluate possible alternatives – cable-stayed bridge and undersea tunnel – for the *Strait* traverse, which concluded its work in May 2021 (STM, 2021). Since then, the project remains on hold; its funding remained outside Mario Draghi's *National Recovery and Resilience Plan* (PNRR) (Repubblica Italiana, 2021) as, despite its focus on Southern Italy's development, the plan has a fixed deadline – 2026 – to finance and execute all the proposed transport-infrastructure works.

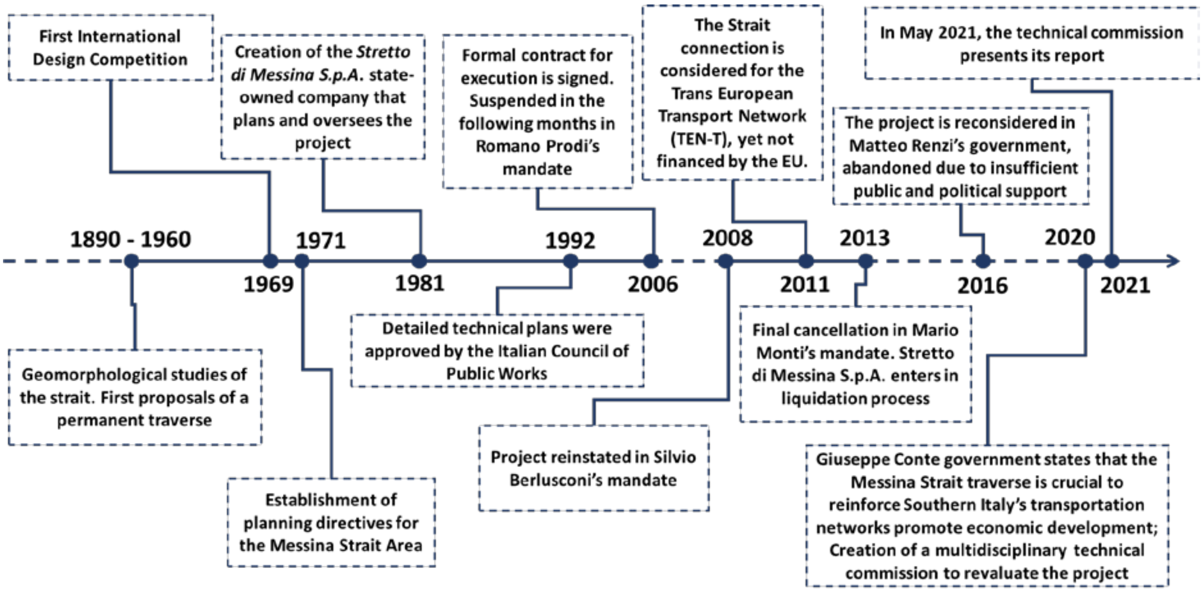

Figure 2. A brief timeline of the *Messina Strait* technical and political discussions.

2.2 Functional and socioeconomic aspects of the Messina Strait area

The *Messina Strait* is a geographical border that comprises a contradiction, as although it structures the interactions between *Messina* and *Reggio di Calabria* through the sea, it also establishes a "spatial barrier" that differentiates their socio-economic phenomena. This creates a division amongst urban areas, relevant in regional and national contexts, that would have otherwise an inclination to be integrated (Musolino, 2018; Reppublica Italiana, 2019).

Albeit in the boundaries of peripheral regions, the provincial capitals of *Messina,* with an area of 213km² and 227.424 inhabitants; and *Reggio di Calabria*, with an area of 239km² and 174.885 inhabitants, could, together, form the third largest urbanized area in Southern Italy in terms of population, after *Naples* and *Palermo*, with almost 6% of the total inhabitants (ISTAT, 2019). In the same manner, these cities possess importance in regional and macro-regional economic terms. As provincial capitals, they are reference business centers for more than 66,000 industrial and services firms, which employ over 165,000 people (Table 1, p.5).

Considering the aggregated numbers for the provinces of *Messina* and *Reggio Calabria*, the provincial capitals house 17.5% of the total business firms and 16.7% of the total number of employees. When related to Southern Italy, those values are still important, and correspond to, 5.3% for firms and 7.3% for employees in total. In terms of value added, one of the key indicators of local and regional economic development, *Messina* attains values over 10.3 billion euros, while *Reggio di Calabria* surpasses the 8.7 billion-euro mark. Together, both cities account for almost 18% of the total value added within their regions, and 5.5% of the total in Southern Italy (Table 1).

Table 1. Socio-economic data for *Messina* and *Reggio di Calabria* – Aggregated urban areas and overall percentual participation when compared with aggregated regional totals (*Calabria* and *Sicily*) and aggregated macro-regional totals (Southern Italy)

Socio-Economic Data	Total (Urban Areas)	Aggregated – Calabria and Sicily (%)	Aggregated - Southern Italy (%)
Population			
Reggio di Calabria	536.487	28,1%	2,6%
Messina	618.713	12,6%	3,0%
Messina and Reggio di Calabria	1.155.200	16,9%	5,7%
Value added (Millions €)			
Reggio di Calabria	8.674	31,1%	2,4%
Messina	10.337	12,9%	2,9%
Messina and Reggio di Calabria	19.011	17,6%	5,3%
Businesses			
Reggio di Calabria	28.308	26,1%	2,3%
Messina	38.407	14,1%	3,1%
Messina and Reggio di Calabria	66.715	17,5%	5,3%
Employees			
Reggio di Calabria	66.486	25,6%	2,7%
Messina	99.311	13,5%	4,6%
Messina and Reggio di Calabria	165.797	16,7%	7,3%

Source: Elaborated by the authors based on ISTAT data (2019)

Messina and *Reggio di Calabria* have had a historical functional complementarity and shared several potentialities to integrate their independent productive, exchange and logistics hubs (Gambi, 1965). This complementary, already noted in the 1960's, persists nowadays, as recent studies based on economic quantitative indicators – such as locational quotients – reveal important sectorial spatializations on both sides of the *Strait* (Musolino & Pellegrino, 2021; 2022). Hence, tendencies still point-out towards a path of interdependence between the productive activities among both *Messina* and *Reggio Calabria* provinces.

Regarding the industrial sector, *Messina's* main branches are in energy, oil, chemical, plastics, steel, and textile production – with *Milazzo's* refinery and steel mill being important sources of revenue for the province. *Reggio Calabria's* province, instead, specializes in the lumber and furniture, and in the food and beverages sectors, associated to the Calabrian tradition in agriculture, wine, citrus and olives production along the Tyrrhenian and Ionian coasts. In the services sector, *Messina* holds an important specialization in tourism, as well in healthcare, while *Reggio Calabria* stands outs in transport and logistics, housing the only commercial airport in the *Strait* area, as well as Italy's largest transshipment seaport – *Gioia Tauro*[2], that establishes the seafaring connection with regional and global shipping networks, especially serving traffic coming from Southeast Asia countries such as Singapore, Malaysia, and China. Therefore, *Reggio Calabria* has the potential to perform a strategic role in exports, given the industrial production on *Messina's* side and its own agro-industrial production.

[2] In 2021, *Gioia Tauro* handled more than 38 million tons of goods and almost 3.15 million containers, being the ninth in Europe and the fifth in the Mediterranean in terms of container traffic. For more information, see: https://www.assoporti.it/media/10454/adsp_movimenti_portuali_2021-agg140322.pdf https://www.porteconomics.eu/?s=Gioia+Tauro.

Complementarities across the *Strait* are, however, hindered by inadequate seafaring-based transportation (Delfino et al., 2011), despite the presence of several ports with rather diverse functions. On the Sicilian side, there is the *Messina* port that, besides its main docking area, has two smaller boarding sites in the north – dedicated to vehicle ferries – and in the south, in the *Tremestrieri* port, which is mainly dedicated to cargo freights. In the Calabrian side, besides the multipurpose port *Reggio di Calabria*, there is the *Villa San Giovanni* seaport, which handles passengers, vehicles, and railroad freight cargo, being the maritime connection between the road-circulation networks on both sides of the *Strait* (See: Figure 4, p.8).

One would expect, given the importance of these cities, the presence of several seaports and their geographically adjacent positions, that this would lead to intense commute relationships. Nevertheless, data demonstrates that those movements are rather limited, owing to the shortcomings pointed out in Delfino et al. (2011).

Commute flows across the *Strait* amount to less than 5,000 a day, and account for only 1.7% of the total commutes within *Messina* and *Reggio di Calabria* metropolitan areas. In addition to that, the number of journeys in-between the provincial capitals has declined by 45% in the period from 1991 to 2011 (Musolino & Pellegrino, 2022). The yearly passenger traffic across the *Messina Strait*, is, however, is considerable: in the 2019-2020 period, passenger transit in *Strait* ports amounted to over 36 million people, 48.7% of this total, in *Messina's* ports. Much of this traffic is made of non-commuter movements with supra-local origin, therefore, associated to tourism, a factor that also explains the verified reduction of 60.2% in the number of passengers from 2019 to 2020 (Delfino et al, 2011; *Autorità di Sistema Portuale dello Stretto*, 2021), which may be related to travel restrictions due to the COVID-19 pandemic. Additional evidence regarding functional integration hindrances comes from private-sector data, as cross-strait investment flows are also limited: subsidiaries located in *Reggio di Calabria* and *Villa San Giovanni* owned by firms based in *Messina* represent 1.4% of all subsidiaries, while the percentage in the opposite direction is 0.8% (Musolino, 2018).

2.3. The Strait and the Local, Regional and Supra-regional circulation networks

Italian territorial planning policies emphasize a sustainable urban-regional development that, while it considers the cities' local importance, it also considers their position in relation to the European context (Dematteis and Bonavero, 1997; Dematteis, 2008). Thus, the *Messina Strait* traverse, beyond a proposal oriented to local, regional, and national development, is likewise inserted into the scope of the European Territorial Frames (ETF's) and of a *Trans-European Transport Network* (TEN-T) (European Commission, 2013).

Di Ludovico, et al. (2021) demonstrate that most areas in Southern Italy remain currently excluded from the ETF's that define Europe's Main Urban and Productive Agglomerations (MEGAs) (ESPON, 2005), due to their limited reach and density of their road and railroad infrastructure when compared to Northern and Central Italy. Moreover, it is demonstrated that the absence of a permanent connection between *Sicily* and *Calabria*, jeopardize the otherwise significant road and railroad traffic that exists among the independent extents of *Messina-Catania*, *Messina-Palermo,* and *Reggio di Calabria-Naples*; important as *Naples* is Southern Italy's potential MEGA (Di Ludovico et. al, 2021, p.7).

The completion of the tract between *Messina* and *Reggio Calabria* would finalize the TEN-T Helsinki-Valletta Corridor (Figure 3), integrating Europe's northmost and southmost regions. These aspects corroborate the *Messina Strait* traverse not only as a project of national interest, for regional development, but also attest to its importance at a European scale.

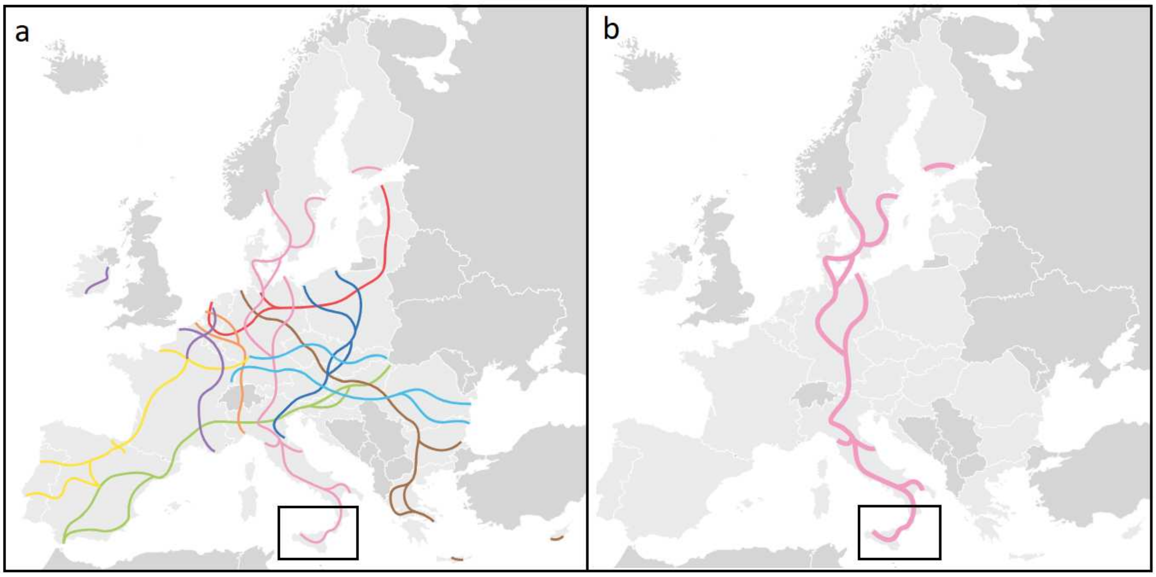

Figure 3. Messina Strait relative position towards Trans-European Transport Networks (a) and Helsinki-Valletta Corridor (b). © Wikimedia Commons, 2021**.**

While similar in their overall spatial structure, fundamental differences arise amongst *Messina* and *Reggio di Calabria*, when their relations with regional and supra-regional road-circulation networks are considered.

Messina's urban area is an important node set in the extremity of a secluded, albeit continuous road-network, the *Sicily Island*. Given the relative nearness among the cities, it constitutes a commute-functional area with *Catania*, *Sicily's* second largest urban area after the regional capital, *Palermo,* that is established along the *Strait coast* towards the south (Figure 1, p. 2). *Reggio di Calabria*, although a main node in Southern Italy, central within a fragmented and non-cohesive network of small urban settlements, is one of the outermost nodes in the Italian mainland road-circulation network, being also at the extremity of its regional-bound system. Moreover, its urban area is rather distant from other large urban centers, such as the regional capital, *Catanzaro* (Figure 1, p.2), thus, placed in a relatively segregated position (ISTAT, 2011; 2019; ESPON, 2014)

Still, a connection among these hierarchically distinct road-circulation networks at a regional scale tends to also change endogenous and exogenous movements in both urban areas. While at regional and supra-regional scales, these effects tend to be rather minor, as the movements tend to become concentrated in the traverse and distributed across both sides of the *Strait*; those transformations tend to be quite profound at local and micro-regional scale, which are more sensible to alterations in movement dynamics.

In this context, the geographical position in which the *Messina Strait* traverse is set can lead to the emergence of rather different accessibility patterns and *preferential routes* at local and micro-regional scales, that cannot be addressed without a configurational analysis. Hence, it is important to simulate the potential effects that underlie the connections' positioning on the urban agglomerates' morphologies, to provide a necessary analytics framework that ponders the effects on spatial integration and shared functional centralities for the area, allowing to see if the projects comply with the sustainable goals for the region.

3. Datasets and Methods

3.1 Configurational databases and territorialization

To evaluate the morphological changes in Calabrian and Sicilian road-circulation networks that result from different connection proposals across the *Messina Strait*, we must address the systems' configurational properties. This requires processing of several Road-Centre Line (RCL) graphs, that highlight different network centrality metrics.

Compatibility among the configurational models is ensured through using a same road-graph database, obtained from the OpenStreetMap (2021) repository. Databases comprise the whole Calabrian and Sicilian road-circulation networks (Figure 1, p.2) and are generalized to exclude any road-elements unsuited for configurational analysis – parking-lots, cableways, waterways, mountain trails, etc., which are not representative of vehicular-based movement and distorted the overall results. Regional maps are sectioned to comprise the road-infrastructures set in the municipalities that comprise *Messina* and *Reggio-Calabria* Local-Labor Areas (*Sistemi Locali di Lavoro – SLL)*, which consists in the territorialization used for our analysis (Figure 4).

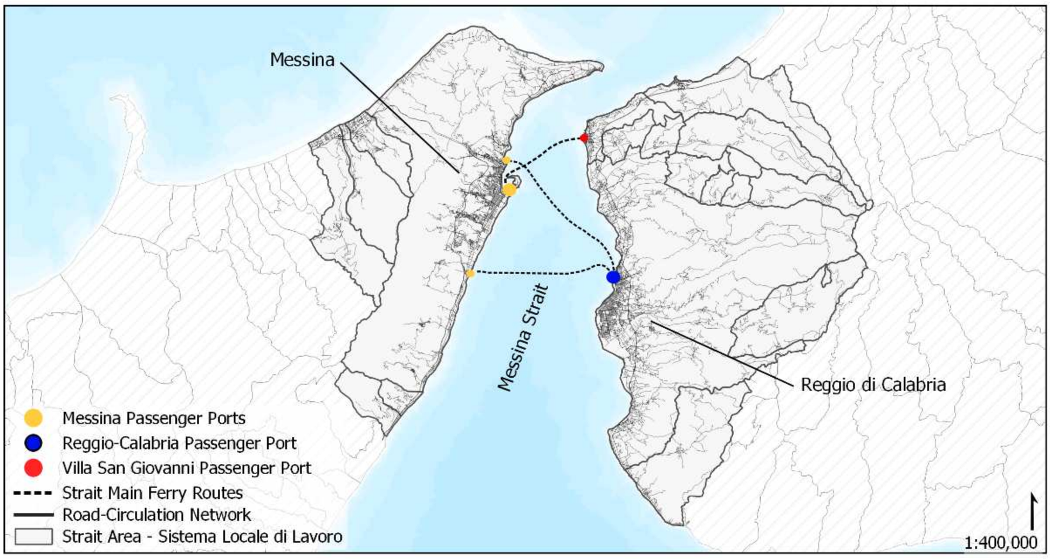

Figure 4. *Messina* and *Reggio Calabria* Local-Labor Areas (*Sistemi Locali di Lavoro - SLL*) territorial division and passenger ports' location.

Local-Labor Areas represent a functional-based territorialization of Italy defined by the Italian Statistics Institute (ISTAT) and represent the areas "where most of the population that comprises the labor force inhabits, works and tends to exercise their socioeconomic relations; and where the firms can find the main part of the labor force necessary to occupy the offered job positions" (ISTAT, 2014).

The extent of the Local-Labor areas is defined by the degree of attraction of a central city, which concentrates the internal and external commuting flows from the surrounding towns. Both *Messina* and *Reggio di Calabria* are the main cities within their Local-Labor Areas, which comprise respectively 6 and 12 municipalities[3]. In the current setting, urban commute dynamics between *Messina* and *Reggio Calabria's* Local-Labor Areas are structured by the passenger seaports located in *Messina*, *Villa San Giovanni*, and *Reggio di Calabria*

[3] Municipalities of the Local-Labor Areas - in the Sicilian side: *Messina, Itala, Rometta, Saponara, Scaletta Zancela*, *Villafranca Tirrenia;* in the Calabrian side: *Reggio di Calabria, Campo Calabro, Calanna, Cardeto, Fiumara, Laganadi, Motta San Giovanni, San Roberto, Santo Stefano in Aspromonte, Sant'Alessio in Aspromonte, Scila, Villa San Giovanni.*

municipalities (Figure 4, p.8). It is important to note, however, that since maritime routes do not possess a rigid spatialization, and can diverge according to sea conditions, those connections are not considered in the configurational analysis, as our network analysis methodology requires a strict spatialization. From the Local-Labor area graphs (Figure 4, p.8) we draw the traverses across the strait, connecting the road-infrastructures, in order to analyse three cases (Figure 5).

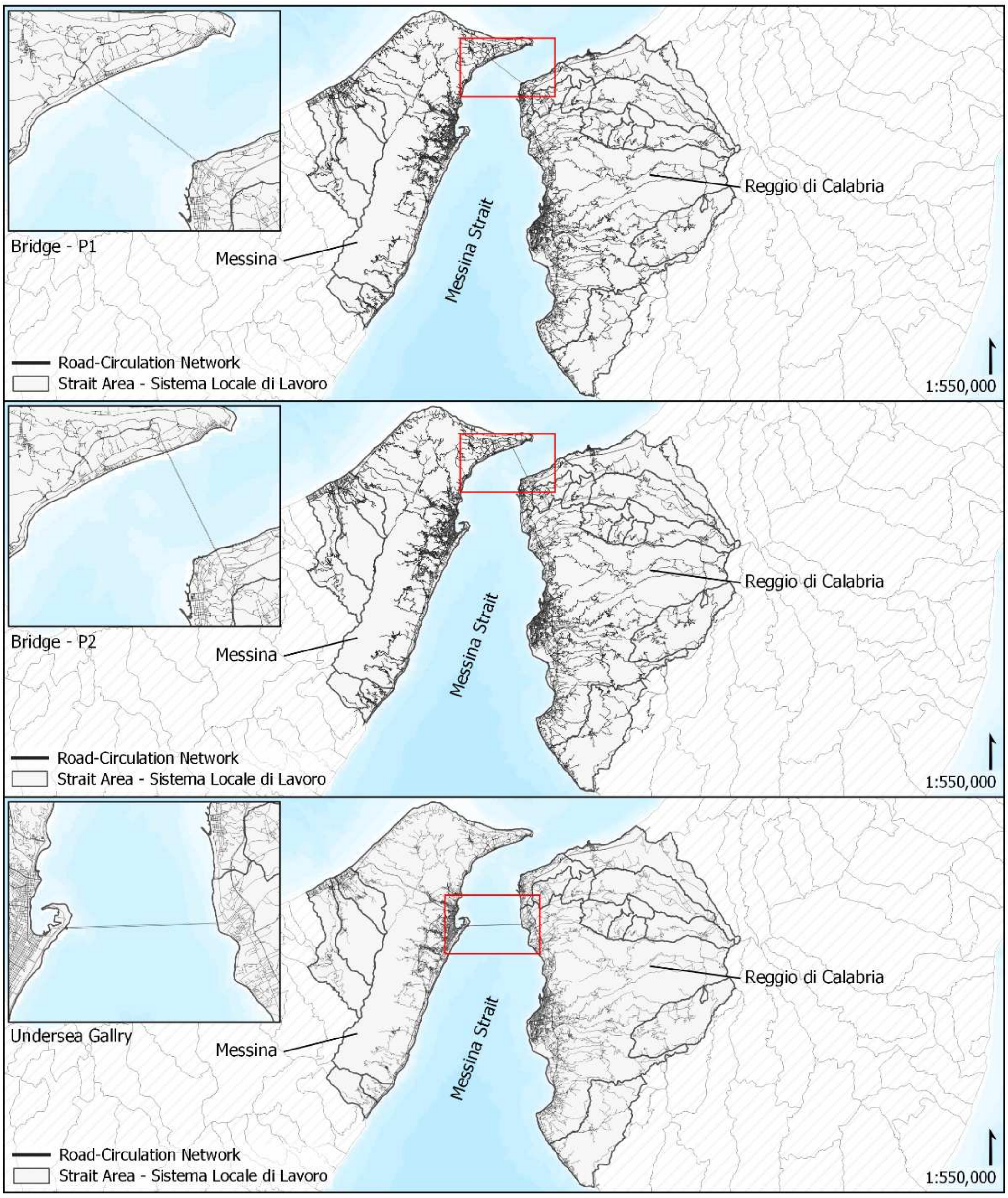

Figure 5. *Messina* and *Reggio Calabria* Bridge P1, Bridge P2 and Undersea Tunnel traverse proposals.

Five models are constructed based on the projects mentioned in Brancaleoni et.al. (2011) and the STM (2021) report: the Messina Local-Labor Area; and the Reggio-Calabria Local-Labor Area independent road-circulation networks (Figure 4, p. 8); two systems comprising the connection both Local-Labor Areas through distinctly placed suspended bridges (P1 – that represents the proposal discussed in 2021, and P2 – that represents the 2013 canceled project insertion), and a system connecting both Local Labor Areas through an undersea tunnel (Figure 5, p.9).

In a recent viability assessment, Saccà (2019) described and amended the traverse proposals described by Brancaleoni et.al. (2011), which envisioned further road-infrastructure changes, with planned expansions for the Calabrian and Sicilian highway systems, most of which were also considered in the 2021 working group report (STM, 2021). The proposed configurational analysis, however, does not incorporate all the transit-oriented amendments that are set to extend beyond *Messina* and *Reggio-Calabria's* Local Labor Areas. Additions are restricted to the access roads and highway structures that connect the current road-circulation network and the envisioned strait traverse structures, maintaining current grid morphologies mostly unaltered, since the objective is to evaluate the linkages effects on the regional setting, not the entire highway projects. Therefore, the plans depicted in Brancaleoni et al. (2011), in Saccà (2019) and in the STM (2021) report were only used as references in the models' to set the positions where the bridges and the undersea tunnel are to be built.

3.2 Configurational methods and spatial analysis

To construct the configurational models, we use Space Syntax Angular Analysis (Turner, 2001), a methodology that models RCL-based networks road-infrastructure configuration and measures (Turner, 2005; 2007): its movement potentials – Angular Integration metric – and its *preferential routes* hierarchies – Angular *Choice* metric.

Angular Analysis' initial step consists on creating angular segment maps in the in DepthMapX 0.8 (2020) software, where RCL road-elements' are converted in the vertices of a j-graph (Figure 6). These are then weighted according to the angle (angular coefficient) between each connected pair of vertices (road-elements). The polylines that represent roads in a graph are then segmented (angular segmentation) depending on angle variations (in radians) amidst the vertices' pairs (t-intersections, crossings); continuity among road-elements is preserved when no interruptions or direction changes happen (Figure 6).

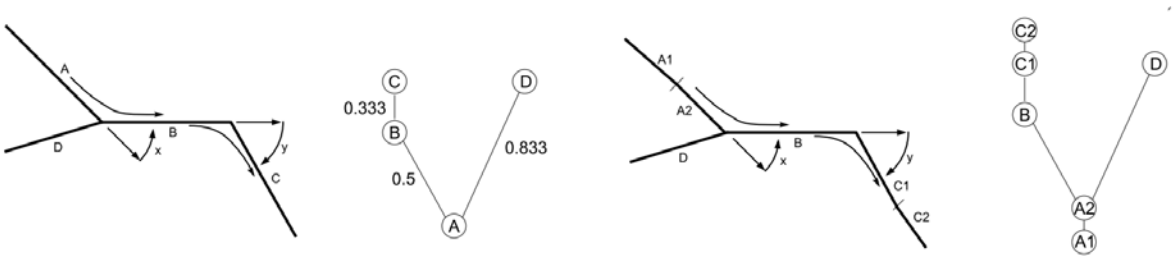

Figure 5. Angular segmentation principles, angular coefficients and graph decomposition (Turner, 2005)

Angular coefficients are individual values that correspond to a weighted topological step and allow to assess depth differences between the urban spaces (road-elements) through considering the shortest angular paths from each road-element to all possible destinations in the network. Depth is a component used to calculate network centrality hierarchies; in Space Syntax (Hillier. 2006), Angular Integration, an equivalent to *mathematical closeness* centrality, uses depth to calculate the average costs of traveling over the shortest paths, with minimum change of directions from each road-element to all possible destinations in the network. Hence, it depicts a road-element *to-movement* potential, or its *relative accessibility* – how central a road-element position is in comparison to all other road-elements depth. On the other hand, Angular *Choice* counts the number of times a road-element is traversed, considering the shortest angular paths, from each road-element to all possible destinations within the network. Being the Space Syntax equivalent to *mathematical betweenness* centrality, this measure depicts the *through-movement*, or the *preferential routes* in the system structure. Normalizing Angular Integration and *Choice* results is a fundamental step for comparative studies that depict systems with different depths and sizes terms of road-elements number. Normalized Angular Integration (NAIN) and Normalized Angular *Choice* (NACH) (Hillier, et al., 2012) bring *closeness* and *betweenness* absolute values to comparable ranges, by weighting them by each system's Total Depth, thus, its size. This allows qualitative and quantitative comparisons regarding centralities' distribution, hierarchies, and values. NAIN and NACH have significant correlations with the positioning of economic activities (Altafini, et al., 2021), and the Space Syntax theories support the concept of monopolistic attractors (Cutini, 2001), urban equipment that generate and attract movement within the road-circulation network despite their relative accessibility within the urban grid.

Such analyses are important, as they manage to depict how from determines the spatial configuration in terms of: a) movement potentials – which inform tendencies functional centralities emergence at urban and regional scales; and b) *preferential routes*, that inform freight and transit at both urban and regional scales. From these measurements, it is possible to infer how changes imposed by the connection across the strait might enhance – or maintain – polycentricity tendencies, create or reinforce tunnel effects, or change the urban hierarchy structures, therefore transforming the interactions between the urban agglomerates. Such changes can lead to complementarity or specialization of the consolidated urban centralities, as well as changes in commuting patterns. Simulations are then spatialized on a GIS-environment (QGIS, 2020), and compared regarding their configurational properties.

As a complement to the qualitative and quantitative configurational analysis, we also estimate a Lorenz Curve (Lorenz, 1905; Pezzica et.al, 2022) using the models' NAIN and NACH data. In economics, this curve is used to represent differences in income distribution, compared to an ideal, equal distribution. Here, instead, we use the Lorenz Curve, not to compare with an ideal setting, but to plot and compare the NAIN and NACH values distribution across the models. This relatively simple statistical analysis is appropriate to better address the differences between the connected systems, and how much those conserve or diverge, in terms of their centralities distributions, both from the current state, defined by the independent systems of *Messina* and *Reggio Calabria*, and among the different traverse proposals.

4. Results and Discussion

4.1 Configurational Analysis Results

Results for the independent networks' models demonstrate that the *Messina* Local-Labor Area has higher NAIN absolute values than the *Reggio Calabria* Local-Labor Area, attributable to its larger integration core extension (Table 2; Figure 7, p.12). Still, both systems are similar in that regard, being characterized by compact urban cores possessing predominantly orthogonal grid morphologies, which define non-hierarchical and pervasive functional centralities.

Table 2. System Characteristics and Normalized Angular Integration and Normalized Angular *Choice* minimal and maximal values.

Measured System	System Characteristics	NAIN – Min. Max. Values	NACH – Min. Max. Values
Messina SLL	Independent Network	0.076 – 0.379	0.000 – 1.491
Reggio-Calabria SLL	Independent Network	0.041 – 0.243	0.000 – 1.329
P1 - Suspended Bridge	Linked Network	0.046 – 0.297	0.000 – 1.436
P2 – Suspended Bridge	Linked Network	0.045 – 0.295	0.000 – 1.430
Undersea Tunnel	Linked Network	0.047 – 0.327	0.000 – 1.428

Both *Messina* and *Reggio di Calabria* urban expansions tend to linearity, as their urbanization spread through axes parallel to the seashore. These inform a rather constant distribution of *relative accessibility* values across their historical and functional centers The integration core in *Reggio di Calabria* municipality extends beyond its municipal borders, towards *Villa San Giovanni* municipality and the passenger seaport establishes one of the seafaring connections between the twin-cities (Figure 7, p. 12). Urban core linear characteristics also explain the higher NACH values found for the *Messina* Local-Labor Area, where the urban expansion morphology drives a longer, continuous, and more interconnected axis that tends to capture vehicular flows along the coastal areas (Table 2, Figure 8, p.12).

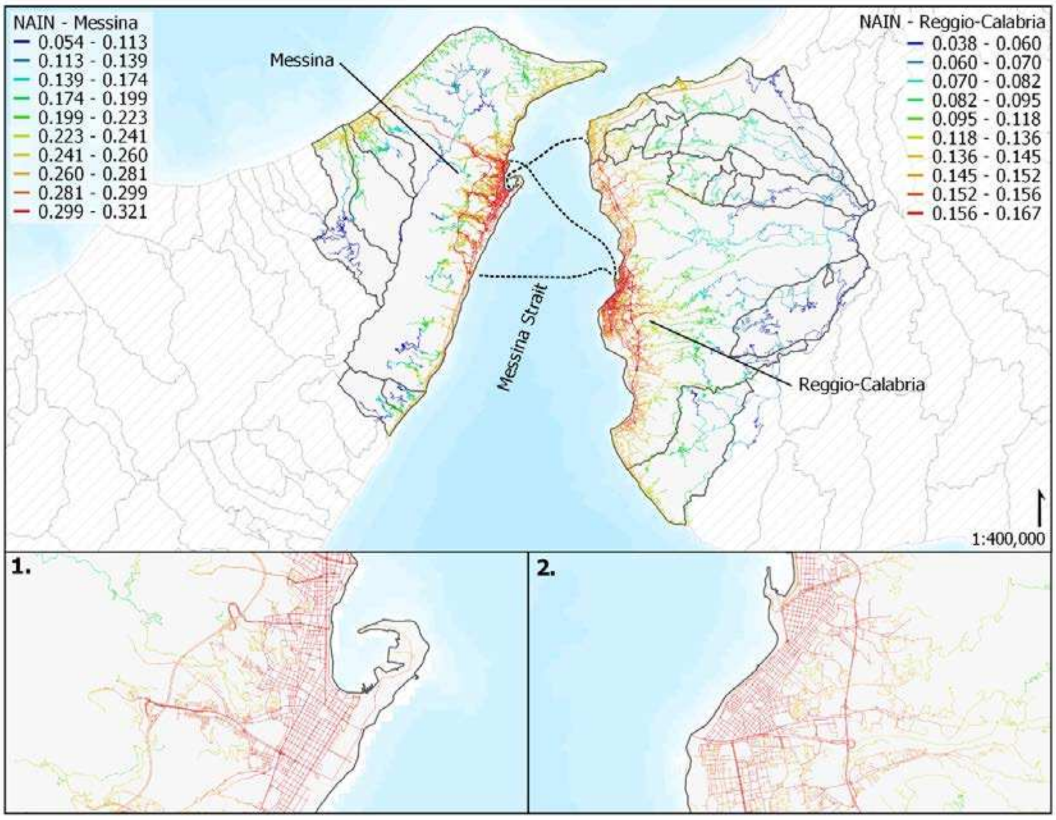

Figure 7. Normalized Angular Integration (NAIN) analysis for the independent *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation network.

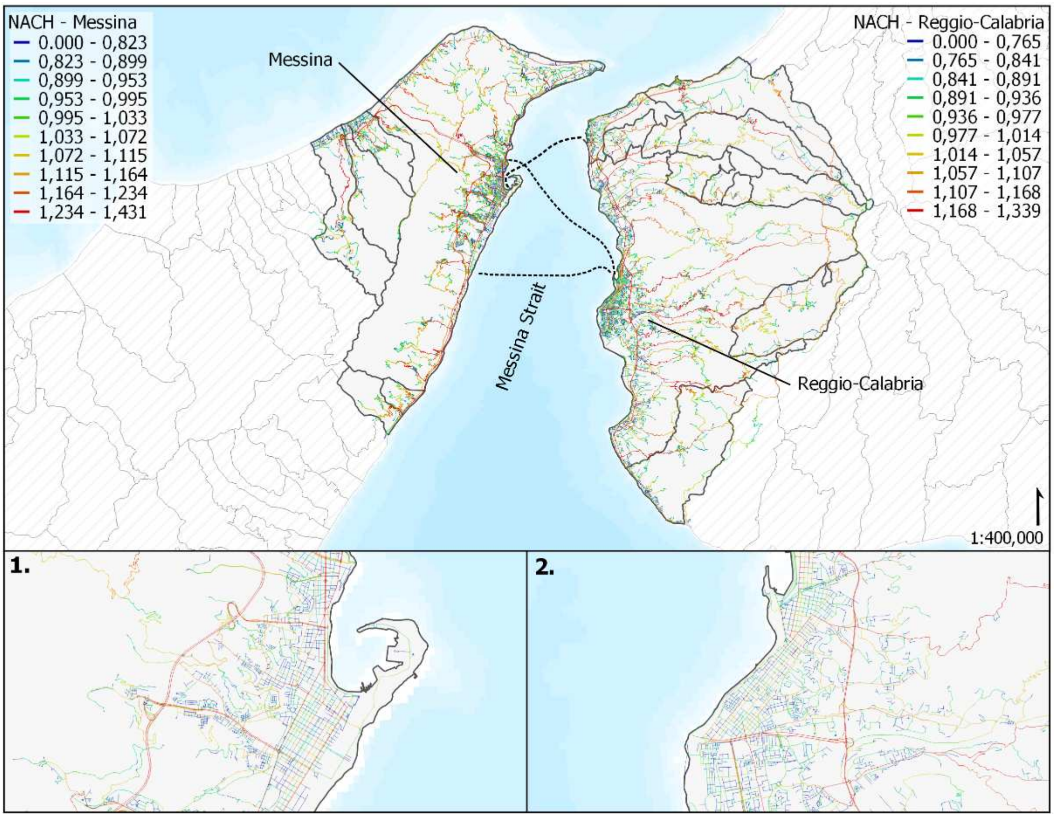

Figure 8. Normalized Angular Choice (NACH) analysis for the independent *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation network.

Messina and *Reggio Calabria* Local-Labor Areas demonstrate a significative fragmentation of their road-circulation networks towards their hinterland areas, which leads to overall lower

NAIN values and a segregated condition for the remainder municipalities that are set within mountain and valley areas. Integration cores' peripheries are confined by highway systems characterized by partial ring-roads surrounding both cities functional centralities.

Albeit *relative accessibility* distribution logics tend to be similar for both urban areas, *Reggio di Calabria* possess an important morphological contradistinction when compared to *Messina*, as the southmost area of its functional centre – where the *Reggio Calabria's* airport is located – is set beyond a natural divide, the *Calopinace* river. This imposes a hierarchical difference in *relative accessibility* patterns, as the roads alongside the river confine the historical urban core and divide *Reggio di Calabria's* functional centrality area. These roads are *preferential routes* in the system and capture movement due to its linkage with the highway system that commands the urban expansion axes (Figure 7, p. 12; Figure 8, p.12). Although differences in overall NAIN values between those areas are negligible for the independent system, this divide undermines the even distribution of *relative accessibility* within the functional core. Therefore, this can constitute an element of fragility, which has the potential to produce a *segregated* space in *Reggio di Calabria* urban system in the event of configurational changes that substantially alter the overall hierarchies within the spatial network.

Several configurational transformations happen in the road-circulation network when *Messina* and *Reggio Calabria* Local-Labor Areas are connected by a single axis, either being the Bridges or the Undersea Tunnel. Spatial modelling anticipates an extensive reorganization of the systems' *relative accessibility* patterns and functional centralities distribution on all three cases (Figure 9, p.13; Figures 10, 11 p. 14). NAIN absolute values shift towards intermediate ranges, lower than the ones observed in *Messina* independent network but still higher than the ones found in *Reggio Calabria's* Local-Labor Area (Table 2). The NAIN Lorenz Curves demonstrate that the Undersea Tunnel tends to have a distribution that is closer to the *Reggio Calabria* system, while both bridges are closer to the *Messina* system (Figure 12, p.15).

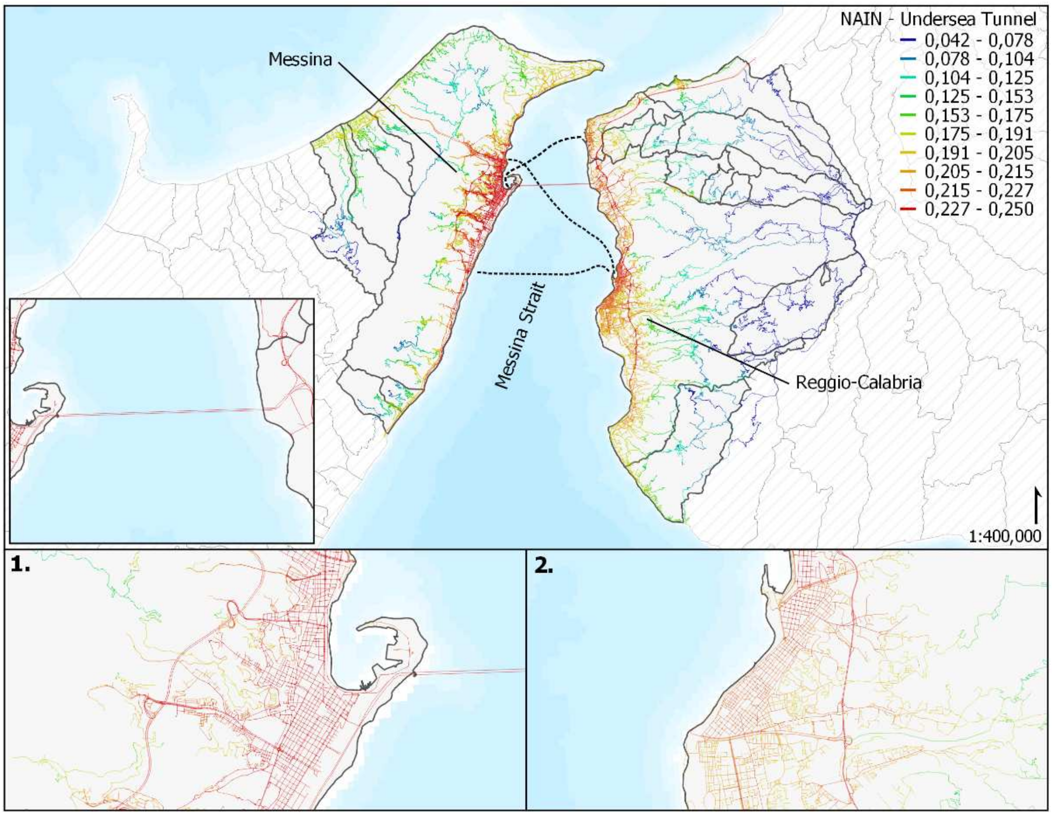

Figure 9. Normalized Angular Integration (NAIN) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Undersea Tunnel proposal.

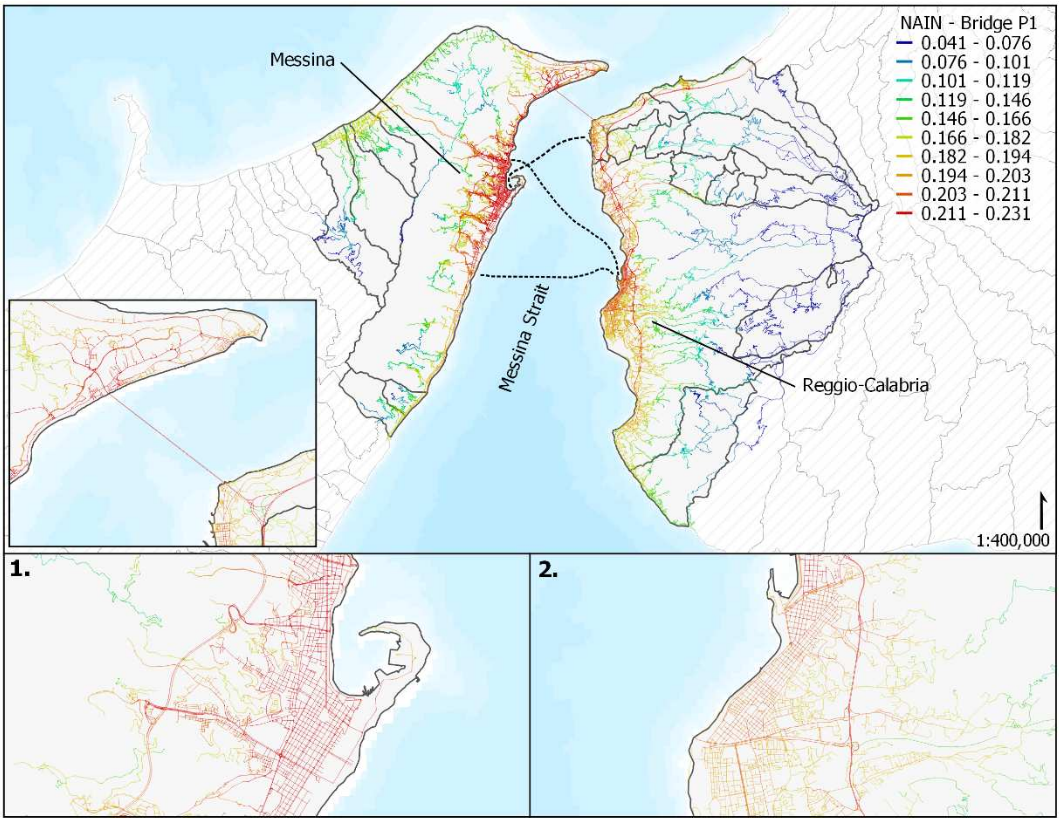

Figure 10. Normalized Angular Integration (NAIN) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Bridge P1 proposal.

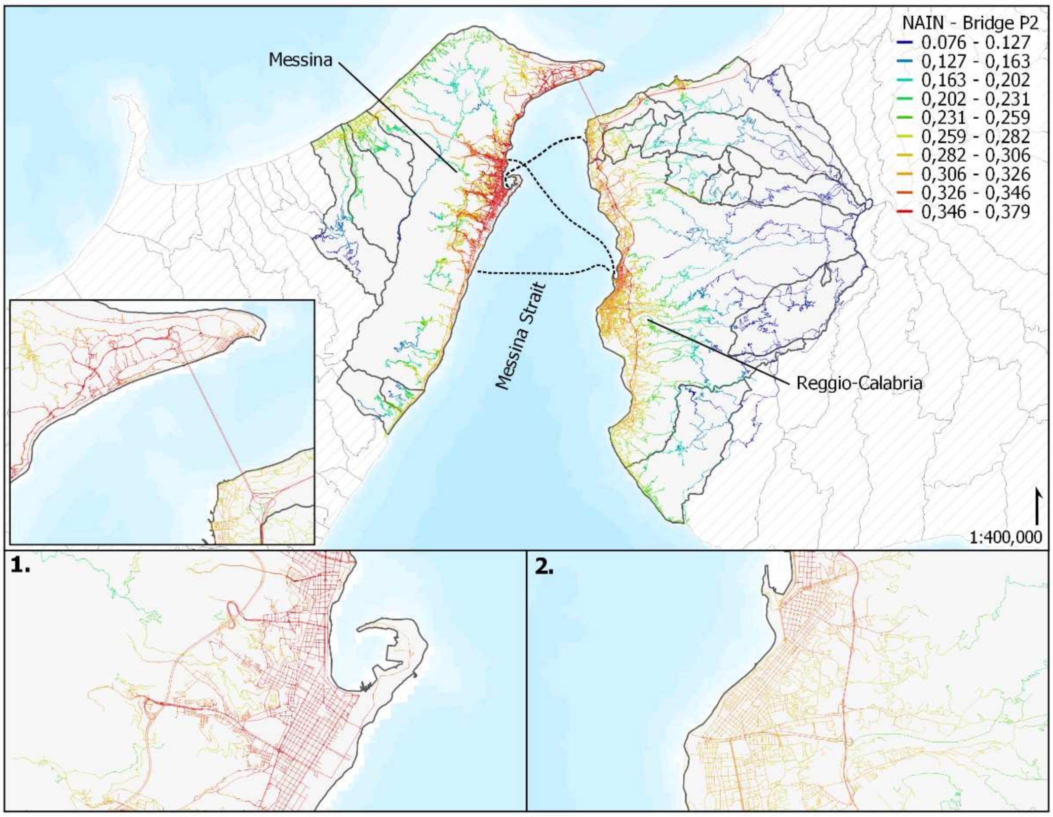

Figure 11. Normalized Angular Integration (NAIN) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Bridge P2 proposal.

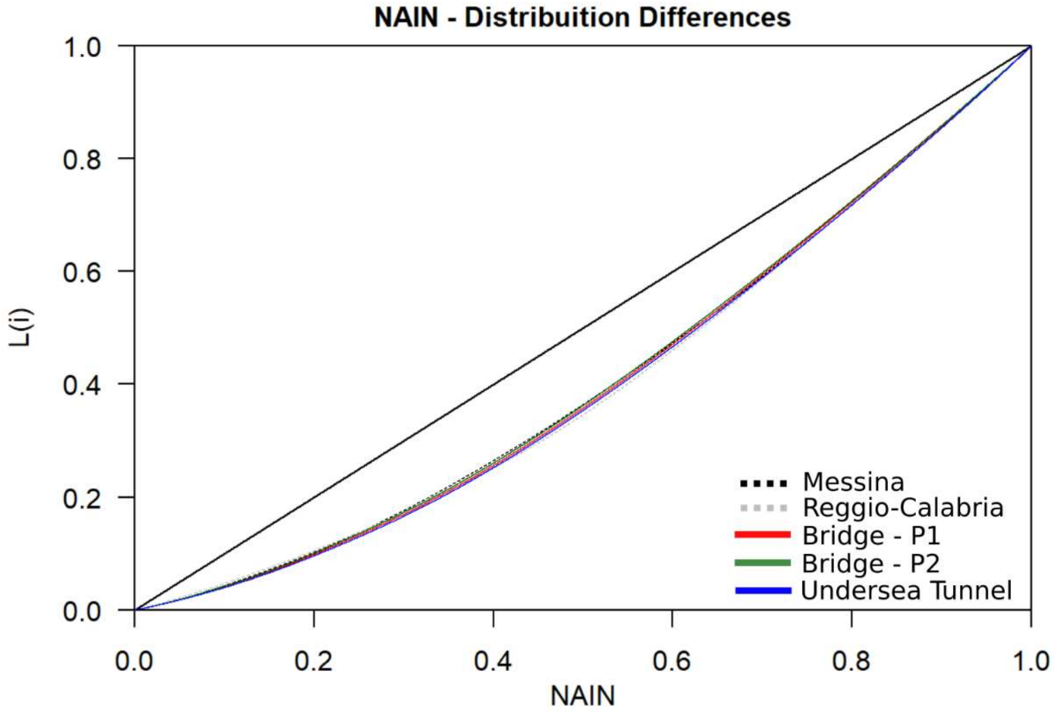

Figure 12. Lorenz Curves comparing NAIN values distribution

While results for the three simulations seem to indicate an overall reinforcement of *Reggio Calabria's* Local-Labor Area *relative accessibility* (Table 2), the models' spatialization shows that these increments do not happen in *Reggio di Calabria's* consolidated functional centrality, but near where the traverse structures are set (Figure 9, p.13; Figures 10, 11 p. 14).

Reggio di Calabria's urban area, instead, possesses lower NAIN values when compared to its independent system counterpart, in opposition to the general maintenance of the integration patterns within *Messina's* urban area (Figure 7, p.12). A restriction to the 10% of the road-elements with the highest NAIN values allows to compare the integration core position across all the simulations (Figure 13, p.16). It reveals that changes in *relative accessibility* distributiveness tend to be more profound in *Reggio Calabria's* Local-Labor Area, where a traverse causes a general shift in *Reggio di Calabria's* integration cores towards *Villa San Giovanni* municipality – and towards the *Messina's* side of the strait. Moreover, the degree of those configurational changes tends to be smaller in the Undersea Tunnel proposal (Figure 9, p.12) and greater on the Bridges P1 and P2 proposals (Figures 10, 11, p.14), which are placed in the Calabrian Peninsula's northern peripheries. This denotes that the traverse distance has an important influence on *Reggio di Calabria's* integration core strength.

Simulations' results also demonstrate that a connection between the road-systems tends to privilege *preferential routes* that extend from *Messina* (Figure 14, p.16; Figures 15; 16, p.17) towards the northern mainland – where the *Gioia Tauro* seaport is located (Figure 1, p.2) – above all in the Bridges P1 and P2 proposals. Although there is a negligible difference in terms of NACH values distribution, as indicated by the superimposed Lorenz Curves (Figure 17, p.18) the connection represents a prospect of improvement in vehicular flows between Sicilian and Calabrian regions. Still, the simulations indicate that the changes in configuration also have the potential to increase "tunnel effects" in the regional road-circulation network, and redirect movement away from *Reggio di Calabria*'s urban areas (Figure 18, p.18).

In this context, while the traverses may enhance the connection between the twin-cities, they may also lead to the *Reggio Calabria's* Local Labor Area road-system being surpassed in importance and suppressed by the *Messina* side of the strait constituting a sensible dominance effect over the twin cities Functional Urban Area (FUA) – (Figure 13, p. 16; Figure 18, p.18).

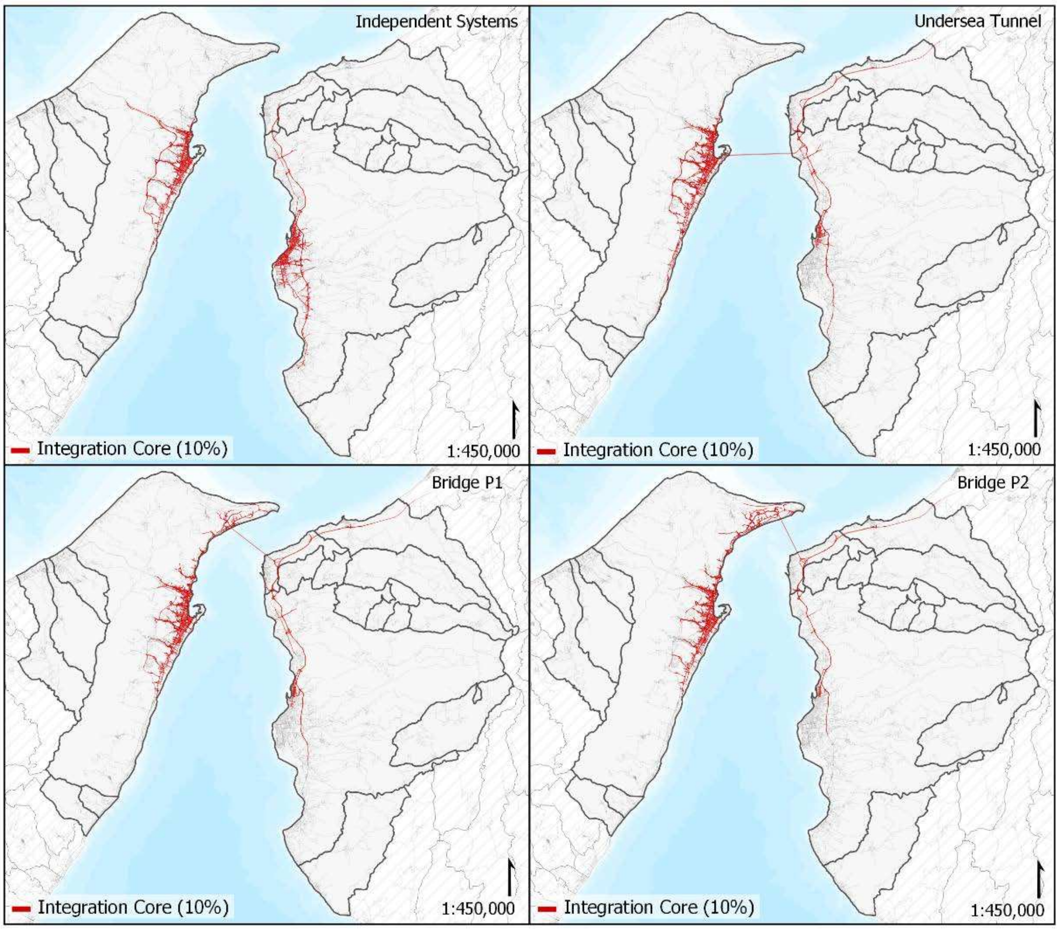

Figure 13. Comparison between the Integration Cores (NAIN – 10%) spatial distribution

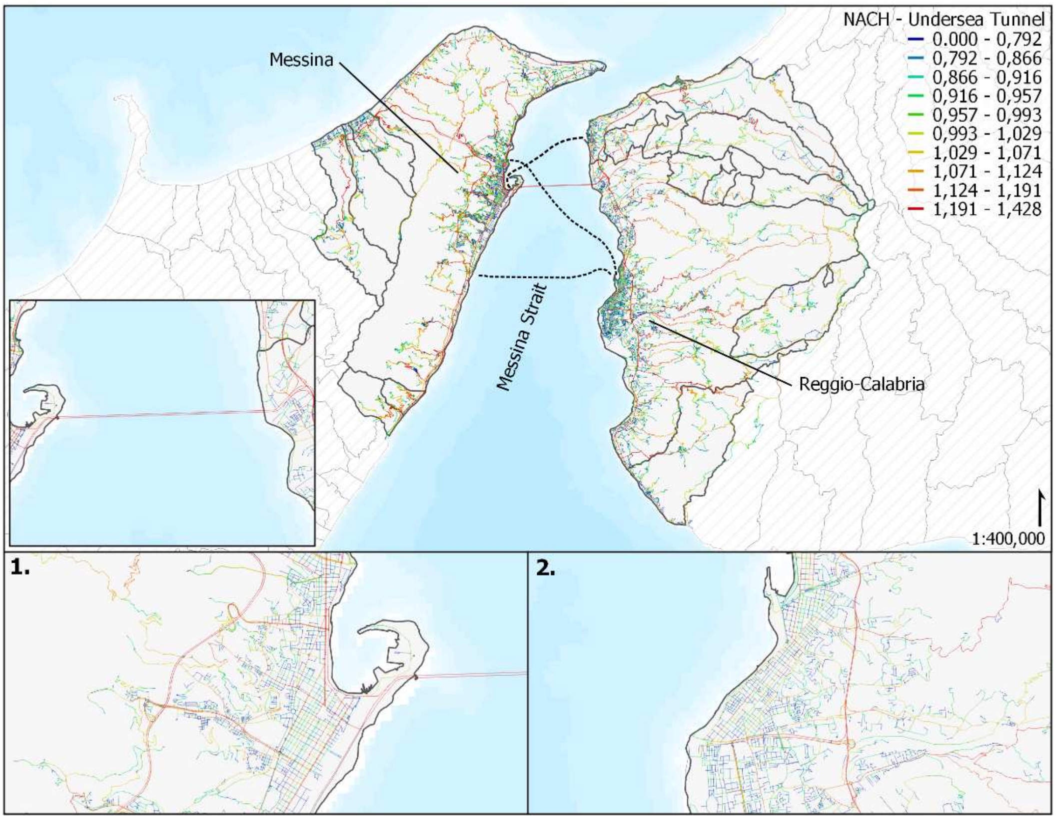

Figure 14. Normalized Angular Choice (NACH) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Undersea Tunnel proposal.

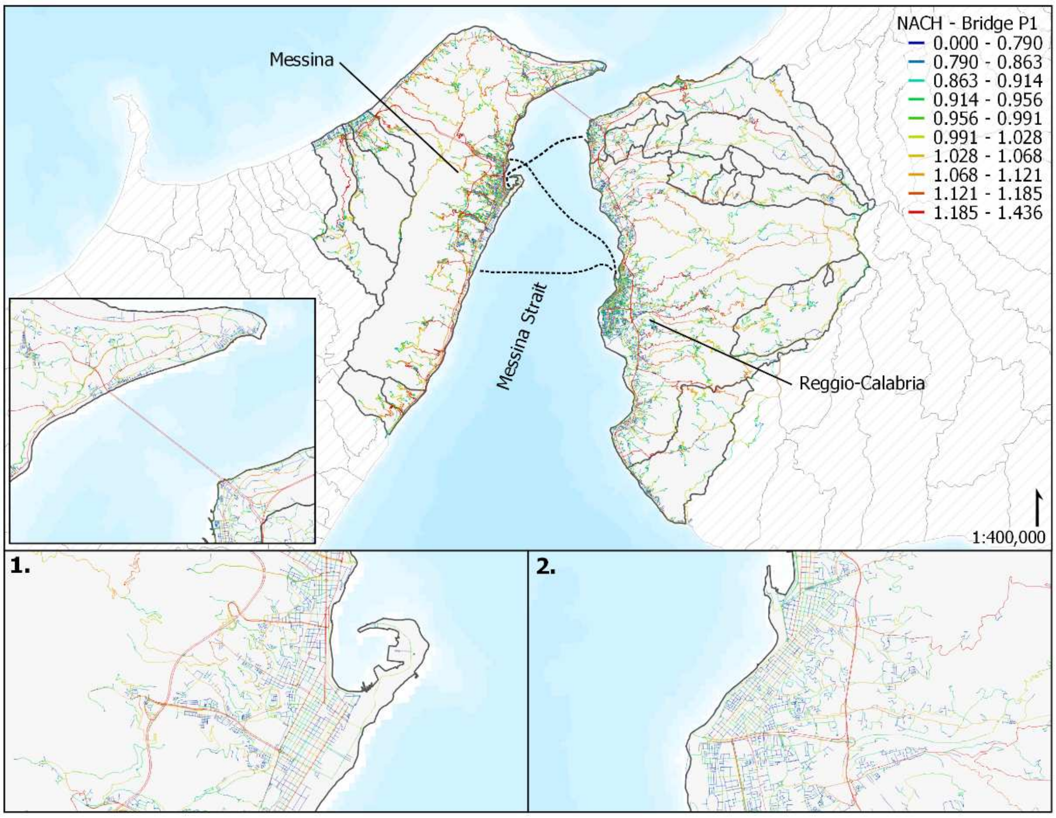

Figure 15. Normalized Angular Choice (NACH) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Bridge P1 proposal.

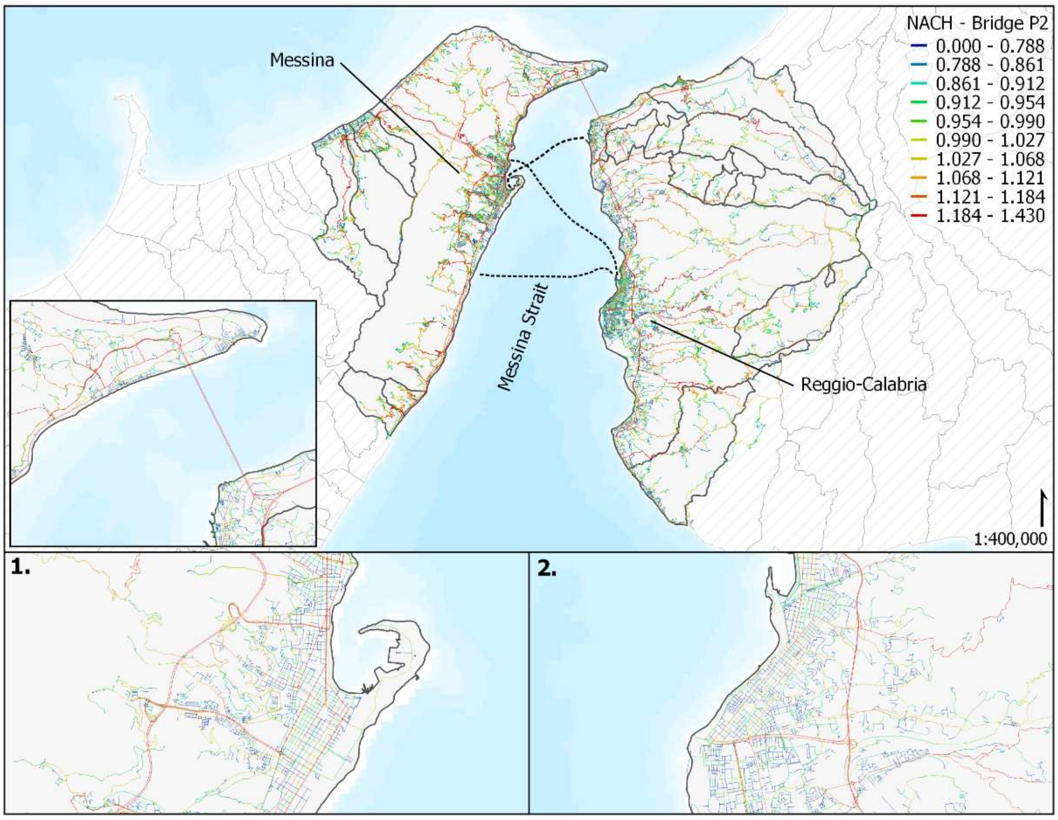

Figure 16. Normalized Angular Choice (NACH) analysis for the connected *Messina* and *Reggio Calabria* Local-Labor Areas road-circulation networks – Bridge P2 proposal.

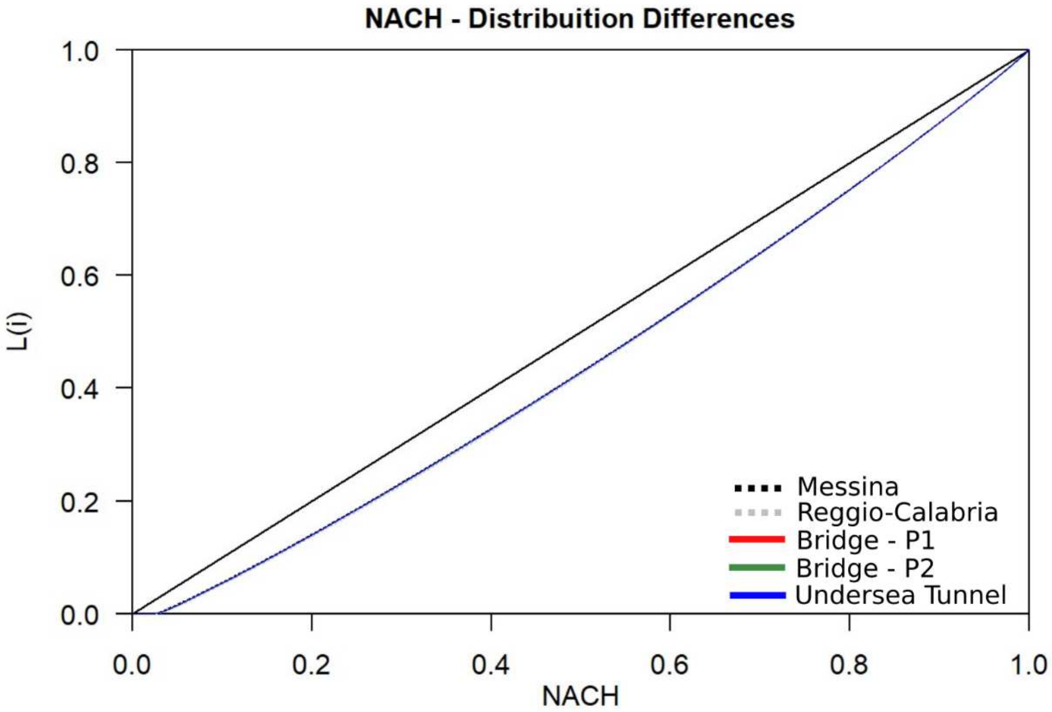

Figure 17. Lorenz Curves comparing NAIN values distribution

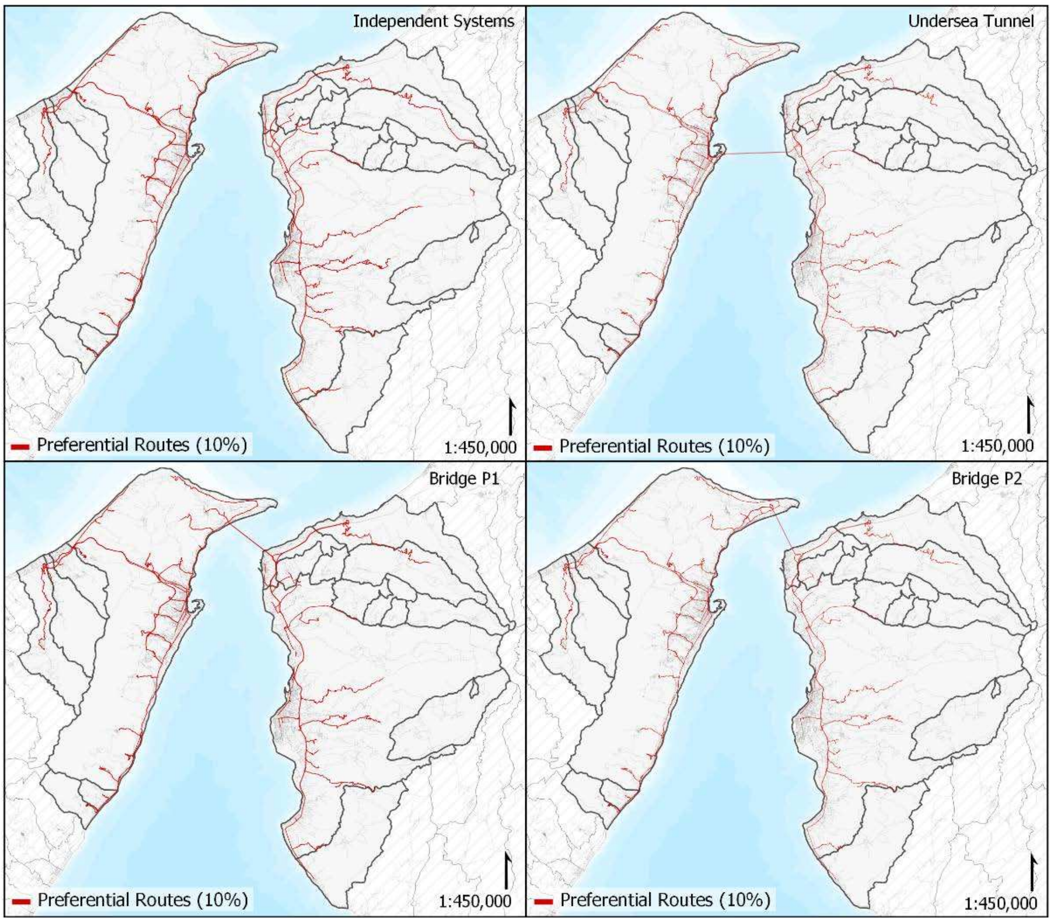

Figure 18. Comparison between the *Preferential Routes* (NACH – 10%) spatial distribution

4.2 Discussion – how a permanent connection would reshape the Messina Strait

Simulation results demonstrate that establishing a permanent connection across the *Messina Strait* would considerably change the road-circulation network configurational logics among *Messina* and *Reggio Calabria* Local-Labor Areas, and cause the potential reshape of the twin-cities relationships.

Both Bridge proposals (P1 and P2) cause a general shift in the *relative accessibility* patterns, relocating the centralities towards the *Messina* side of the strait. The movement concentration in *Messina's* northern peninsula, where the bridges are to be placed (Figures 10; 11, p.14) is a factor that can lead to the emergence of a novel functional centrality – or a polycentrality – in the area, that is coherent with *Messina's* urban expansion tendencies. Nevertheless, the spatial configuration that emerges from the simulations reveals that the Bridges P1 and P2 tend to unevenly distribute the integration cores – and, to some extent, the *preferential routes* – across *Reggio Calabria's* and *Messina's* Local-Labor areas. Hence, this decreases movement potentials and create "tunnel effects" that redirect flows away from *Reggio di Calabria* urban centre. Geographical distance is the main factor behind how sharp the decreases in *Reggio di Calabria* inner-movement potentials are, as Bridge P2 – which is positioned farther from the urban centre – promotes a greater decrease in *relative accessibility* when compared to P1 (Figure 13, p.16) compromising *Reggio di Calabria's* historical core vitality more. Such spatial dynamics can create a situation where the city of *Messina* may surpass and suppress *Reggio di Calabria* importance in the twin-cities context, at least from the configurational standpoint.

Confronted with socio-economic data (Table 1, p.5), the configurational changes that derive from a connection can reflect into a hierarchical divide between the twin-cities, even though the general tendencies point out towards interdependence. As stated in the results, the bridge connection causes a shift in movement potentials, that can lead to the emergence of a functional centrality in *Messina's* northern area. This, in turn, tends to attract more population to that side of the strait. Moreover, higher movement potentials reinforce the territorial conditions that favor business placement – above all in sectors that depend on local movement such as retail, services, and logistics. Consequently, this also tends to increase the number of employees within *Messina's* Local-Labor Area since, even if populational increases happen in *Reggio Calabria's* side of the strait, the workforce would be drawn towards *Messina's* emergent functional centrality. Such aspects can raise territorial disparities between the twin-cities, as *Messina* already surpasses *Reggio di Calabria* concerning these socio-economic parameters (Table 1, p. x). Therefore, it tends to somewhat jeopardize the reciprocity among economic and productive systems that define a shared Functional Urban Area (FUA).

Notwithstanding that the configurational changes have the potential to increase territorial disparities, it is undeniable that they also positively reinforce the overall commuting patterns between *Reggio Calabria's* and *Messina's* Local-Labor Areas, as it diminishes their dependence on seafaring. Furthermore, the traverses can improve the regional transport as it creates a direct *preferential route* that connects *Messina* to the *Gioia Tauro* transshipment port in the Calabrian region (Figure 1, p.2; Figures 15; 16, p.17). This opens another path for Sicilian agricultural and industrial exports.

In comparison to P1 and P2 proposals, the Undersea Tunnel tends to promote a more even *relative accessibility* distribution among both urban agglomerates, as *Reggio di Calabria* integration core tends to be better preserved due to the traverse insertion position – closer to the urban centers (Figure 13). The creation of a functional centrality near *Villa San Giovanni*, concentrates movement potentials in *Reggio Calabria's* Local-Labor and tends to minor the hierarchical divide that would be created between the twin-cities, as population, business and employees are attracted towards that area. However, it should be noticed that the current urban development in the area is limited, which justifies the lesser movement concentration in comparison with the area in *Messina*. Comparing all proposals from a spatial configuration standpoint, the Undersea Tunnel seems to better contemplate the Italian planning goals for local-regional balanced and sustainable development, as it preserves the movement patterns within *Messina* and *Reggio di Calabria* historical cores, assuring the maintenance of their vitality, while enhancing regional transformations that favor the growth and development within the Local-Labor Areas.

5. Conclusions

Messina and *Reggio di Calabria* urban areas are twin-cities that share an important functional space in a particular geographical setting – the *Messina Strait*. Relations across the *Strait* are currently established through seafaring transport, which defines and structures the movement between urban areas. Nevertheless, the absence of a permanent connection hinders the twin-cities further functional and spatial integration, due to the innate limitations of seafaring-based transport. In this context, minoring the territorial and socio-economic disparities between *Messina* and *Reggio di Calabria* can be related to the spatial integration robustness of their Local-Labor Areas road-circulation networks, that is, their consolidated functional centralities strength.

Analysing the spatial configuration that emerge from a permanent traverse is then crucial, as it unveils how different geographical positions change the movement patterns within the urban agglomerations, and what are the consequences in terms of their functional centralities' vitality. In addition to that, changes in spatial configuration can also reshape socio-economic interactions between the twin-cities since those can be movement dependent.

Regarding the *Messina Strait* traverse, the analyzed positions (P1 and P2 cable-stayed bridges, and Undersea Tunnel) reveal that the Tunnel – which is set in a closer position in relation to both urban centers – tends to minor the disparities in movement distribution, maintaining a balance in the functional centralities between *Messina* and *Reggio di Calabria*. On the other hand, P1 and P2 proposals tend to reinforce the centralities on *Messina's* side of the *Strait*, improving its connection with *Reggio Calabria's* regional logistic structures.

Although all the alternatives considerably modify the spatial configuration at local and micro-regional scale, both bridge insertions result in more profound changes, that tend to jeopardize the *relative accessibility* patterns within *Reggio di Calabria's* road-circulation network, diverting movements away from the urban area which undermines its functional centrality strength. Such changes may lead to the emergence of hierarchical differences between the twin-cities, where *Messina* surpasses and suppresses *Reggio di Calabria*, turning the Calabrian provincial capital into *Messina's* periphery. A loss in *relative accessibility*, coupled with "tunnel effects", that redirect movement away from one side of the *Strait* has the potential to disrupt existent functional interdependencies.

The results attained through the simulation of a connection between the road-infrastructures of *Messina* and *Reggio di Calabria* through the *Messina Strait* represent an emblematic case, and several lessons can be learned and applied worldwide in projects that foresee a connection between two cities – or urban areas. Beyond the engineering-design feasibility, projects ought to consider the current and *post-hoc* spatial configuration, as linking two road-networks may have unprecedented consequences in terms of movement distribution, that may hinder, or even counteract the desired objectives. Further studies regarding the *Messina Strait* are set to address the limitations of the current approach. The ongoing research intends to model the macro-regional movement dynamics, to better understand the consequences of a connection at this scale. Moreover, an in-depth analysis of socio-economic and commuting data, associated to the placement of economic activities is important to associate movement dynamics to the role of the monopolistic attractors – such as ports, airports, industrial areas, and institutional buildings in establishing the twin-cities interactions

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