Describing and Understanding the Morphology of the Urban Landscape. The Case Study of Cagliari, Italy

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Abstract. The development of a morphological analysis of the built environment emerges as a central issue for comprehending the structural properties of the urban layout and its generative processes and for establishing a knowledge framework for guiding planning decisions. The proposed study presents an analysis that combines space syntax and geo-spatial analysis tools to describe urban form quantitatively. The suggested analysis is structured as follows: i) definition of the case study and identification of available datasets; ii) definition of metrics for the description of the built environment; iii) discerning of distinct areas of the urbanised region, homogeneous in terms of configurational and functional properties. The proposed analysis is utilised to analyse the metropolitan area of Cagliari, in Sardinia, Italy. The case study underlines the relevance of developing a morphological understanding of urban form for addressing two issues: i) the definition of metrics for the description of the built environment, and ii) the discerning of distinct areas of the urbanised region. The proposed analysis contributes to applying the Geodesign paradigm to the urban realm by supporting the understanding of the spatial culture of a place.

Keywords: configuration · morphology · space syntax · urbanity · geo-design

1 Introduction

Urban morphology emerges as a privileged dimension for understanding the structural properties of the urban fabric and for developing the information base for urban policies.

Urban morphology is the study of urban form and of the processes responsible for its generation. More precisely, the term refers to a method of analysis used in urban design to investigate principles informing the transformation of the built environment [1]. An alternative conceptualisation, relative to the discipline of Geography, refers to

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urban morphology as the study of the topological, dimensional, geometrical relations that structure the urban fabric. Moreover, in the field of environmental psychology, urban morphology emerges as a central perspective for describing the impact of built environment components on perceptions, preferences, cognition, and social practices of urban populations [2–6]. This contribution presents the preliminary stage of a study aimed at defining an analysis that combines configurational and geo-spatial analysis to quantitatively describe the urban environment and measure the components of the urban fabric that influence users' perceptions and practices.

Consequently, the presented study addresses two questions: i) the definition of metrics for describing the built environment, and ii) the discerning of distinct areas of the urbanised region.

The development of a method analysis for quantitatively describing the built environment is instrumental in supporting informed decisions in urban policies by facilitating the identification of relations between urban form and social life, the identification of critical areas.

2 Theoretical Framework

Building on the Conzenian tradition, the urban form is conceptualised as the result of the geometrical and topological relations among building plots, land uses, spaces of mobility, and components of the ecological infrastructure.

The measurement of the components of urban form is instrumental to the recognition of portions of the built environment qualified by distinct levels of urbanity [7] and latent vitality [8–11]. Building on previous studies, specific factors related to urban form components, including spatial configuration, porosity, access to public transport, building density, density and diversity of uses, and access to urban green infrastructure (UGI), are identified as criteria for individuating distinct parts of an urbanised area. Empirical studies over time identify these urban form factors as variables influencing specific aspects of urbanity and of the use of spaces [6, 10, 12–15].

In particular, configurational properties are investigated as determinants of natural movement and co-presence across spaces. These spatial practices influence the distribution of economic activities and the formation of urban centralities. Configuration refers to spatial relations among elements interdependent in a global structure. In particular, the configurational properties of closeness and betweenness centrality determine the importance of space as a destination or as a movement space and, thus, its accessibility and intensity of use [12, 14–19]. Porosity is formalised in terms of the density of street segments, and it describes the availability of alternative routes. As a result, it is related to the distribution of pedestrian mobility, social interaction, and the availability of sites for commercial activities [20]. The organisation of the public transport infrastructure, described in terms of the distribution of stations and bus stops, influences the conditions of access to employment, services, and social and cultural activities [21]. Moreover, the distribution and quality of UGI components determine the conditions of access to ecosystem services. The density and diversity of points of interest are related to the vitality and vibrancy of the built environment; vitality and vibrancy, in turn, represent central objectives of sustainable urban development [10, 11, 14]. Lastly, the structure

of the built fabric is described in terms of building density; Building density is related to the level of demand that, in turn, influences the density and diversity of uses and, consequently, the intensity of street life [20]. Therefore, the study focuses on defining metrics for describing properties of urban components to understand the distinct spatial conditions of an urbanised area. The formalisation of urban components' properties and the analytic analysis's structure are described in the subsequent sections.

3 Datasets and Methods

The proposed analysis combines geospatial and configurational analysis to describe in quantitative terms the urban form of the Metropolitan City of Cagliari (MCC) in Sardinia, Italy. The MCC consists of 17 municipalities (Cagliari, Assemini, Capoterra, Decimomannu, Elmas, Maracalagonis, Monserrato, Pula, Quartu Sant'Elena, Quartucciu, Sarroch, Selargius, Sestu, Settimo San Pietro, Sinnai, Uta, and Villa San Pietro), has approximately 420,000 inhabitants and an area of 1,248 square kilometres (Fig. 1). The MCC has many valued and unknown POIs (urban, public, commercial activities and recreational-cultural amenities), but all of them are part of an invaluable heritage [8, 22–27].

The study is articulated on four metrics: a ground-surface indicator (GSI), an ecological infrastructure indicator (ENV), a permeability indicator (PER), and a Land-Use indicator (USE). These indicators measure, respectively, the density of the built fabric, the distribution and quality of permeable surfaces, the centrality and density of street segments, the distribution of the nodes of the public transport infrastructure and the density and diversity of Points of Interest (POIs). The unit of analysis is the 150m * 150m cell of a regular square grid superimposed on the study area. The subdivision of the study area into regular square modules ensures the comparability of the units of analysis and the representation of the interdependence of public open spaces, building plots, and land uses [7, 8, 22]. The size of the modules ensures a detailed description of the area of study [7]. The individual and composite indicators are normalised in the 0–1 interval, to enable the aggregation of distinct metrics. The land use indicator is formalised as the mean of the density and diversity of POIs. The density of points of interest is formalised as the number of POIs contained in the i-th cell [9]. Points of interest are defined as point locations related to specific urban amenities. Four categories of points of interest are defined: residential buildings, public services (such as educational facilities, hospitals, public offices, banks, and post offices), commercial activities, and recreational-cultural amenities (such as sports facilities, restaurants, cultural sites).

Diversity is measured via Shannon's diversity index [9, 23]. The Ground-surface indicator is formalised as the ratio of the surface area of the projections of portions of buildings included in the i-th cell to the surface area of the i-th cell [7, 27, 28]. The permeability indicator is calculated as the mean of four metrics measuring the centrality and density of street segments and the distribution of bus stops and stations. These indicators are, respectively, the average Normalised angular integration (NAIN) and the average Normalised angular choice (NACH) of the segments intersecting the i-th cell, the total length of the portions of street segments contained in the i-th cell, and the density of the nodes of the public transport infrastructure.

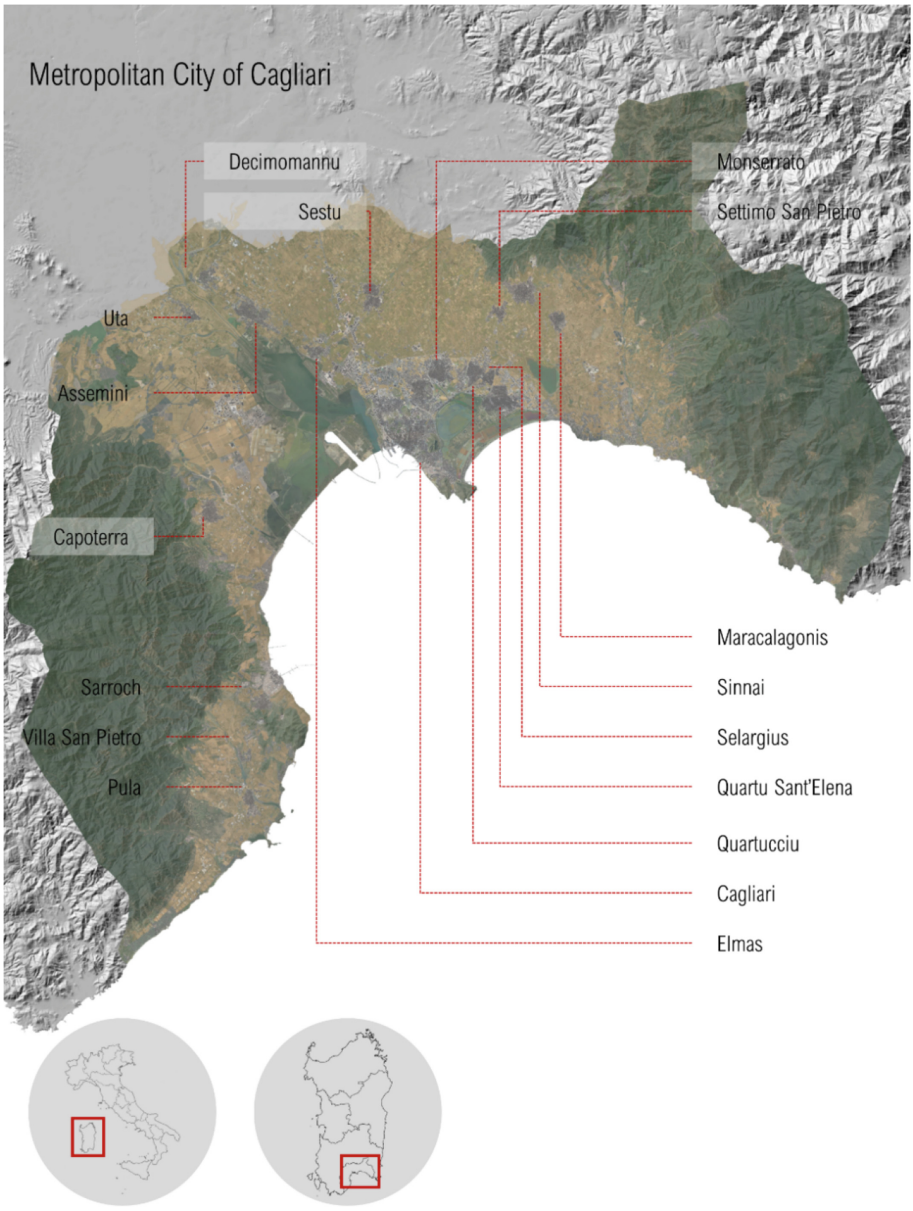

Fig. 1. The Metropolitan City of Cagliari

The latter is calculated as a function of the distance from the nearest node and of the number of nodes contained in the i-th cell. In particular, the NAIN and NACH metrics are utilised to measures the centrality of individual spaces, in order to understand the impact of the configuration of the built environment on patterns of movement. Indeed, configuration can be defined as the set of topological relations among spatial units that are

interdependent within a larger structure. The distribution of movement within the urban environment and patterns of co-presence are influenced by topological relations because they determine the accessibility of spaces. Also, the location of economic activity and the development of urban centers are influenced by the simultaneous presence of people in the most important, integrated locations [29–34].

The indicators normalised angular segment Integration (NAIN) and normalised angular segment Choice (NACH) formalise the characteristics of closeness and betweenness centrality. The former refers to the distance – in terms of sum of angular deviations – of each space from any other space comprised in a spatial structure. The latter refers to the probability that a space is intersected by the shortest route between any pair of spaces comprised in a spatial layout. These properties of centrality result in the significance of a place as a destination and in its 'through-movement' potential, respectively. These metrics are measured via the software Depthmap X and are calculated for all spatial elements of the segment map of the metropolitan area, considering an 800 m radius around each element.

A segment map is a representation of the organisation of a spatial system. It is derived from an axial map or, in the case of complex metropolitan structures, from a database of road centrelines via a process of simplification of over-articulated geometries. The 800 m radius is selected in order to consider the most accessible areas in terms of pedestrian movement.

The ecological infrastructure indicator is calculated as the sum of surface areas of natural and semi-natural land cover parcels in the i-th cell, multiplied by a factor indicative of the environmental quality of the j-th land cover and divided by the surface area of the i-th cell.

The spatial elements are then categorised according to the values of the ground-surface indicator, the permeability indicator and of the ecological infrastructure indicator.

The categories identified represent specific spatial conditions; lastly, the land use indicator is calculated to measure the latent vitality of the distinct spatial needs of the area of study and identify critical areas. The subsequent sections describe the application of the proposed analysis and present the findings from the analysis of the MCC.

4 Results

The analysis of the MCC reveals nine distinct spatial conditions (Fig. 2).

Compact dense central areas, including the cores of ancient formation of the municipalities comprised in the MCC, are identified by values of GSI and permeability superior to 0.4, and environmental quality inferior to 0.1.

The Land Use indicator (Fig. 2) ranges from 0 to 0.95, presenting a significant variation (standard deviation equal to 0.22), representative of the concentration of points of interest in specific parts of the Metropolitan Area, particularly in the ancient core of the City of Cagliari.

This particular area emerges as the most integrated and vibrant portion of the MCC. The emergence of centres of ancient formation of the Municipalities constituting the MCC as compact integrated and vibrant cores reveals the potential polycentric structure of the MCC (Fig. 3, 4, 5, 6).

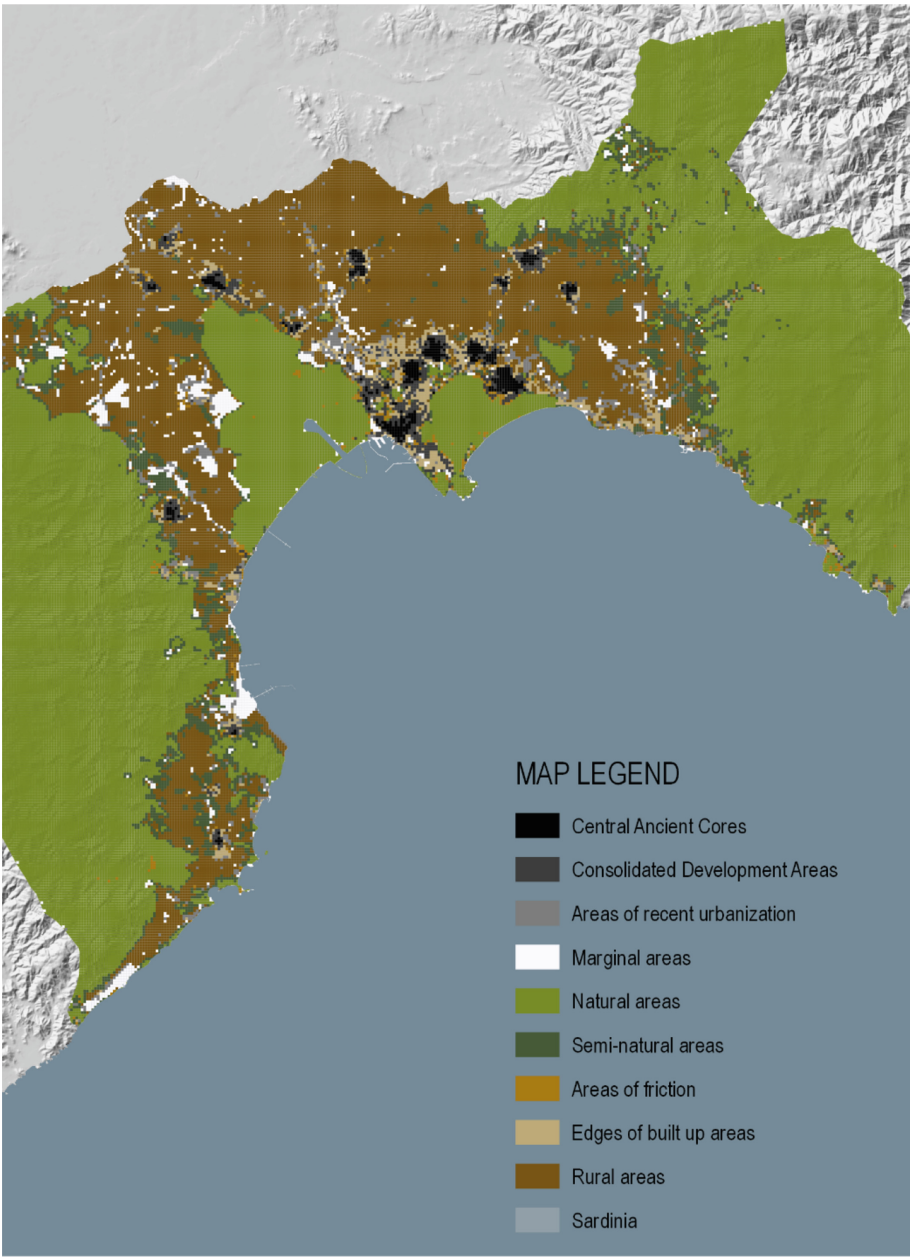

Fig. 2. Spatial Conditions in the MCC

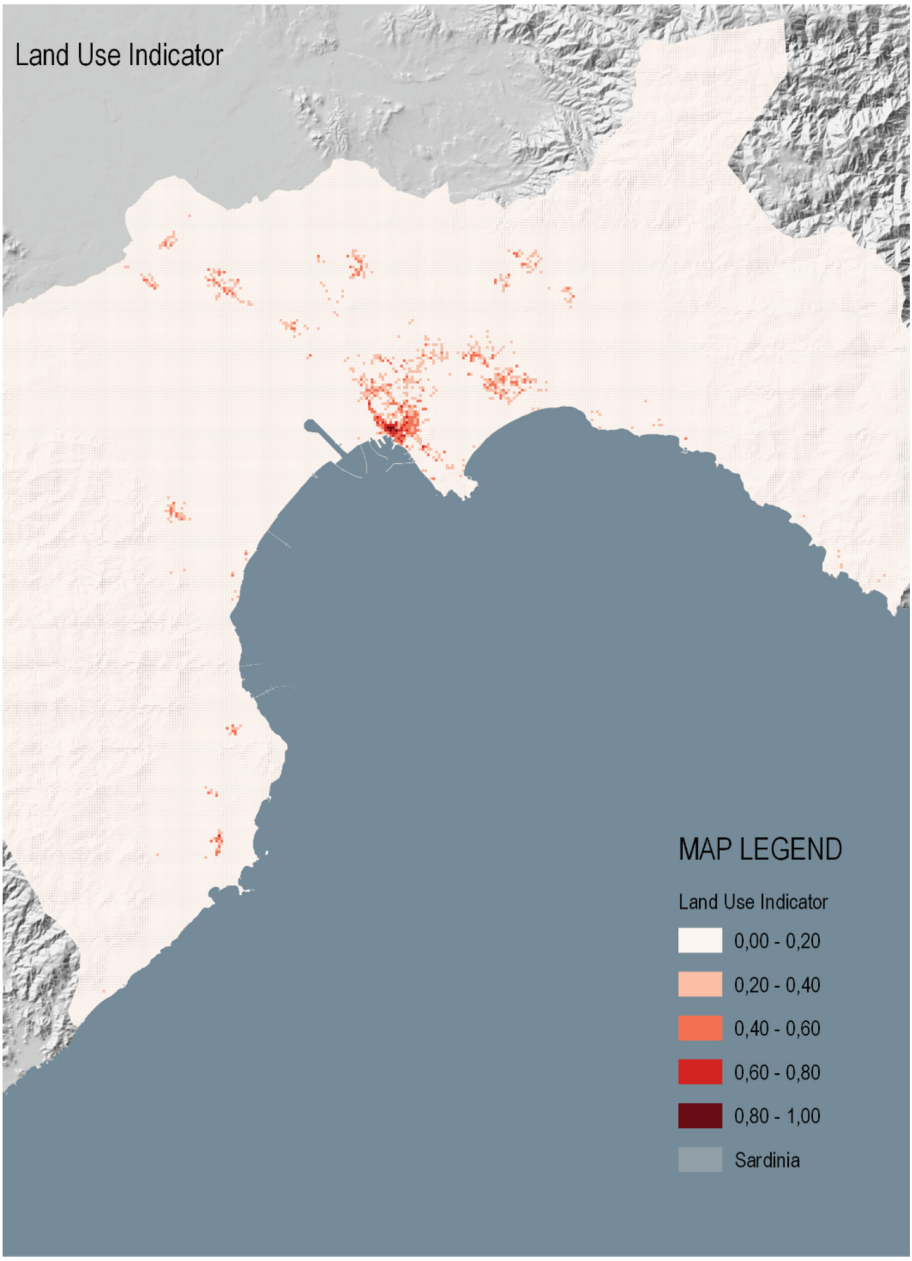

Fig. 3. Values of Land Use Indicator (USE) in the Metropolitan City of Cagliari (MCC). Values are grouped in 5 categories, based on equal intervals

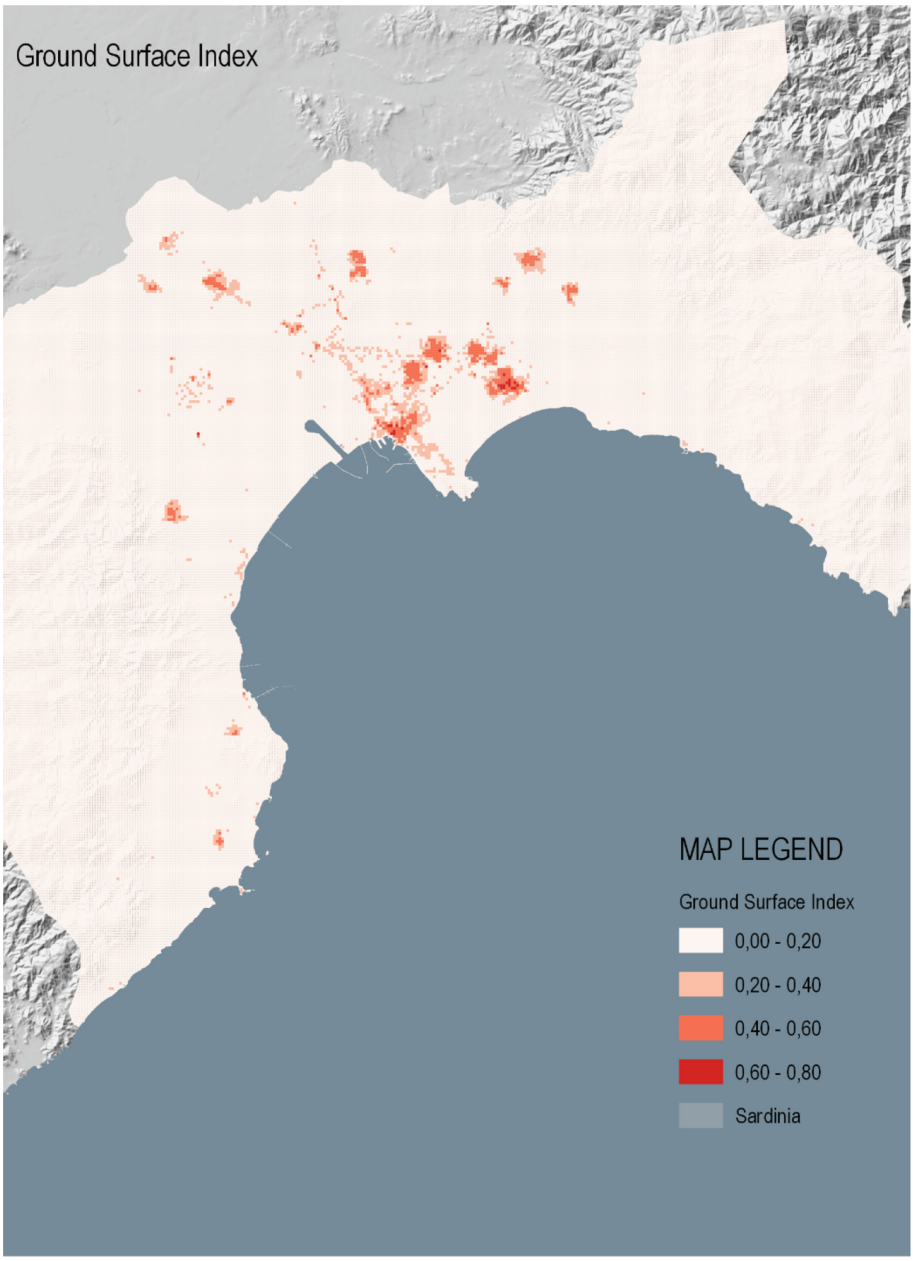

Fig. 4. Values of the Ground Surface Index (GSI) in the MCC

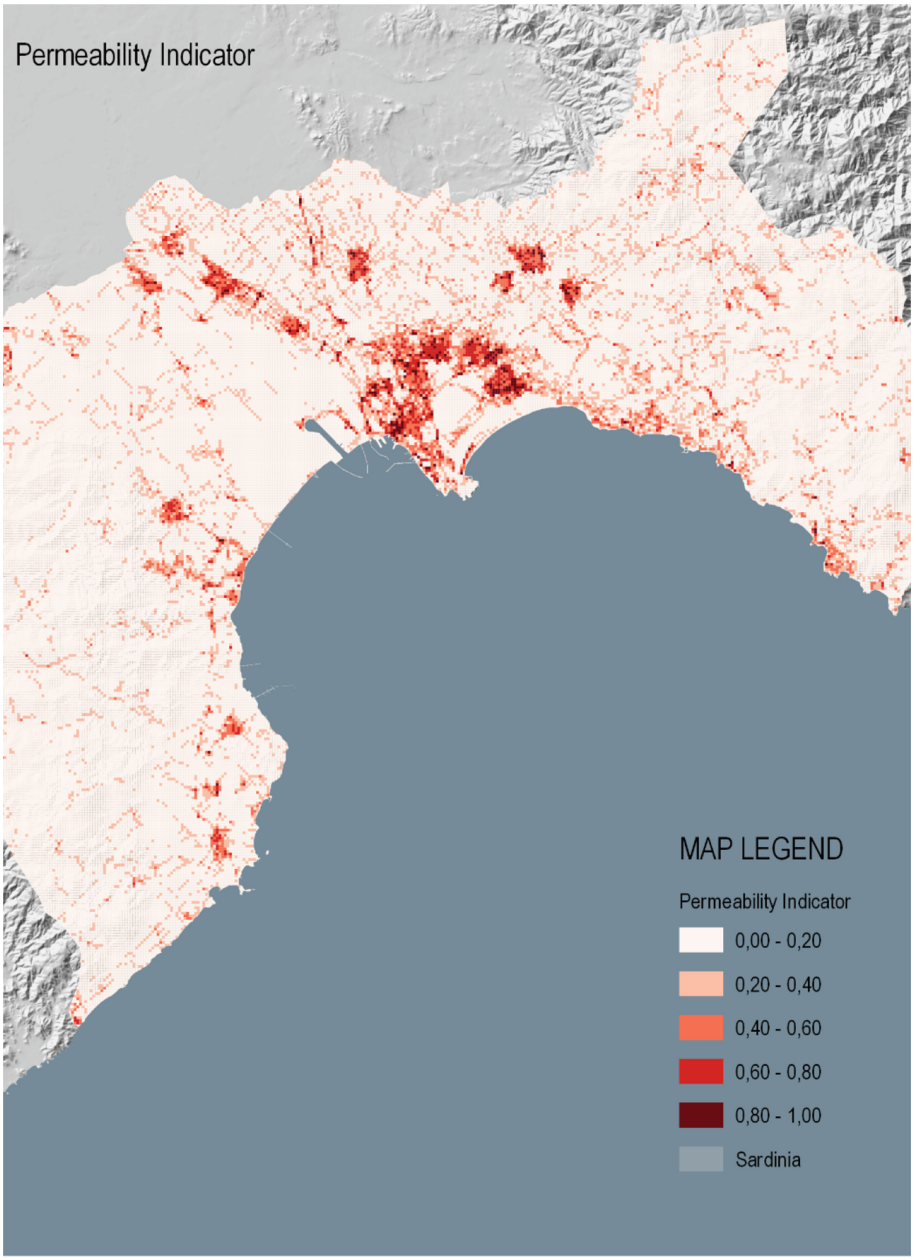

Fig. 5. Values of the Permeability Indicator

Consolidated development areas present a less dense urban fabric ($0.2 \leq GSI \leq 0.4$) and permeability superior to 0.4 and comprise compact modern districts contiguous to

ancient cores. Density and diversity are inferior to central ancient cores (mean equal to 0.16) (Fig. 4 and 5).

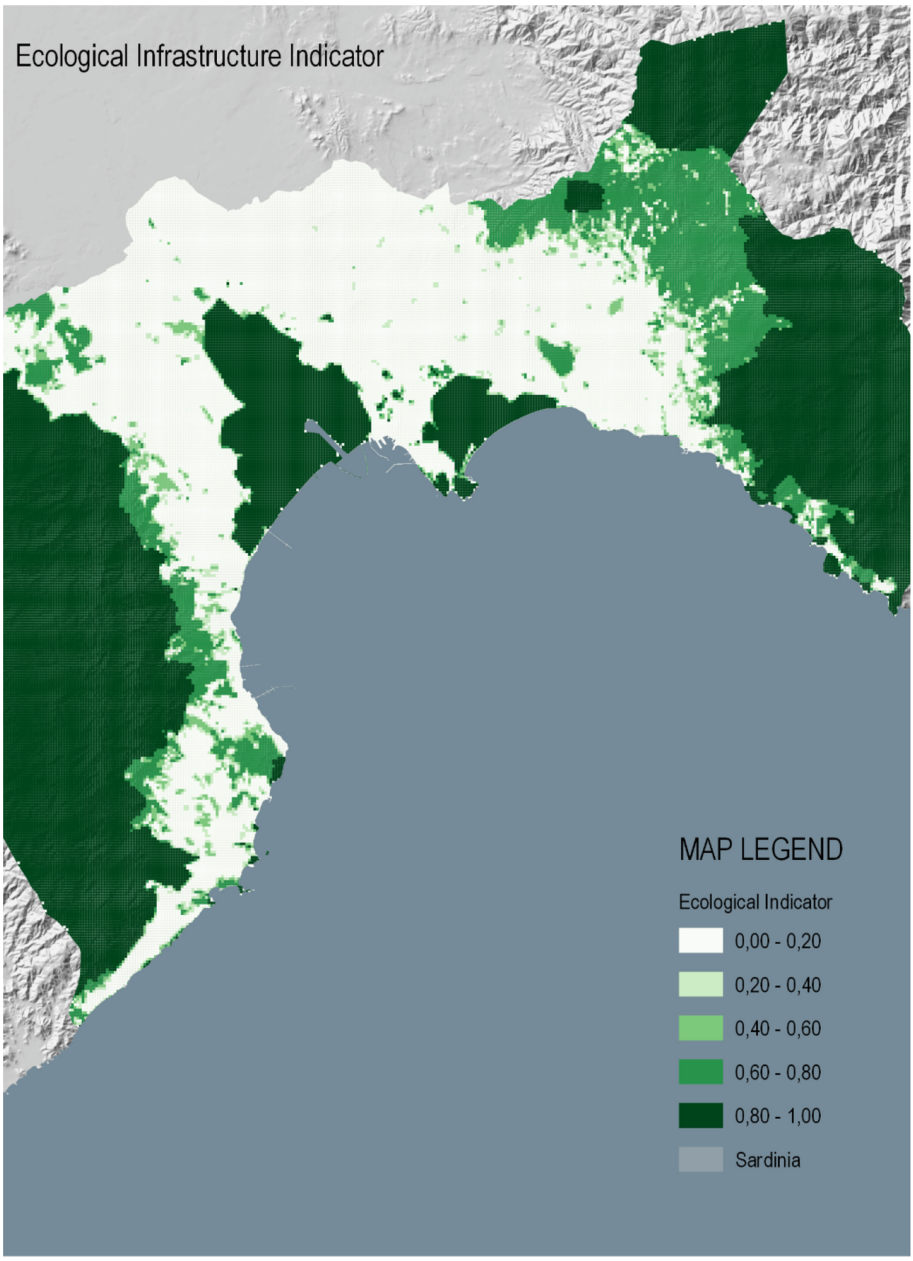

Fig. 6. Values of the Ecological Infrastructure Indicator (ENV) in the MCC

Significant values are observed in compact districts in the municipalities of Cagliari, Assemini, Decimomannu, Pula, Quartu and Quartucciu. Significant spatial conditions, presenting inadequate density and diversity of services, are represented by areas of recent urbanization ($0.0 < GSI \leq 0.4$; $0.2 \leq PER \leq 0.4$; $ENV < 0.1$), edges of built areas, identified as accessible areas ($PER \geq 0.4$) of dispersed urbanization ($0.0 < GSI \leq 0.2$), and areas of friction ($GSI > 0.1$; $ENV > 0.1$) separating built areas and components of the ecological infrastructure.

Moreover, a metropolitan ecological infrastructure emerges, articulated on distinct spatial conditions: Natural Core areas ($GSI < 0.1$; $ENV > 0.6$), transition areas ($GSI < 0.1$; $0.2 < ENV \leq 0.6$), rural areas ($GSI < 0.1$; $0.1 < ENV \leq 0.2$). Lastly, a critical condition is represented by marginal areas, including urbanised areas, presenting inadequate access conditions, and fringe spaces along with major transport infrastructures.

5 Conclusions

The distribution of centrality and integration conditions and built density reveal the polycentric structure of the MCC. Ancient compact areas and consolidated development areas emerge as vital cores, indicating the persistence, at distinct levels of scale, of a structural relation of dependence of the marginal areas on central, compact cores.

In particular, at the metropolitan scale, the compact ancient core and contiguous consolidated areas in the city of Cagliari emerge as the vibrant core of the MCC (Fig. 3). Natural core areas, transition areas, fragments of rural landscape and fringe areas along infrastructure emerge as components of regional ecological infrastructure. They can be conceptualised as metropolitan-scale amenities providing a diversified set of provisioning, cultural, and regulating ecosystem services – including production, recreation, and eco-tourism. The aim is to reinforce the ecological, economic, cultural, and symbolic role of areas of environmental quality. Lastly, the gradient of POIs density reveals the emergence of local centres along arterial metropolitan roads and inter-district distribution roads. As a result, the case study underlines that understanding the urban structure enables the recognition of distinct spatial conditions and the definition of requirements for urban strategies; in particular, four actions are central: i) the location of metropolitan scale amenities in built areas permeable edges and along with major infrastructures; ii) increasing density and diversity of land uses in areas of recent urbanisation, in particular in minor urbanised centres; iii) increasing conditions of access in urbanised marginal areas and of pedestrian access to local centres emerging in areas of dispersed urbanisation and along arterial roads, and iv) the project of a linear system of open spaces, functioning as ecological corridors, public spaces, and routes for soft mobility.

This analysis is the preliminary stage of a study that investigates the integration of spatial and configurational analysis into procedures and tools, enabling the quantitative description of urban form components determining the latent vitality of the urban environment. The objective is to structure an information base for supporting urban planning strategies based on criteria of sustainability, social inclusion, and spatial justice.

More precisely, the future development of this research will explore the influence of the structure of urbanised areas on three distinct topics. The first topic is related to individuals' emotional response to the built environment. The research will integrate

the spatial and configurational analysis of the built environment with machine learning techniques for the analysis of micro-scale aspects of the design of urban spaces and deep learning techniques for facial emotion recognition [35, 36]. The aim is to explore the impact of macro-scale morphological factors of the built environment and micro-scale aspects of the design of urban spaces – including the presence of vegetation, the presence of active street frontage, and the geometry of the urban space – on individuals' emotional response, formalised in terms of basic emotions – including joy, surprise, anger, sadness and disgust – and evaluated via deep learning techniques. The second topic is related to climate alterations and will focus on the analysis of the impact of the morphological features of the urban environment on micro-climate and on users' comfort. More precisely, this research will integrate spatial and configurational analysis of macro-scale morphological attributes of urban areas, machine learning techniques, based on street space images, for the analysis of micro-scale components of urban spaces – including presence of vegetation, morphology of the urban canyon, sky - view factor and building-view factor - and social media data on individuals' activity patterns. The objective is to measure the influence of macro-scale urban form factors, and of microclimatic conditions determined by the geometrical features of urban spaces on individual and social practices in the public spaces. Within this perspective, the future development of the proposed procedure will include the utilisation of clustering functions, based on machine learning and deep learning techniques [37–39], to improve the identification of distinct urban zones presenting analogous conditions in terms of configuration, density and diversity of functions, contiguity to natural and semi-natural areas, and access to public transit. Lastly, a third potential development concerns the use of the proposed set of metrics for the analysis of the pattern of urbanisation at the regional scale, by integrating different methods of analysis [25, 26, 40–42]. The objective is to understand the latent functional inter-dependencies between rural areas, peripheral centers, metropolitan and urban areas that constitute the framework for a trans-scalar, polycentric organisation of the settlement structure at the regional scale.

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