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A method for assessing the vitality potential of urban areas. The case study of the Metropolitan City of Cagliari, Italy

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Abstract

Vitality and Urbanity emerge as key goals of strategies for urban sustainable development as necessary prerequisites for varied and prosperous cities. Vitality and urbanity are characteristics that emerge from the diversity of urban public spaces activities and have an impact on a people's sense of place. The proposed research examines the built environment components that impact urbanity and vitality and develops an analytic method for quantifying the potential of urban form to promote urbanity and vitality. The research investigates four aspects: (i) the conceptualization of urbanity and vitality; (ii) the identification of factors affecting urbanity and vitality; (iii) the definition of indicators and protocols; (iv) the application of the proposed analytic method for measuring the vitality potential of the Metropolitan City of Cagliari (MCC), in Sardinia, Italy. This study underlines the relevance of combining space syntax and spatial analysis techniques in order to address four issues concerning sustainable urban development: quantitative description of urban-friendly conditions, identification of spatial manifestations of social and economic processes, understanding of criticalities, and formulation of policies and strategies for reinforcing vibrant urban spaces. Thus, the proposed analytic method contributes to the application of the Geodesign paradigm to the urban realm by supporting the understanding of the conditions affecting the vitality and urbanity of the built environment.

Keywords: Configuration, Morphology, Vitality, Urbanity, Geo-design

Introduction

Urbanity and vitality emerge as central characteristics of competitive and functional cities in the debate on the urban environment. The original conception of the urban public space as the stage on which the drama of social life unfolds, with viewers and players exchanging continuously (Mumford 1937) identifies the multiplicity of subjects and practices as the central aspect of urban life and of the urban sphere. This idea of multiplicity and diversity is embodied in the concepts of urbanity and vitality. Urbanity refers to the specific configuration of socio-political relations, activities, and identities embodied in urban form and defining a sense of place. Vitality refers to the plurality of practices and of pedestrian populations accommodated by public spaces. Vitality is defined as the degree to which a space is alive or lively (Montgomery 1998) or as a spatial quality resulting from a unique combination of distinct functions and uses and from a heterogeneous pedestrian population (Maas 1984; Mouratidis and Poortinga 2020).

A well-established tradition in urban studies (Carmona 2019; Hillier 2007; Gehl 2011; Jacobs 2016; Hillier and Hanson 1984; Whyte 1980; Lynch 1960; Conzen 1960) recognizes urban morphology as the preferred dimension for comprehending the social consequences of the structural properties of the built environment.

Thus, urban morphology is the study of the built fabric of urban form, as well as the processes and agents responsible for its generation. The term refers to a technique of analysis used in urban design with the purpose

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of determining the principles or rules influencing urban design (Gebauer and Samuels 1981). An alternative definition, relative to the disciplinary field of Geography, refers to urban morphology as the study of the physical and spatial characteristics of the urban structure. As a result, the research questions addressed by this study include a clear definition of vitality and urbanity, as well as the identification and evaluation of macro-scale urban form factors that determine the favorable conditions for the emergence of vital and vibrant places. The combination of these conditions is denominated the vitality potential or latent vitality of the built environment.

More precisely, the study is articulated on seven stages: (i) conceptualization of urbanity and vitality; (ii) definition and description of the case study; (iii) a literature review focused on the identification of structural components of urban form, and their associated properties that influence the vitality potential; (iv) definition of a set of quantitative indicators for quantifying specific properties of urban form components; (v) definition of sub-indicators for describing urban form components; (vi) definition of the relative importance of individual properties and components of urban form, as well as related indicators; (vii) calculation of a synthetic indicator of vitality potential of the urban realm.

This study significantly contributes to the research on the spatial antecedents of urban vitality in three ways. Firstly, this study identifies a set of relevant characteristics of the urban form components that influence the vitality potential of urban spaces. Secondly, by integrating spatial and configurational analysis, this study develops understandable, relevant and pertinent metrics for the investigation of the urban environment at the metropolitan scale, and for the identification of locations that may emerge as vital and vibrant places or, vice versa, as vulnerable areas. This analytic method is instrumental to urban governance and planning processes by supporting the construction of the information base for two distinct actions: (i) identifying emerging vulnerable areas as the object of detailed investigations, based on spatial analysis, agent-based analysis and spatial cognition analysis; and (ii) the formulation of strategies of urban regeneration and re-development.

Lastly, this research, by considering global configurational properties as factors that influence the vitality potential of spaces, integrates space syntax techniques into the geo-design paradigm, thus underlining an original prospect for the application of the geo-design paradigm to the urban environment. Indeed, geodesign is a data-driven paradigm that structures place-making processes via the use of spatial information (Foster 2016; Steinitz 2012). As a consequence, its efficacy in guiding urban planning choices may be enhanced via the development of analytic techniques that integrate spatial analysis and space syntax tools in order to understand the social consequences of urban form.

The article is structured in five sections. Following the introduction, a literature review is provided on the relationship between vitality, urbanity, and urban form components. "Methodology" section describes the methodology and the case study. "Results" and "Discussion" sections show and discuss the findings from the analysis of the case study. Finally, the Conclusion section summarises the results and shows the hypotheses for future research advancement.

Literature review

The literature review is based on the comparative analysis of a subset of open access articles retrieved from the Google Scholar database and related to the topics "urban form", "morphology" "vitality" and "urbanity". The Google Scholar database returns 6770 entries and the Web of Science database identifies 28 articles containing the terms 'urban form', 'urban morphology' 'vitality' 'vibrancy' and 'urbanity'. A sub-set of relevant articles is created according to three criteria: pertinence to the discipline of urban and regional studies; publication on Open Access journals or storage on open platforms; and period of publication included in the time-span 2016–2021 (Annunziata and Garau 2021).

Indeed, the first aspect to examine is the terminological uncertainty around the words urbanity and vitality. The terms "urbanity" and "vitality" are not synonyms. By considering the sociological field, urbanity may be described as a particular configuration of socio-political connections and behaviours that is reflected and replicated by urban form and results in a peculiar sense of place (Montgomery 1998; Boudreau 2010). Sense of place may be considered as a social construct, consisting of a unique mix of beliefs, meanings, symbols, and qualities that a person or a community attributes to a space (Shamai 1991; McCunn and Gifford 2018; Garau et al. 2020a). On the other hand, Vitality can be defined as the capacity of urban places to meet vital functions and biological requirements of individuals or as the synergy created by the diversity of unique commercial and entertainment opportunities and a heterogeneous pedestrian population, or as the result of the intensity and plurality of utilitarian, recreational and social activities staged by the public space and facilitated by the diversity of economic activities and by the complexity of the urban form (Lynch 1984; Maas 1984; Montgomery 1998; Tang et al. 2018; Ye et al. 2018; Zumelzu and Barrientos-Trinanes 2019).

As a consequence, urbanity and vitality are key goals of urban sustainable development: a lively environment fosters entrepreneurialism and wealth as well as attracts

economic activities, tourists, and inhabitants from the creative class (Van den Berg 2017; Chan 2018; Annunziata 2020; Li et al. 2020; Garau et al. 2020b). Moreover, a vital and vibrant environment fosters social contacts and interpersonal relations conducive to trust, co-operation, solidarity (Gehl 2011; Annunziata 2020; Annunziata and Garau 2020, 2021; Pinna et al. 2021).

Urban form emerges as a central factor of vitality and urbanity as a structure integrating a particular configuration of favourable circumstances and limitations for individual and societal activities. In particular, the authors define vitality potential as the quality of spaces arising from topological, functional, geometrical conditions of the urban form that influence the diversity and intensity of activities, as well as the variety of comings and goings, social interactions, and transactions (Montgomery 1998).

Urban form is conceived in terms of three components, within the Conzenian morphological tradition (Conzen 1960): (i) the system of roads and open spaces; (ii) the system of plots and buildings organized on plots; (iii) land-use patterns. Conzen's components mirror those described by Jane Jacobs (Jacobs 2016) as characteristics promoting vitality in the urban environment: combination of land uses, road network layout, typological variety of buildings, and density.

Findings from the comparative analysis

The comparative analysis of the relevant articles finds fourteen factors associated with specific components of urban form as predictors of urbanity and vitality: Closeness Centrality, Betweenness Centrality, Density of Points of interest, Diversity of Uses, Buildings density/floor area ratio, Proportion of built area, Vertical dimension of buildings, Population Density, Block size, Road density, Proximity to transport nodes, Border Vacuums, Real estate value, and Diversity of buildings age. More precisely, border vacuums refer to the existence of artificial impermeable boundaries created by large infrastructures or clusters of mono-functional buildings, that have a negative effect on vitality. Closeness centrality can be defined as the distance of any space of origin from all other destination spaces contained within a spatial structure. It is measured via the a-dimensional variable integration. Betweenness centrality is the probability that the shortest routes from any space to all other spaces in a spatial structure cross a specific space. It is analysed by the a-dimensional indicator choice (Hillier 2007; Vaughan 2007; Yamu and Van Nes 2017; Garau and Annunziata 2020; Garau et al. 2020b). As a result, integration and choice both refer to two fundamental aspects of the impact of urban layout configuration on accessibility and on patterns of activity: (1) the to-movement potential of a space, which explains its significance as a destination, and (2) the through-movement potential of a space which explains its relevance as a movement space (Hillier 2007; Dhanani et al. 2017; Bielik et al. 2018; Garau et al. 2020b; Yamu et al. 2021).

The selected variables, moreover, refer to the configuration and functioning of the components of the urban landscape: Closeness centrality, Betweenness centrality, Block size, Road density, Proximity to transport nodes, in fact, refer to the configuration of the system of streets and public space. Buildings density/floor area ratio, Proportion of built area, vertical dimension of buildings, Real estate value, and Diversity of buildings age describe the articulation and the typological diversity of the built-up area. Population density describes the distribution of residents, and diversity and density of land uses refer to land uses patterns. Finally, border vacuums include both the configuration of the system of arterial routes and the organization of large-scale facilities. Moreover, the significance of these urban form variables is dependent on the perspective from which the urban landscape is analysed: from a Conzenian perspective, centred on plan analysis, vertical dimension of buildings, floor area ratio, and proportion of built area describe the configuration of the built-up area, and are instrumental to the identification of plan units (i.e., areas that present internal structural homogeneity and morphological disunity with adjacent areas). The identification of plan units is dependent on a thorough knowledge of the morphogenetic process. On the other hand, from the perspective of Jane Jacobs and Jan Gehl's studies on active street life, the proportion of built area and building density are related to population density and can thus be viewed as indicators of the level of demand that influences the viability of economic activities, the distribution of primary and secondary uses, and, consequently, the intensity of street life.

The significance of the indicated variables is a key result of the comparative analysis of the selected articles. More specifically, the literature review identifies as a central determinant of urbanity and vitality the distribution of land uses, and in particular, the density and diversity of uses (Tang et al. 2018; Yue et al. 2019, 2021; Zumelzu and Barrientos-Trinanes 2019; Fuentes et al. 2020; Kim 2020; Li et al. 2020; Liu et al. 2020; Niklas et al. 2020; Zhong et al. 2020). A significant influence on vitality is also determined by access conditions, which are determined by the configuration of the streets and public open space system (Ye and Van Nes 2014; Ye et al. 2017; Tang et al. 2018; Delclòs-Alió and Miralles-Guasch 2018; Zeng et al. 2018; Lu et al. 2019; Meng and Xing 2019; Fuentes et al. 2020; Kim 2020; Li et al. 2020; Liu et al. 2020), as well as the organisation of the mass transit system, described in terms of the distribution of its nodes (Tang et al. 2018;

Delclòs-Alió and Miralles-Guasch 2018; Lu et al. 2019; Yue et al. 2019, 2021; Fuentes et al. 2020; Li et al. 2020; Liu et al. 2020; Zhong et al. 2020).

Particularly, distance from transit nodes is cited as a major issue in 50% of the relevant selected articles (Delclòs-Alió and Miralles-Guasch 2018; Lu et al. 2019; Yue et al. 2019; Zhang et al. 2019; Fuentes et al. 2020; Kim 2020). The configurational properties considered are mainly the permeability and porosity of the urban landscape, which are defined by the road intersection spacing (Yue et al. 2019, 2021; Zhang et al. 2019; Fuentes et al. 2020; Kim 2020; Li et al. 2020). Indeed, the permeability of the urban landscape means the availability of numerous alternative routes for the user and promotes pedestrian mobility between areas, increasing opportunities for social interaction and the availability of sites appropriate for commercial activity (Jacobs 2016). Additionally, 50% of relevant selected articles consider the density of road intersections and plot size as significant factors. On the other hand, the existing literature reveals a substantial vacuum, in the understanding of the impact of centrality of street segments, on the vitality field. Indeed, the topological relationships among spaces, which result in the properties of betweenness centrality and closeness centrality, have effects on the pattern of natural movement. In turn, the distribution of pedestrian flows influences the distribution of economic activities and the development of a vibrant urban center's structure (Hillier 1999).

Finally, the density of the built-up area and the density of population are considered to promote vibrancy and vitality (Jacobs-Crisioni et al. 2014; Delclòs-Alió and Miralles-Guasch 2018; Zeng et al. 2018; Lu et al. 2019; Yue et al. 2019; Zumelzu and Barrientos-Trinanes 2019), by establishing levels of demand adequate to sustain economic activities and a diverse range of main and secondary uses (Jacobs 2016). More specifically, variables linked to density of the built-up area and to concentration of population are recognised as significant factors in 45% and 40% of the articles considered for the comparative analysis, respectively.

As a result of the findings from the literature review, vitality and urbanity can be conceptualised as the result of specific characteristics of the urban landscape, such as the centrality of spatial elements, the porosity of the built-up area, the access to mass transit, the concentration of population and density and diversity of land uses. These results serve as the basis for the methodology, in order to assess the vitality and urbanity potential of the urban landscape, which is discussed in the subsequent sections.

Methodology

Layout of the Procedure for the analysis of latent vitality

The suggested methodology combines spatial analysis and space syntax techniques to quantitatively describe the potential of vitality of the built environment. The built-up area, the system of roads and public open spaces, land use pattern, and urban green infrastructure are all recognised as factors of vitality potential or latent vitality, based on the literature review. Indeed, these components define, respectively, the central conditions for vitality and vibrancy: density, accessibility and patterns of movement, availability of amenities, and environmental quality.

The properties selected to describe the components of the urban environment include density of the built-up area and population concentration, as well as density, centrality of road segments and of public open spaces, porosity, distribution of nodes of the mass transit system, as determinants of accessibility, diversity and concentration of amenities, as well as availability of amenities, distribution of urban green areas and of environmental threat sources (Fig. 1).

These properties are quantified using the following indicators: *GSI* Ground surface index, *DPOP* population density, *CH* choice, *IN* integration, *TRN_D* density of transit nodes, *RDI* road intersection density, *DIV* Simpson's diversity index, *D_POI* density of points of interest, *UGA_D* distance from Urban Green Areas and *THR_D* distance from threat sources (See Fig. 2; Table 1).

The 200 m * 200 m cell of a regular square grid superimposed on the area of study serves as the unit of analysis. Subdividing the study area into regular, equal spatial units ensures the homogeneity and comparability of the units of analysis, facilitates the synthetic representation of properties related to the streets system and public open spaces, as well as the built-up area and land use pattern, and enables a detailed description of the urban environment. The definition of the unit of analysis affects the formalisation of indicators.

As a consequence, the indicators density of Points of interest and density of road intersections are operationalized as the number of points of interest and as the number of road intersections contained in the i-th cell, respectively.

More precisely, points of interest are defined as specific point locations related to relevant urban amenities (Garau and Ilardi 2014; Pintus et al. 2019). Points of interest are grouped into four categories: residential buildings; public amenities (education, healthcare facilities, public offices, banks, post offices); commercial activities and recreational-cultural amenities (sports facilities, catering activities, cultural activities, and cultural sites).

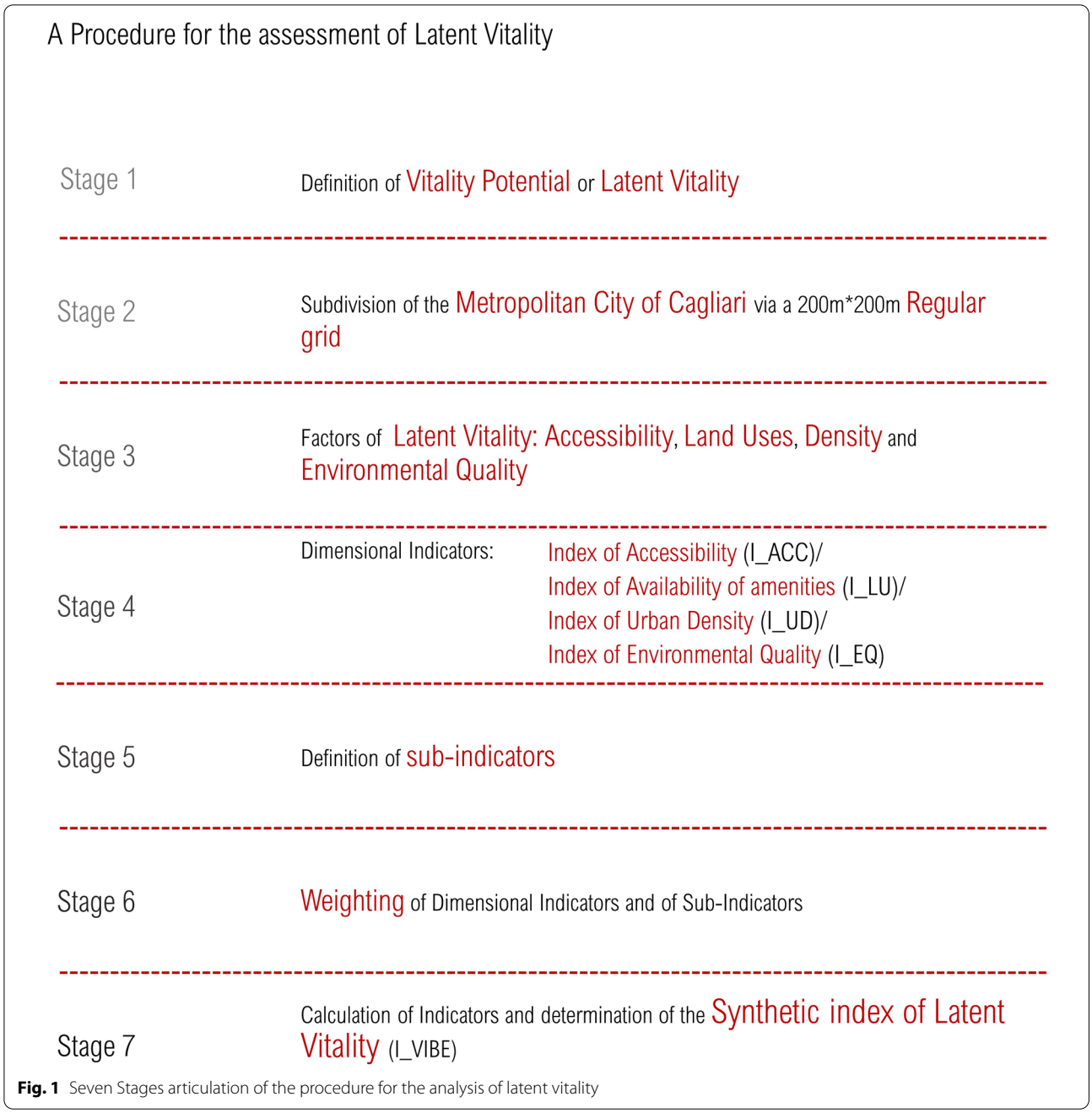

Fig. 1 Seven Stages articulation of the procedure for the analysis of latent vitality

The Ground Surface Index is formalised as the ratio of the total of the surface areas of buildings included inside the i-th cell to the surface area of the i-th cell. Population Density is defined as the weighted average of the population density in the i-th cell's constituent census tracts. Patterns of movement are conceived as the result of the configuration of the system of streets and squares. Indeed, configuration can be defined as the set of topological relations among spatial units that are interdependent within a larger structure. Topological relations define the centrality of spaces, namely their relevance as a destination and as a route, and thus influence the distribution of movement within the urban environment and patterns of co-presence. Additionally, the simultaneous presence of people in the most central, integrated spaces influences the distribution of economic activities and the formation of urban centres (Hillier 1999; Garau et al. 2020b).

The indicators normalized angular segment Integration (NAIN) and normalized angular segment Choice

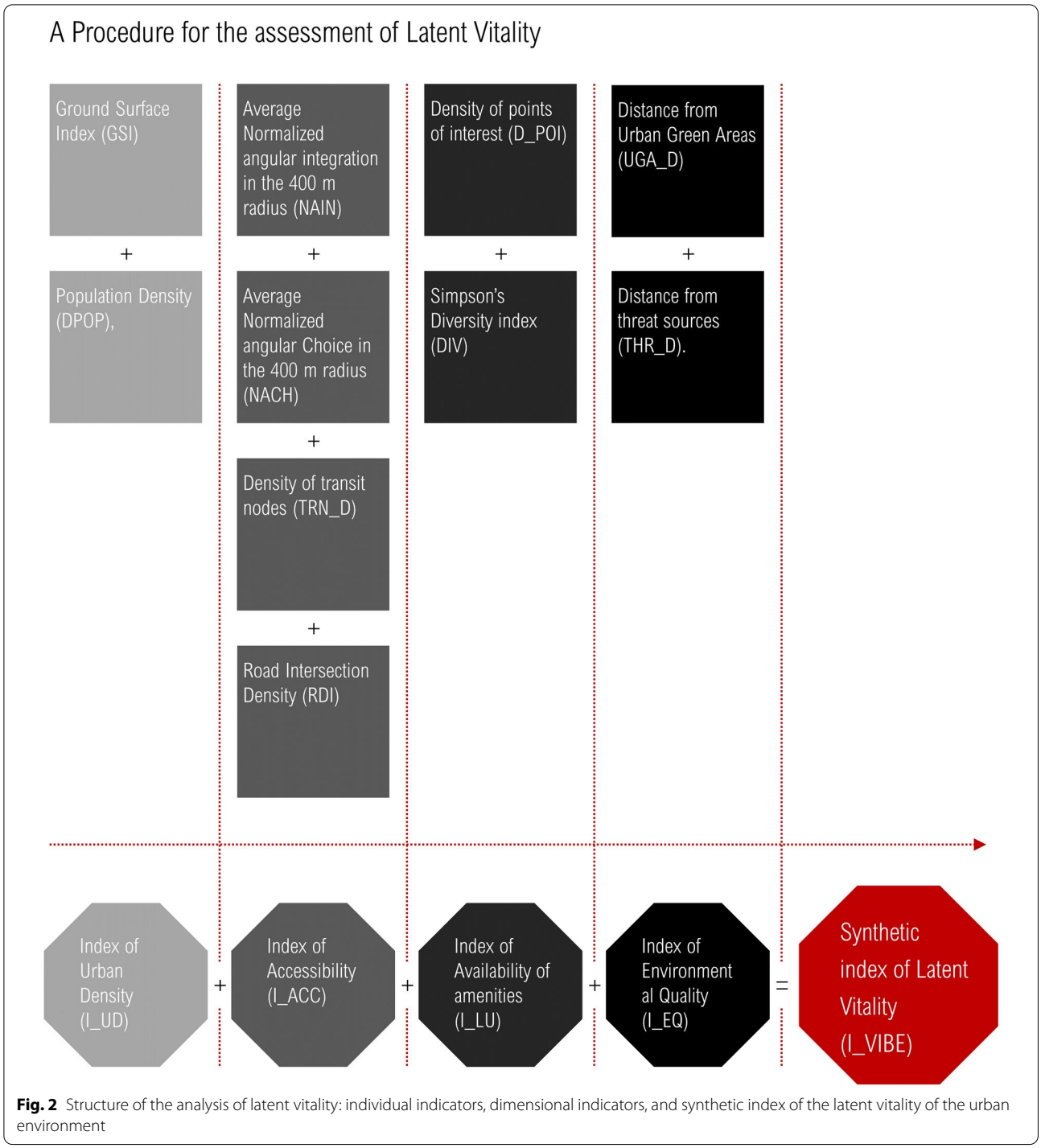

Fig. 2 Structure of the analysis of latent vitality: individual indicators, dimensional indicators, and synthetic index of the latent vitality of the urban environment

(NACH) formalise the characteristics of centrality, and more specifically of closeness and betweenness centrality, which result in the significance of a place as a destination and as a route, respectively. The indicators are measured via the software Depthmap X. Integration is defined as the normalised distance between any space of origin and all destination spaces contained in a structure. Choice measures the probability that a space is comprised in the shortest paths from any space of origin to all spaces of destination in a system (van Nes and Yamu 2021).

These metrics are calculated for all components that comprise the segment map of the metropolitan area,

Table 1 Factors of the built environment, Individual indicators, dimensional Indicators and Synthetic Index of the latent vitality of the urban environment

Dimension of vitality	Built environment factor	Indicator	Formula
Urban density	The density of built-up areas	Ground Surface Index (GSI)	$GSI = Apb_i / Ac_i$ Apb_i = Area of the building projection In the i-th cell; Ac_i = Area of the i-th cell
	Concentration of Population	Population Density (DPOP),	$DPOP = \frac{\sum_{j=1}^{n}\left[\left(\frac{Nab_j}{Act_j}\right) * Aint_j\right]}{Ac_i}$ Nab_j = Number of residents in the j-th census tract; Act_j = Area of the j-th census tract; $Aint_j$ = Area of the intersection of the j-th census tract and the i-th cell; Ac_i = Area of the i-th cell
		Index of Urban Density (I_UD)	I_UD = (GSI * w1) + (DPOP * w2) $W_1 = 0.5$ $W_2 = 0.5$
Accessibility	Closeness centrality	Average Normalized angular integration in the 400 m radius (NAIN)	$NAIN = \log(AI + 2)$ $AI = \frac{1}{n}\sum_{i=1}^{n} d\theta(\pi X, i)$ n = number of segments dθ = angle between any two segments on the shortest path on segment x (van Nes and Yamu 2021)
	Betweenness centrality	Average Normalized angular Choice in the 400 m radius (NACH)	$NACH = \log(ACH + 2)$ $ACH = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\sigma(i,x,j)}{(n-1)(n-2)}$ n = number of segments σ (i,x,j) = 1 if the shortest path from i to j comprises segment x and 0 otherwise (Al-Sayed et al. 2014)
	Transit nodes spacing	Density of transit nodes (TRN_D),	$TRN\_D = Ntn_i$ Ntn_i = Number of transit nodes in the i-th cell
	Road intersection spacing	Road Intersection Density (RDI)	$RDI = Nri_i$ Nri_i = Number of road intersections in the i-th cell
		Index of Accessibility (I_ACC)	I_ACC = (NAIN * w_1) + (NACH * w_2) + (RDI * w_3) + (TRN_D * w_4) $w_1 = 0.10$ $w_2 = 0.10$ $w_3 = 0.28$ $w_4 = 0.52$
Availability of amenities	Intensity/quantity of uses	Density of points of interest (D_POI)	D_POI = $Npoi_i$ = Number of points of interest in the i-th cell
	Diversity of uses	Simpson's Diversity index (DIV)	$DIV = 1/\sum_{i=1}^{n}\left(p_{ij}\right)^2$ p_{ji} = Proportion (n/N) of POIs of the i-th category (n) divided by the total number of Points of interest in the j-th cell(N)
		Index of Availability of amenities (I_LU)	I_LU = (D_POI * w_1) + (DIV * w_2) $w_1 = 0.25$ $w_2 = 0.75$
Environmental quality	Location and size of natural and semi-natural areas	Distance from Urban Green Areas (UGA_D)	$UGA\_D = D_{ij}$ D_{ij} = Euclidean Distance of the i-th cell from the center of the nearest cell comprised in the j-th target (natural and semi-natural) area

Table 1 (continued)

Dimension of vitality	Built environment factor	Indicator	Formula
	Location of industrial facilities and large transport infrastructures	Distance from threat sources (THR_D)	$THR\_D = D_{ij}$ D_{ij} = Euclidean Distance of the i-th cell from the center of the nearest cell comprised in the j-th target (threat source) area
		Index of Environmental Quality (I_EQ)	$I\_LU = (UGA\_D * w_1) + (THR\_D * w_2)$ $w_1 = 0.50$ $w_2 = 0.50$
		Index of Latent Vitality (I_VIBE)	$I\_VIBE = (I\_ACC * w_1) + (I\_UD * w_2) + (I\_LU * w_3) + (I\_EQ * w_4)$ $w_1 = 0.22$ $w_2 = 0.22$ $w_3 = 0.50$ $w_4 = 0.06$

considering a 400 m radius around each spatial element. A segment map is a representation of the configuration of the system of spaces derived from an axial map or, in the case of complex urban areas, from a road centrelines database via a process of simplification of over-articulated geometries. The 400 m radius encompasses the most accessible area in terms of pedestrian movements (Dhanani et al. 2017; Garau and Annunziata 2020; Garau et al. 2020b).

In addition, the values of integration and choice of the i-th cell, are formalised as the weighted average of the values of integration and choice of the segments included in the i-th cell.

The density of transit nodes is formalised as the number of nodes of the mass transit system contained in the i-th cell. Simpson's Diversity Index is a measure of the diversity of points of interest contained in the i-th cell and it is calculated as the inverse of the sum of the square of the proportion of the number of location points of the j-th category contained in the i-th cell. Finally, Distance from Urban Green Areas (UGA_D) and Distance from threat sources (THR_D) are defined as the mean Euclidean distance between locations in the i-th cell and the components of urban green areas and Natura 2000 sites, as well as threat sources, such as industrial areas, arterial roads, ports, and airports. The indicators are normalised via a linear function and expressed by a value ranging from 0—least positive condition of the i-th cell with respect to the j-th indicator—to 1, representative of the optimal condition.

Individual indicators are then aggregated into dimensional indicators, linked to the vitality conditions: an indicator of the availability of amenities (I_LU), a density indicator (I_UD), an accessibility indicator (I_ACC), and an environmental quality indicator (I_EQ). The four-dimensional indicators are summarized by a synthetic index of the latent vitality of the urban environment (I_VIBE).

The weights of the individual and the dimensional indicators are calculated using a pairwise comparison matrix that represents the importance of the i-th indicator relative to the k-th indicator. The relative importance of each indicator is determined according to the significance assigned to the associated property of the built environment by the literature on vitality and urbanity (see Table 2).

As a result, the methodology is divided into four stages: (i) selection of the area of study, identification of available datasets and definition of the unit of analysis; (ii) definition of individual indicators and dimensional indicators; (iii) definition of the weight of individual and dimensional indicators; (iv) calculation of the individual and dimensional indicators and determination of the synthetic index of the latent vitality of the urban environment.

The suggested methodology is used to assess the potential of vitality of the Metropolitan City of Cagliari (MCC). The next section discusses the criteria for selecting the case study.

Selection of the area of study

The Metropolitan City of Cagliari (MCC) encompasses a territory comprising seventeen municipalities: Cagliari, Assemini, Capoterra, Decimomannu, Elmas, Maracalagonis, Monserrato, Pula, Quartu, Quartucciu, Sarroch, Selargius, Sestu, Settimo San Pietro, Sinnai, Uta, Villa San Pietro. The MCC is characterised by a polycentric structure that reveals a complex network of communication and social dependency.

The visible isotropic structure of the compact centres of ancient formation is integrated with the scattered

Table 2 Relative importance of the dimensional indicators of availability of Amenities (I_LU), of Accessibility (I_ACC), Urban density (I_UD), and Environmental Quality (I_EQ)

	Iij (relative importance of the variable in the i-th line compared to the variable in the j-th column)			
	Environ-mental quality	**Access**	**Availa-bility of amenities**	**Urban density**
Environmental quality	1.00	0.20	0.20	0.20
Access	5.00	1.00	0.33	1.00
Availa-bility of amenities	5.00	3.00	1.00	3.00
Urban density	5.00	1.00	0.33	1.00
Total	16.00	5.20	1.87	5.20

	Ratio (I_{ij}/T_j)					
	Environ-mental Quality	**Access**	**Availa-bility of amenities**	**Urban Density**	**Sum**	**Average**
Environmental quality	0.06	0.04	0.11	0.04	0.25	0.0616
Access	0.31	0.19	0.18	0.19	0.88	0.2189
Availa-bility of amenities	0.31	0.58	0.54	0.58	2.00	0.5005
Urban density	0.31	0.19	0.18	0.19	0.88	0.2189

settlements, that colonise and fragment the rural landscape. The scattered settlement system's shape, the functions distribution, and the gradient of density are determined by the radial layout of the network of arterial roads and by the system of environmental dominants. These are defined as the complex of geomorphological, pedological, hydrographical, botanical factors that affect settlement patterns, as well as the location and spatial, functional relations between land uses. More precisely, the environmental dominants of the Metropolitan City of Cagliari comprise the system of wetlands, the system of promontories and sand beaches along the coast, and the system of mountains (Fig. 3).

The interdependence and synergy between environmental dominants, cultural heritage, digital and physical infrastructure, and the built-up area are central to the vision for a resilient, sustainable, and innovative urban environment developed by the Strategic Plan for the Metropolitan City of Cagliari. More clearly, the regeneration of public spaces, the sustainable utilization of natural commercial areas, the strengthening of the network of ecological corridors, and of pedestrian and cycle paths are recognised as key aspects of systemic actions. These actions seek to link natural and semi-natural areas, to preserve and promote the cultural heritage, and to enhance accessibility, conviviality, and liveability. Within this framework, the Strategic Plan for the Metropolitan City of Cagliari (Città Metropolitana di Cagliari 2021) identifies the quality and vibrancy of the public space as a central aspect of urban resilience and sustainability, as well as a necessary condition for fostering social cohesion, promoting economic viability, attracting economic activities, visitors and inhabitants, all in line with a broader trend in contemporary urban policies (Van den Berg 2017; Zhang et al. 2019; Berg and Carvalho 2020; Città Metropolitana di Cagliari 2021; Jia et al. 2021). The adoption of policies targeted at enhancing economic viability, social cohesion, and well-being is particularly relevant in a setting where socioeconomic and demographic dynamics demonstrate polar opposing trends. The population increase and the recovery of economic activity are accompanied by a decrease in individual income and average levels of service quality (ISTAT 2020). More specifically, in the period 2009–2019, the population increased by 1.8 percentage points in Cagliari and by 3.0 percentage points in the other municipalities of the MCC. Moreover, the balance of new enterprises to discontinued activities is positive, ranging between 101 and 500, in the period 2012–2016. On the other hand, levels of individual income decreased by 2.8 percentage points in the period 2012–2017, and the level of quality of services, although superior to that found in southern Italy's urban and provincial regions, remains modest at 54.6, on a scale of 0 to 100. The contextual conditions result in a modest level of the index of economic well-being, equal to 39.7, and of the index of sustainable and equitable well-being, equal to 41.3, both measured on a scale of 0 to 100 (ISTAT 2020). As a consequence, the importance of vitality as a central aspect of the Strategic Plan and as a lever for reinforcing social cohesion, sustainable and equitable well-being and attractiveness and competitiveness of urbanized areas determine the significance of the MCC as a Case study for the development of metrics for the

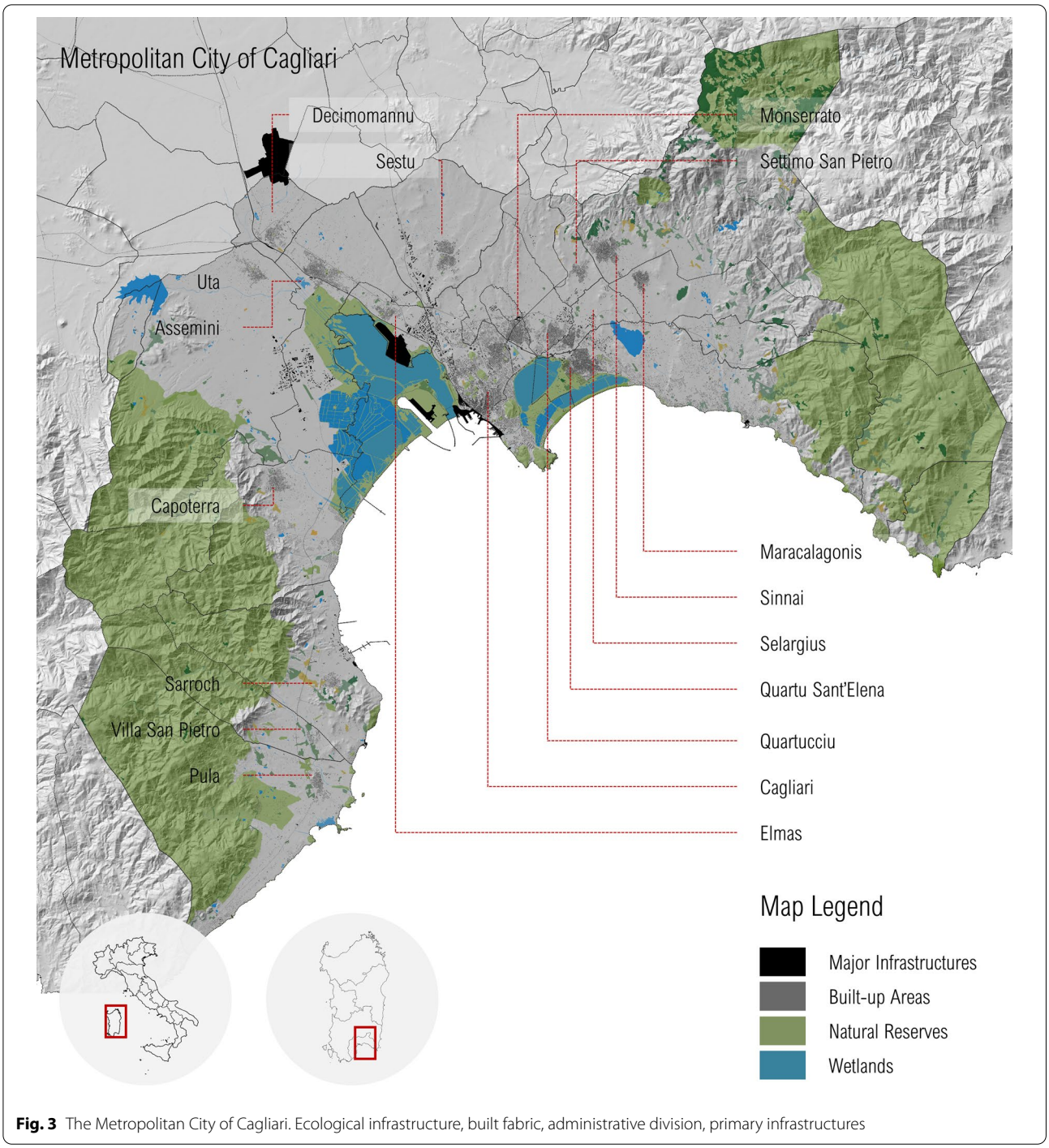

Fig. 3 The Metropolitan City of Cagliari. Ecological infrastructure, built fabric, administrative division, primary infrastructures

assessment of vitality. Furthermore, the increasing demand for transparency, and for the rationalisation of territorial and urban planning decisions underlines the importance of research aimed at developing metrics and tools for the quantitative analysis of the urban environment and of conditions that influence patterns of individual and collective practices. The following sections explain how the proposed methodology is applied to the MCC, as well as the study's results.

Table 3 Values of the dimensional indicators and of the synthetic index of the latent vitality of the urban environment and related measures of central tendency and dispersion

Indicator	Area	Max	Min	Median	Mean	Standard Deviation
Synthetic Index of the Latent Vitality of the Urban Environment (I_VIBE)		0.743	0.00	0.060	0.065	0.071
	Centres of ancient formation	0.743	0.009	0.376	0.380	0.162
	Areas of consolidated development	0.69	0.027	0.292	0.318	0.121
	Areas dispersed urbanization	0.569	0.000	0.030	0.056	0.079
	Fragments of the rural landscape	0.095,	0.006	0.031	0.032	0.013
	Areas of pre-eminent Environmental Quality	0.371	0.051	0.060	0.064	0.013
Index of availability of Amenities (I_LU)		0.729	0.000	0.000	0.013	0.067
Index of Accessibility (I_ACC),		0.919	0.000	0.000	0.044	0.082
Index of Urban density (I_UD)		1.000	0.000	0.001	0.042	0.144
Index of Environmental Quality (I_EQ)		1.000	0.000	0.669	0.653	0.337

Results

The analysis reveals the heterogeneity of the MCC, characterized by complex sequences of natural and semi-natural areas, compact urbanised areas, fragments of the rural landscape, industrial areas, and the fringe areas of dispersed urbanization.

The Index of the potential of vitality demonstrates the coexistence of different settlement conditions. The centres of ancient and original formation include the most vital areas of the municipalities comprising the MCC. More precisely, the values of the synthetic index of the latent vitality of the urban environment (I_VIBE) measured for the centres of ancient and original formation vary from 0.009 to 0.743 (Table 3).

The municipalities of Sarroch and in the San Gregorio district have scores ranging from 0.009 to 0.200, suggesting a modest vitality potential; the central districts of Cagliari have values ranging from 0.700 to 0.743, showing high levels of latent vitality of the built environment (Fig. 4).

Measures of central tendency, such as the mean and the median, are equal, respectively, to 0.380 and 0.376, and indicate general modest levels of latent vitality in the denser areas of MCC. Dispersion measures, particularly the standard deviation of 0.162, show significant variance in vitality potential throughout the MCC. By examining latent vitality, the analysis highlights the prominence of the central districts of Marina, Stampace, and Villanova, in the urban area of Cagliari, as well as of local centres located at the edge of the centres of ancient formation in the municipalities of Quartu, Selargius, Quartucciu, and Pirri (Fig. 5).

Moreover, the vitality potential is lower in the areas of consolidated and recent development, ranging from 0.027 to 0.690. Particular, values between 0.027 and 0.20 are observed in the monofunctional residential suburbs of Poggio dei Pini, Flumini, and Foxi, as well as in fringe areas located along spatial boundaries and borders defined by major infrastructures and arterial roads(for instance along the Provincial Road 2 in the municipalities of Assemini and Elmas), by slopes (around San Michele, Tuvixeddu and Sant'Elia hills in the Cagliari area), and by the fringed marginal areas of compact settlements (for instance, in the edge of the municipalities of Decimomannu, Settimo San Pietro, Sinnai and Uta). Values ranging from 0.60 to 0.690 are found in the municipality of Cagliari and underline the development of a cluster of local centres in the districts of San Benedetto, (particularly in the areas close to Piazza Repubblica and Piazza San Benedetto), Bonaria, Sant'Avendrace and San Michele (Fig. 3). Outer areas of dispersed urbanization emerge as a site for industrial activities, large commercial facilities, and major infrastructures, and show marginal to adequate levels of latent vitality as defined by values of the synthetic index of the latent vitality of the urban environment (I_VIBE) in the range 0.00–0.569 (Fig. 6).

More specifically, spatial elements, located along arterial roads in Cagliari and Quartu Sant'Elena are characterised by values of the index of Latent vitality that vary between 0.40 to 0.60, suggesting an adequate vitality potential.

Fragments of rural landscape and natural and semi-natural areas comprising a metropolitan-scale green infrastructure have low vitality ratings, ranging from 0.006–0.095 and 0.051–0.371, respectively (Figs. 7, 8).

Natural areas of great relevance are located along the coast, most notably, in the Poetto zone, in areas contiguous to the culturally important Nora site, and in tourism-related areas located close to Geremeas and Torre Delle Stelle. These sites present levels of latent vitality ranging

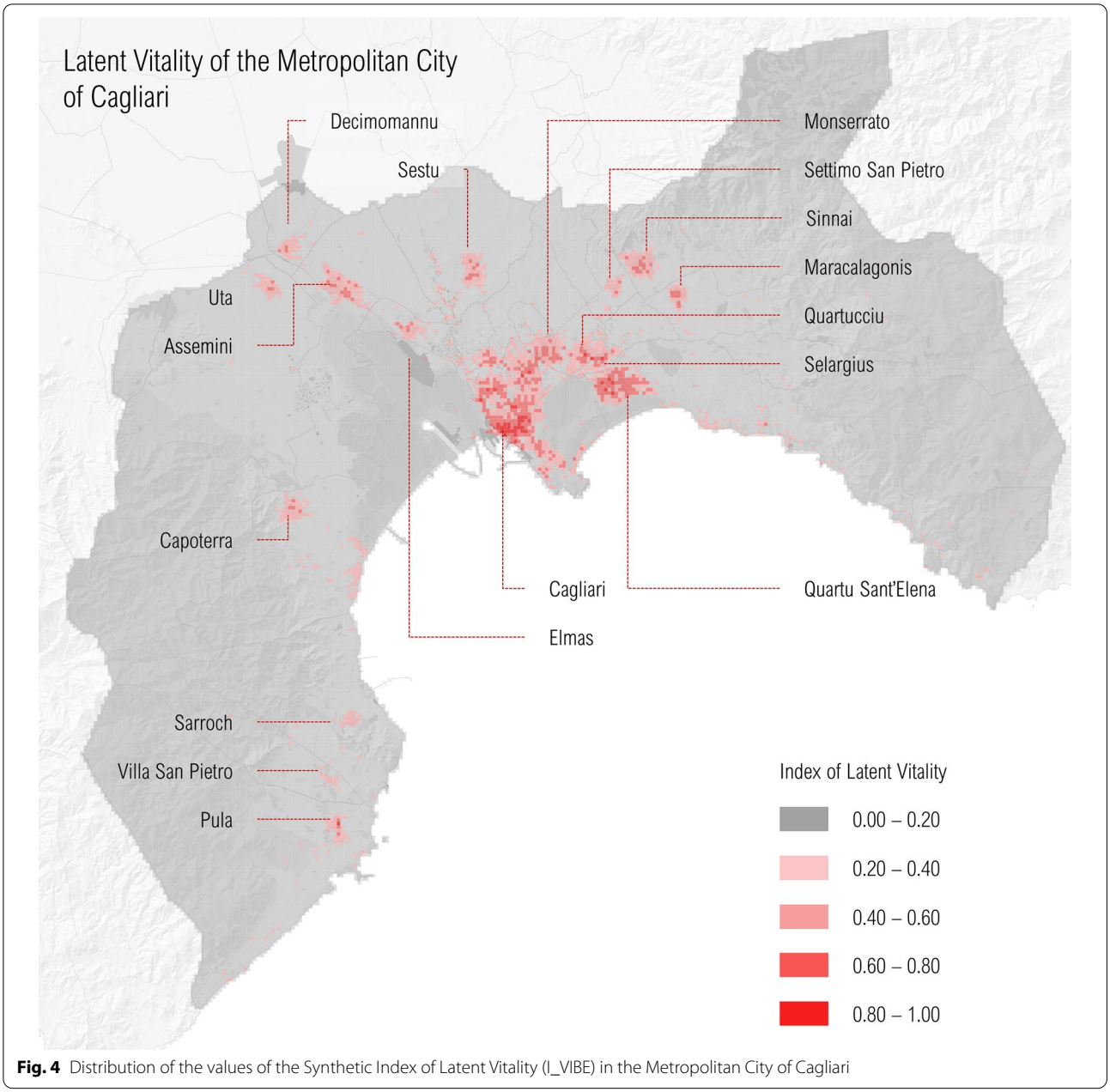

Fig. 4 Distribution of the values of the Synthetic Index of Latent Vitality (I_VIBE) in the Metropolitan City of Cagliari

from0.20 to 0.40, thus suggesting an insufficient vitality potential.

The centre of ancient formation of the historic districts of Cagliari represents the most vibrant areas of the MCC, as shown by the high levels of density and diversity of uses and points of interest (Fig. 9).

Particularly, the cells that cross the historic compact districts of Marina, Stampace, and Villanova, and comprise the vibrant spaces of Piazza Yenne, Largo Carlo Felice, Piazza Savoia, Via G. Manno, Via G. Garibaldi, present values of the Land Use Indicator ranging from 0.700 to 0.729. Additionally, most integrated and accessible areas, as defined by values of the indicator of accessibility (I_ACC) comprised in the range 0.800–0.919, are located in Cagliari and in the municipalities of Quartu Sant'Elena and Quartucciu. These areas are located along distributor roads and arterial roads that link the areas of consolidated development and the denser districts of the municipalities contiguous to Cagliari (Fig. 10).

The population concentration and the density of the built-up area are particularly relevant in the compact districts of ancient formation and of consolidated development in the

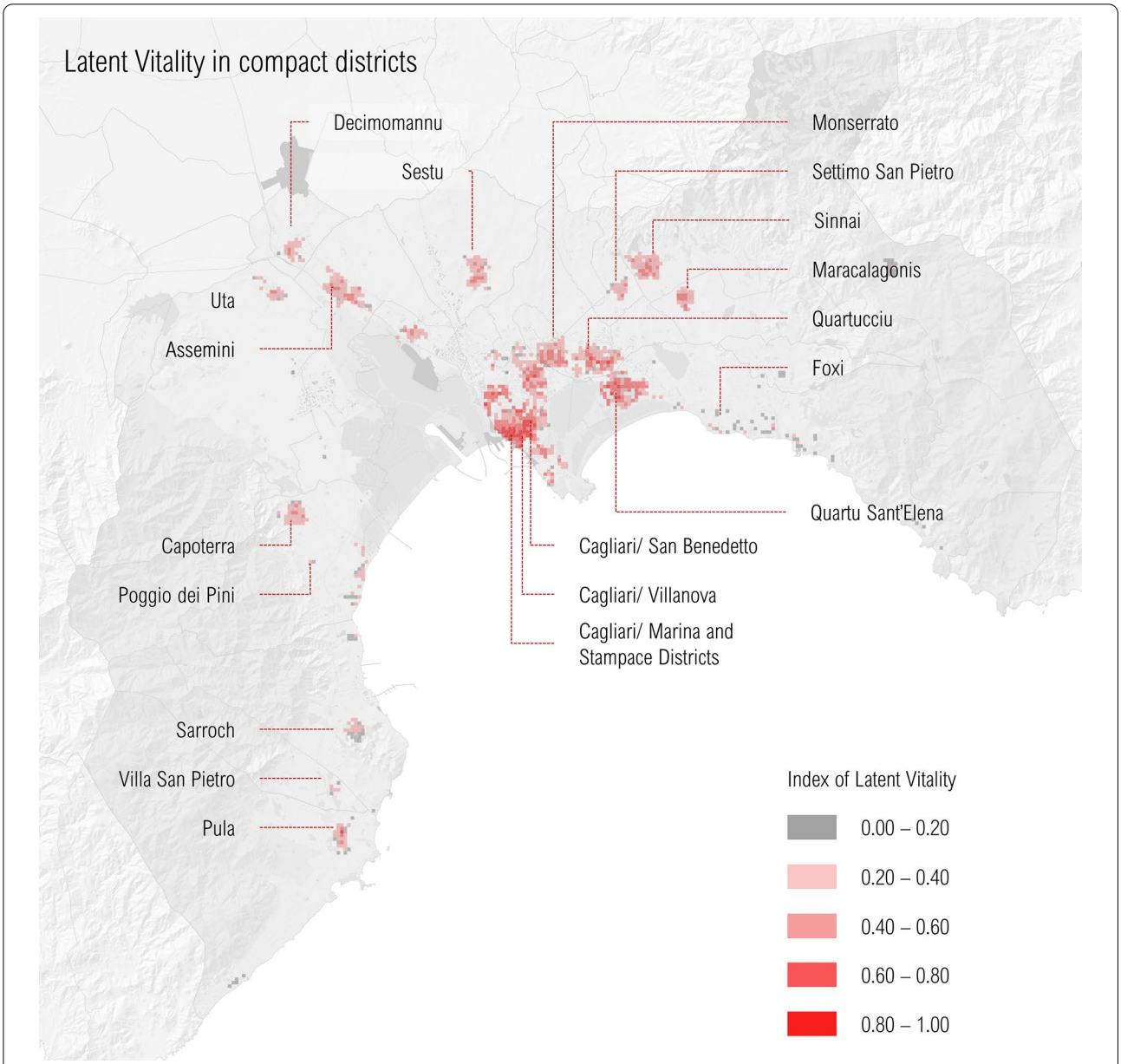

Fig. 5 Distribution of the values of the Synthetic Index of Latent Vitality (I_VIBE) across the centres of ancient formation and the compact areas of development in the Metropolitan City of Cagliari

areas of Cagliari, Monserrato, Quartu Sant'Elena, Selargius, Sinnai, and Sestu. Particularly, areas with values of the indicator of population concentration in the range of 0.90 to 1.00 are found in the compact and denser districts of Quartu Sant'Elena, Quartucciu, Monserrato, and in the districts of Pirri, Villanova, and Marina in Cagliari (Fig. 11).

Finally, the indicator of environmental quality underlines the relevance of separated core areas that comprise the system of natural reserves and sites of communitarian importance (Fig. 12).

The following section presents and discusses the findings from the analysis of the MCC, as well as the implications for the enhancing of the vitality potential.

Discussion

The results presented in the previous section, and particularly the analysis of land cover and of indicators of environmental quality, density of residential areas, density of population and density and diversity of land uses, enable the identification of the structure of the MCC and

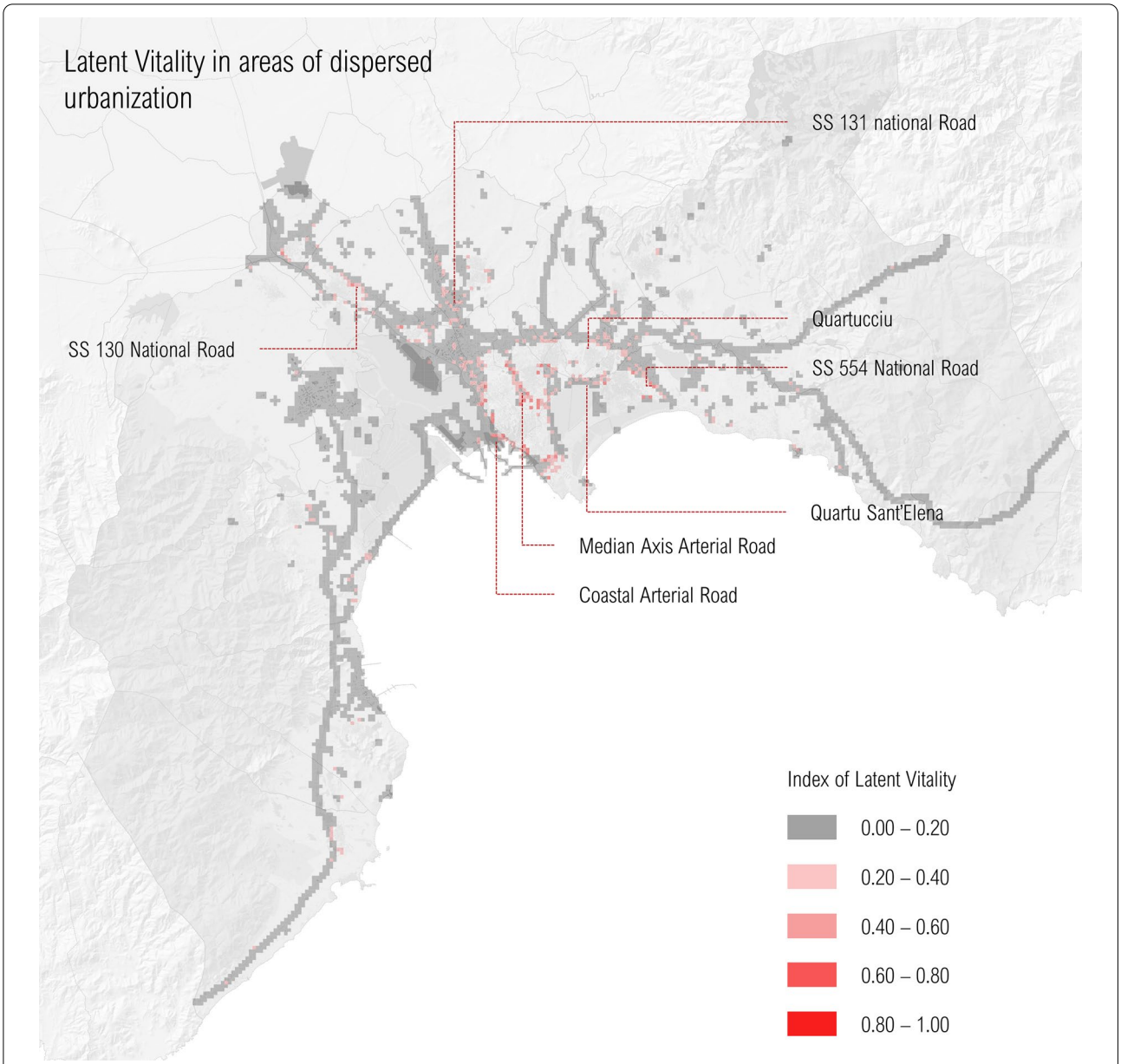

Fig. 6 Distribution of the values of the Synthetic Index of Latent Vitality (I_VIBE) across the areas of dispersed urbanization in the Metropolitan City of Cagliari

the identification of distinct spatial conditions, including compact urbanised areas, fringe areas of dispersed urbanization, fragments of rural landscapes and areas of eminent environmental quality. Particularly, the compact areas of the centres of ancient formation and the contiguous areas of consolidated development emerge as cores of vibrant spaces, presenting a significant concentration of population, determining adequate levels of demand for specialised functions, and a relevant density and diversity of land uses and points of interest. As a consequence, a structural relationship of marginal areas' dependence on central compact districts—that represent cores of economic, cultural, and social practices—is still recognizable, and is replicated at distinct scales.

Specifically, a core-periphery relationship is clear between districts within individual municipalities, and across the municipalities of the MCC. The municipality of Cagliari and the core areas of cities contiguous to Cagliari show the pre-eminent values of latent vitality. As a result, the MCC has a polycentric structure, constituted

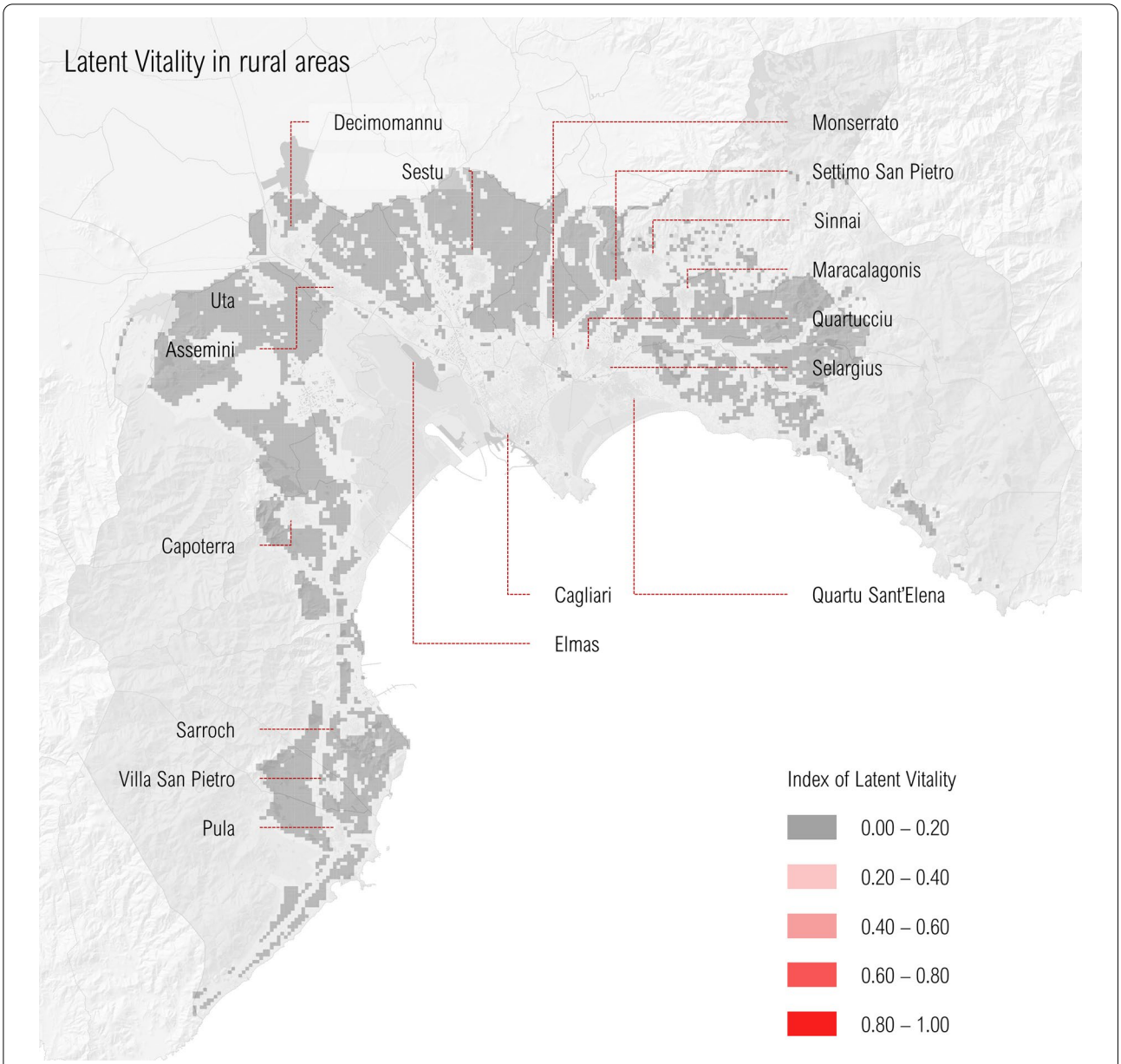

Fig. 7 Distribution of the values of the Synthetic Index of Latent Vitality (I_VIBE) across the fragments of the rural landscapes in the Metropolitan City of Cagliari

by a pre-eminent core (the compact districts of Marina, Stampace, Villanova, and San Benedetto in Cagliari); a system of secondary centres, represented by the areas of ancient formation and of consolidated development in the municipalities contiguous to Cagliari (including Quartu Sant'Elena, Selargius, Quartucciu, Monserrato, and Pirri); and a system of local centres, composed of the core areas of the municipalities located in the outer areas of the MCC (including Elmas, Assemini, Uta, Decimomannu, Settimo San Pietro, Sinnai). A significant component of the landscape of the MCC is represented by areas of pre-eminent environmental quality constituted by special protection areas and sites of community importance, including the system of wetlands of Santa Gilla and Molentargius and the reserves of Monte Arcosu and Sette Fratelli. Areas of pre-eminent environmental quality represent core areas of regional ecological infrastructure and can be conceptualized as metropolitan-scale amenities providing a diversified set of ecosystem services to the entire MCC.

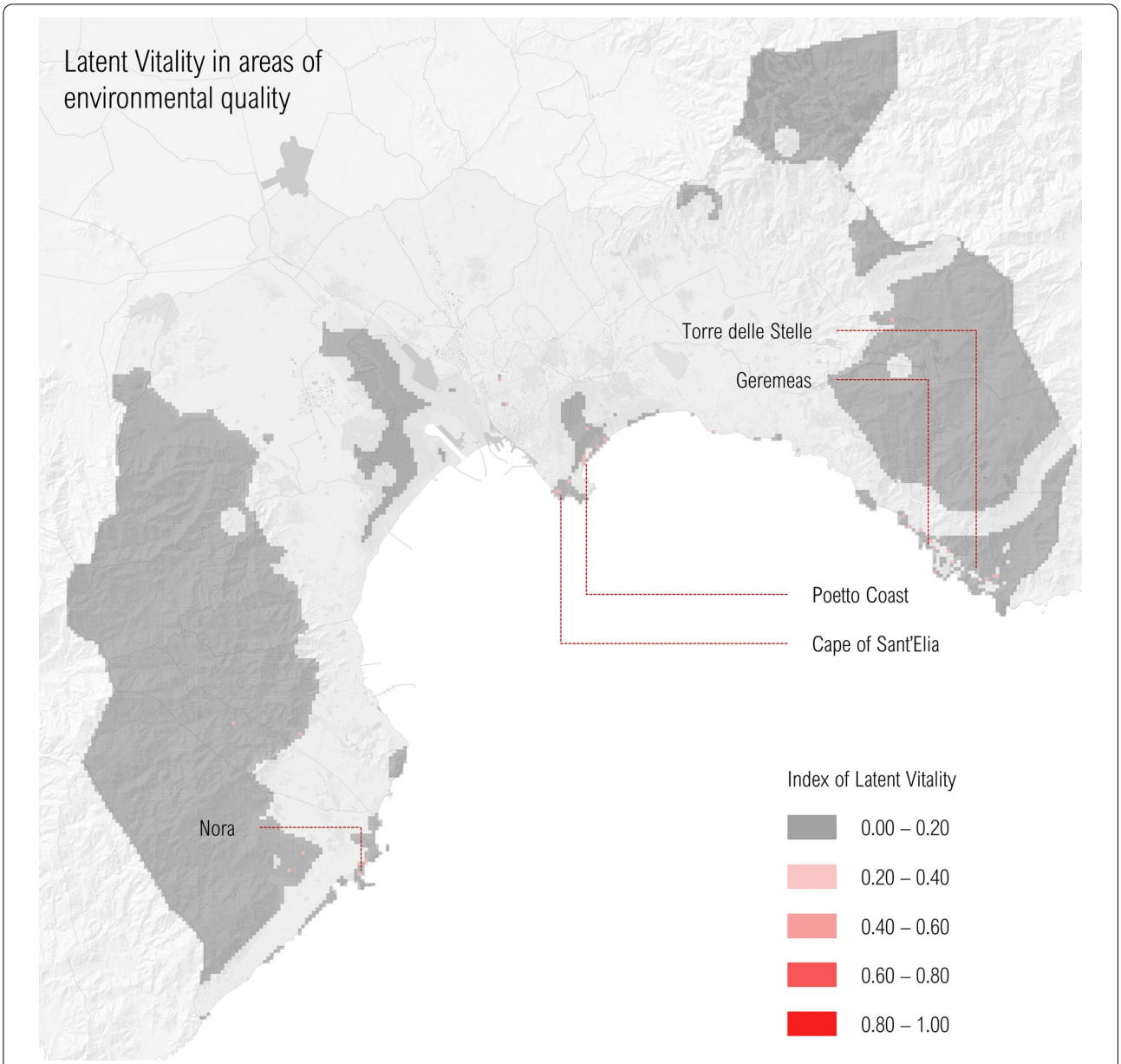

Fig. 8 Distribution of the values of the Synthetic Index of Latent Vitality (I_VIBE) across the areas of pre-eminent environmental quality in the Metropolitan City of Cagliari

There is a specific need for policies targeted at enhancing cultural and regulating services—including recreation and eco-tourism—to reinforce the ecological, economic, cultural, and symbolic role of areas of environmental quality.

Within this framework, fragments of the rural landscape, particularly those with a high natural value, such as annual crops associated with permanent crops, crops incorporating natural and semi-natural areas, stabilised grassland, emerge as central spaces of production of material goods and as components of ecological corridors.

Additionally, fringe areas and areas of dispersed urbanization represent a significant spatial situation. This spatial condition includes areas with low environmental quality (Distance from major transport and industrial infrastructure < 0.2), low density of the built-up area of residential areas (GSI < 0.2), and moderate density of points of interest (D_POI < 0.6). Fringe areas contain a diversified set of metropolitan scale functions and

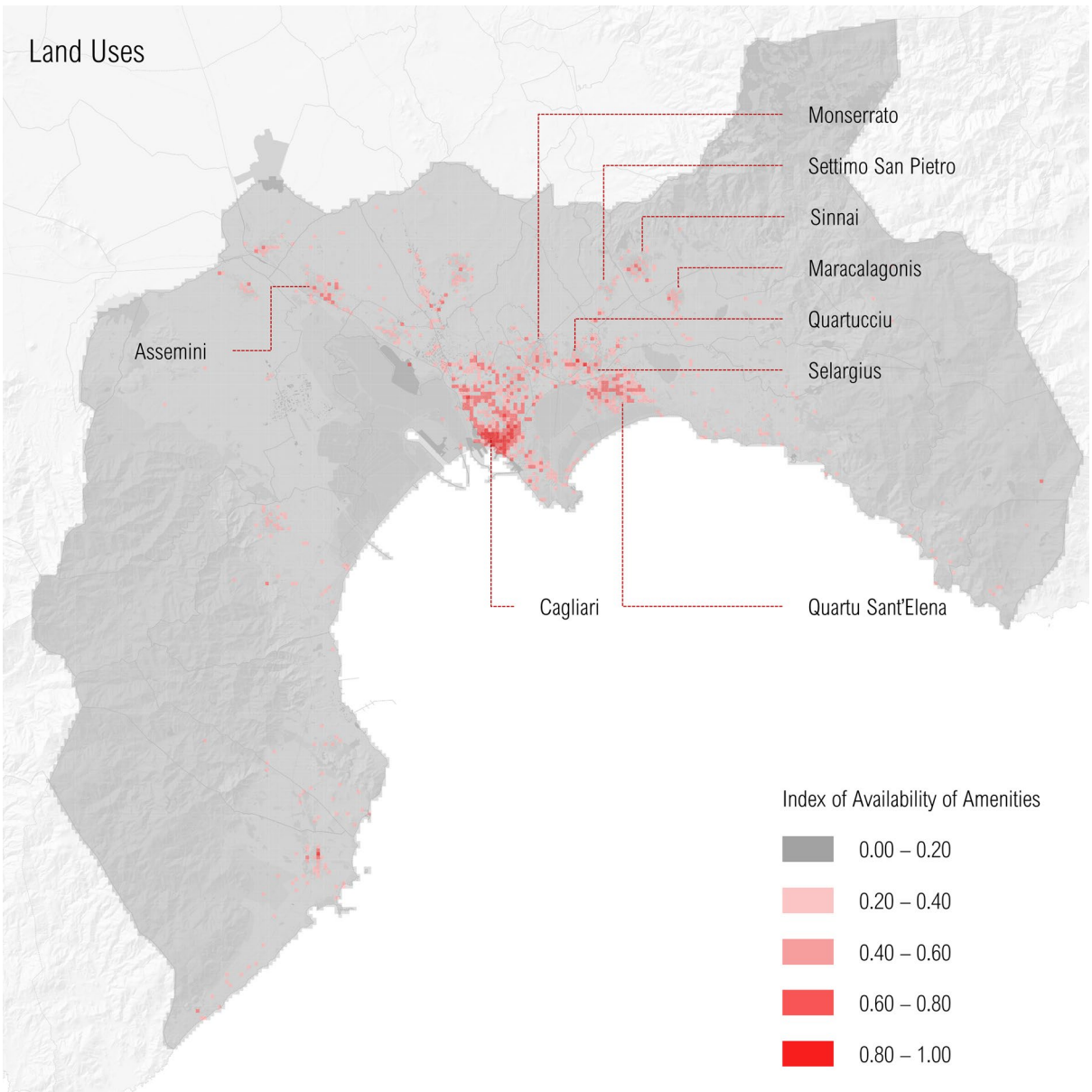

Fig. 9 Distribution of the values of the Index of Availability of Amenities (I_LU) across the the Metropolitan City of Cagliari

facilities, including transport infrastructures, industrial areas, and specialized commercial activities. The location of specialised commercial activities along the edges of transport infrastructures influences the development of new centres of the MCC. The reinforcement of cores of production, consumption, and social practices, their reconnection to the compact urbanised areas, and the improvement of conditions of accessibility, emerge as a central issue for the project of the landscape of the dispersed urbanization. In particular, four actions emerge as central aspects of the planning of the MCC: (i) the location of new metropolitan scale facilities and functions outside compact built areas and along major infrastructures; (ii) the improvement of the diversity of land uses and the integration of diversified secondary uses with urban and metropolitan scale amenities; (iii) the re-configuration of the mass transit system, in order to structure transversal corridors, tangential to the urban area of Cagliari, aimed at serving inter-municipal movements in the suburban area, and at connecting the municipalities of the metropolitan area and the emerging functional poles of the Metropolitan City; and (iv)

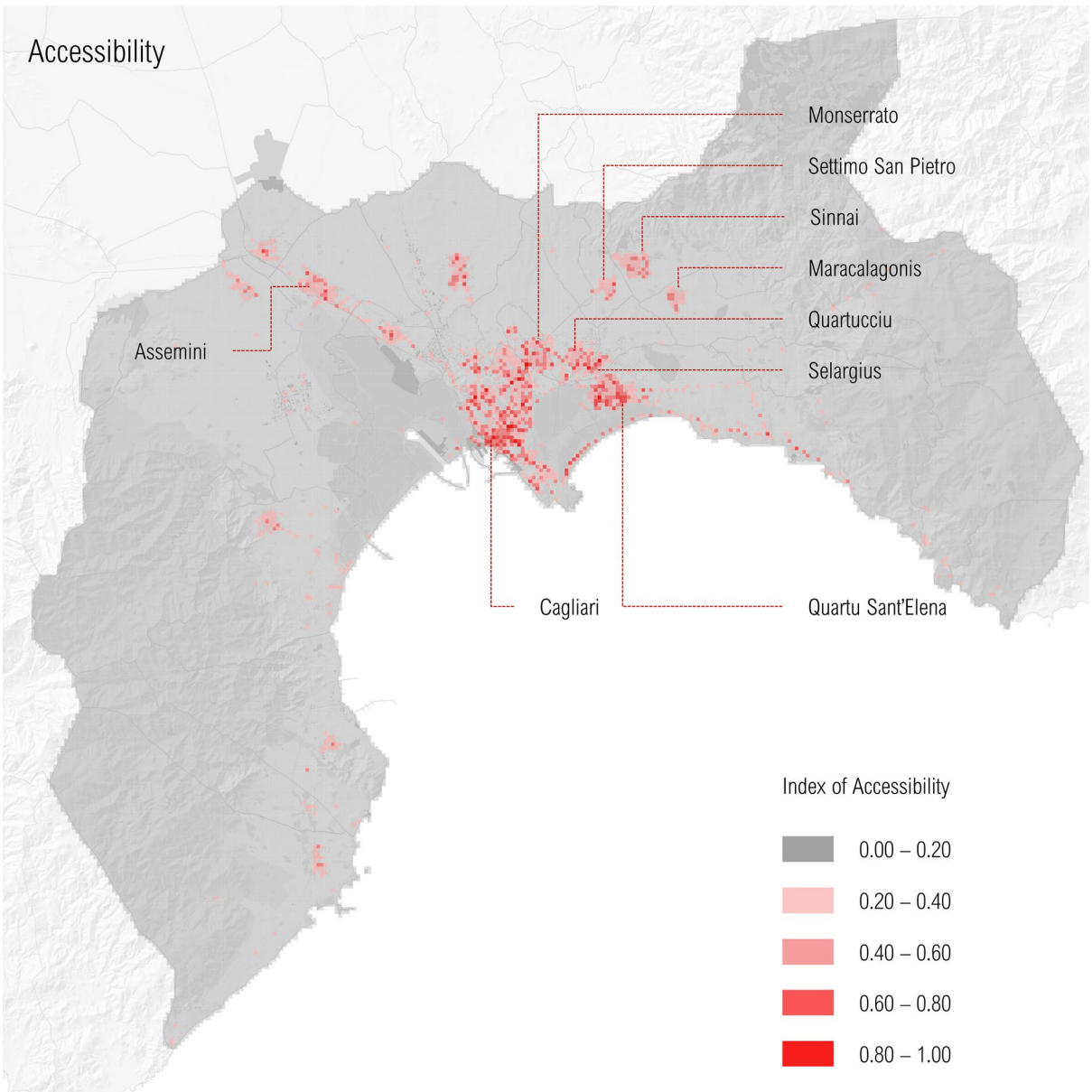

Fig. 10 Distribution of the values of the Index of Accessibility (I_ACC) across the Metropolitan City of Cagliari

the project of a system of linear open spaces, functioning as ecological corridors, public spaces, and routes for soft mobility. In particular, the findings indicate the need for a continuous, multi-layered metropolitan-scale system of pedestrian and cycle routes configured to improve the porosity of the MCC, the transversal permeability of large transport infrastructures and the conditions of access of vulnerable users to the emerging centralities of the metropolitan city. This system could be articulated on four distinct levels: strategic corridors along the radiocentric system of arterial roads, connecting major urban centers, main transport nodes and emerging centralities; Integrative routes, connecting strategic corridors, local transport nodes, minor urban centers; Local routes, serving movement of distribution from strategic/ integrative routes to sub urban areas and areas of dispersed urbanization; and eco-touristic routes in areas of environmental quality.

A conclusive consideration concerns data quality and the need for validated open databases as a precondition for the application of the geo-design paradigm to the urban environment, and, consequently, for

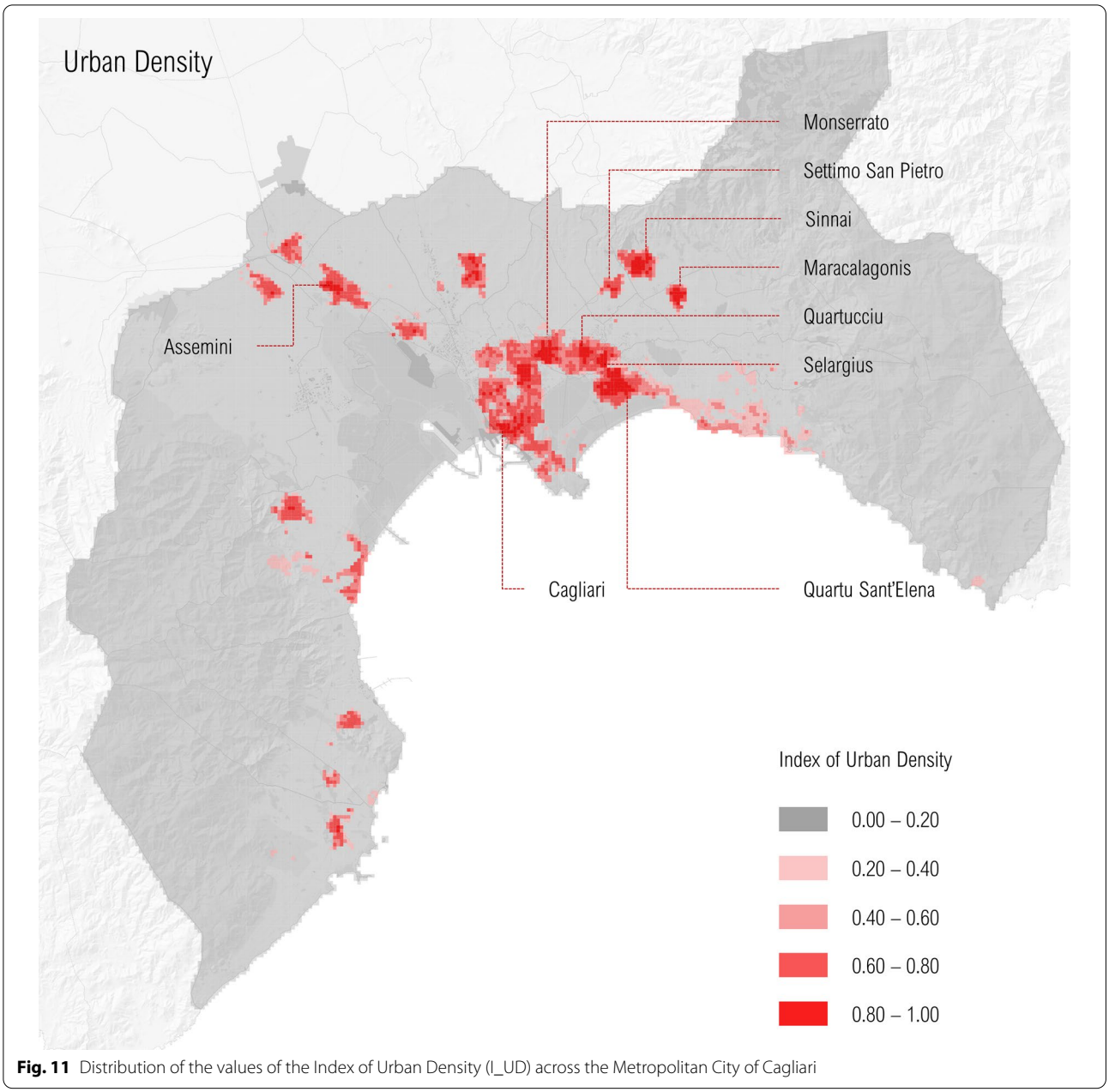

Fig. 11 Distribution of the values of the Index of Urban Density (I_UD) across the Metropolitan City of Cagliari

supporting informed decisions in the context of urban and territorial planning. The creation of procedures for quantitatively describing the built environment in a meaningful and trustworthy manner requires the availability of consistent, accurate, and comprehensive data. Indeed, data retrieved from freely available volunteered geographic information (VGI) mapping services and related to the distribution of land uses are often incomplete and inaccurate. However, issues related to inconsistency, redundancy, incompleteness of data related to the configuration of the road system, and the functions and morphology of built-up areas are also seen when data is obtained from regional and municipal territorial information systems.

These limitations emphasise the need for initiatives, involving commercial and public sector organisations, as well as academic institutions, to improve the

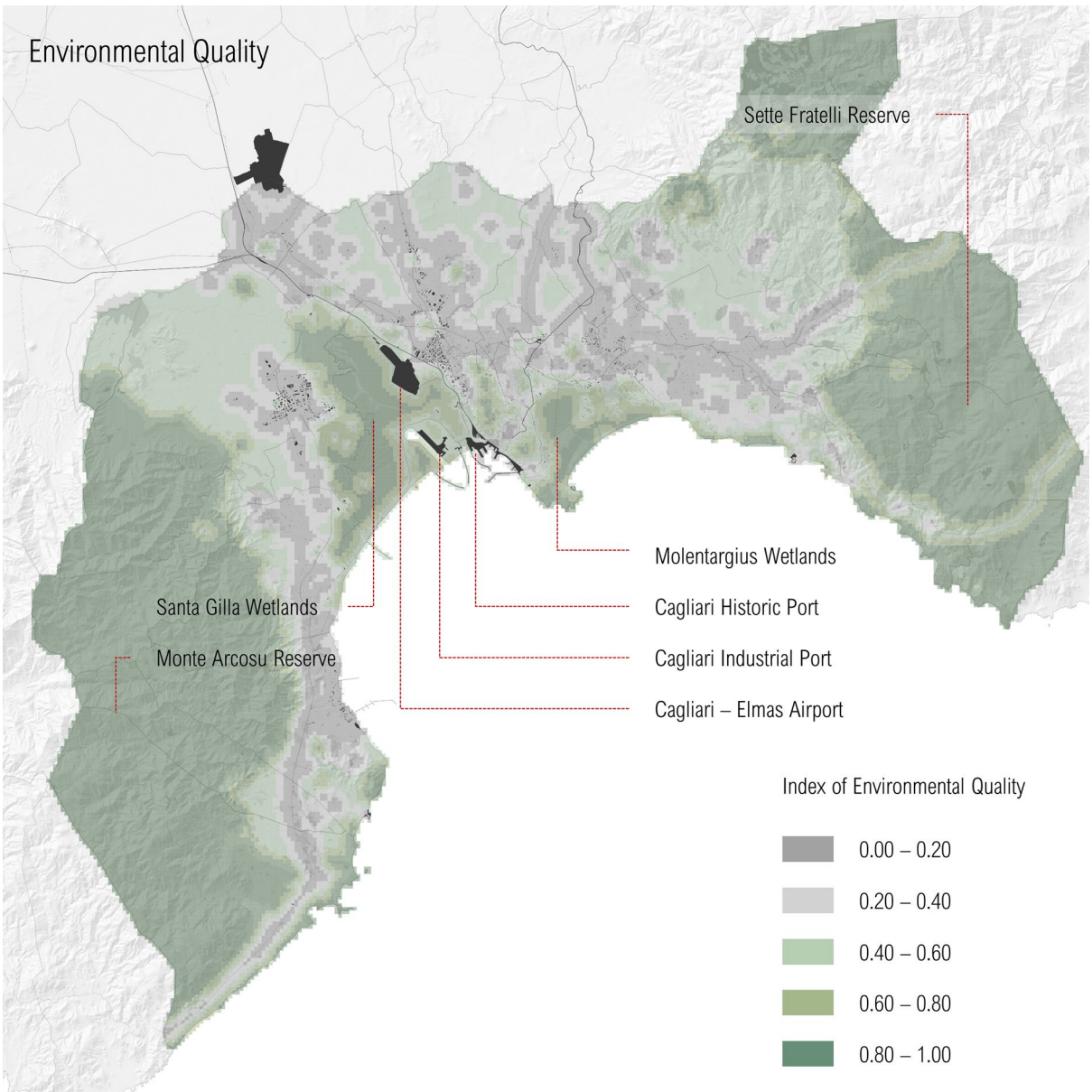

Fig. 12 Distribution of the values of the Index of Environmental Quality (I_EQ) in the Metropolitan City of Cagliari

currency, consistency, completeness, and accuracy of geographical databases.

Conclusions

This paper discusses the theoretical and methodological framework for developing a procedure for assessing the vitality potential of a metropolitan city and shows the findings from the analysis of a case study, represented by the Metropolitan City of Cagliari.

Consistently with the theoretical perspective embodied in the geo-design paradigm, this research emphasises the need of creating analytical tools for understanding the urban environment for urban and territorial planning. This aspect is central to the structuring of the knowledge base required to support the decision-making within the context of the planning process. More precisely, the proposed methodology supports the spatial planning process in the phase of the study of the area of interest, in the construction of its representation and its evaluation in terms of the potential of the components of urban form to foster

vitality and vibrancy and in the identification of critical areas.

As a result, the relevance of this study to the research on urban planning is threefold. Firstly, by developing a methodology for providing a synthetic, comprehensive, and understandable description of the vitality potential of a metropolitan city, this study experiments with the building of a methodological framework for applying the geo-design paradigm to urban planning. Secondly, this study presents a review of the existing literature and identifies a set of relevant properties of the components of urban form that determine conditions conducive to vitality. As a consequence, the vitality potential is formalised as the product of the conditions of density, environmental quality, availability of amenities, and accessibility, all of which are determined by specific properties of the components of the urban environment, including the configuration of the mass transit system and of the system of roads and public spaces, the concentration of population and the structure of built-up areas, the distribution of green areas and the distribution and diversity of land uses. Lastly, this study underlines the relevance of both global and local configurational properties of spaces in determining the accessibility of spatial elements and, hence, in fostering vitality potential. In particular, this study underlines a vacuum in the existing literature on urban morphology, related to the analysis of the influence of the configuration of the urban layout on patterns of activities. More precisely, studies on urban morphology tend to focus on the influence of road density and block size on the local distribution of pedestrian movement, hence building on findings from Jane Jacobs' research. On the other hand, existing studies marginally consider the impact of the global properties of betweenness centrality and closeness centrality on urban-scale patterns of natural movement, and, consequently, on the process of formation of centres of economic activity.

Nevertheless, this study presents two limitations. The first limitation concerns data availability and quality and consists in the formalization of conditions of environmental quality exclusively in terms of the proximity to green areas and major transport and industrial infrastructures, and in the formalization of the density of built-up areas in terms of the ratio of the projection area of buildings to the surface area of the unit of analysis. The second limitation concerns the weighting of individual and dimensional indicators and refers to the need to consider users' individual characteristics (age, gender, abilities, needs, and purposes) and contextual aspects (socio-economic factors and cultural constructs) when determining the relative importance of the attributes of urban form. As a result, the development of the research will focus on five specific aspects: (i) inclusion in the analytic protocol of the floor area ratio index as a more representative metric of the density of built-up areas; (ii) identification of indicators of the condition of ecosystem services generated by the metropolitan ecological infrastructure; (iii) definition of methodologies for determining the relative importance of properties of components of urban form via structured session groups, involving experts and different groups of users; (iv) determination of the impact of global configurational properties and metrics of environmental quality on latent urban vitality (v) Identification of social, political and economic trends that determine factors of risk for the metropolitan area and measurement of the related exposure and vulnerability of the elements of the built environment.The aim is to increase the validity and representativeness of the synthetic index of latent vitality of the urban environment, as well as the relevance in urban planning of the analytic methodology, by increasing its effectiveness in enabling the recognition of the distinct spatial conditions of the metropolitan areas. Thus, the development of the research will be aimed at increasing the relevance of the analytic method with respect to three areas of territorial planning: Firstly, structuring a comprehensive cognitive framework of the present state of a metropolitan city, and the consequent identification of vulnerable components of the built environment and of fragile areas. Secondly, supporting the definition of specific trajectories of development for the different areas of the metropolitan city and lastly, evaluating the impacts of different intervention scenarios, in terms of the emergence of new centralities and of the modification of the role of existing centres.

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Authors' contributions
This paper is the result of the joint work of the authors. In particular, "Literature Review", "Methodology" (with sub-paragraphs), and "Results" were written jointly by the authors. Chiara Garau wrote the abstract, "Introduction", and "Discussion". Alfonso Annunziata wrote "Findings from the comparative analysis" and "Conclusions". All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

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