The Role of Spatial Proximity and Urban Functions Density in the Sports Mega Events

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Abstract. The Sport Mega Events (SMEs) are large-scale events that involve many spectators, participants and organizers. The assessment of accessibility and the related management of people, public and private vehicles flows for stadiums during SMEs, is a major challenge for mobility management and the containment of environmental interference, in order to ensure safety and health for the local community.

In the Italian context there is a lack of collaborative convergence between the technical-scientific community and the Italian National Olympic Committee (CONI): the latter refers to a regulation (CONI standards for sports systems, 2008) obsolete for accessibility, thus highlighting the need for improvement and adaptation to current needs. In addition, increased community awareness of the crucial importance of sustainable mobility, energy efficiency and reduction of air pollution, also motivated by the 2030 Agenda objectives, highlights the need for gradual changes in the lifestyle of the communities themselves.

The authors' research, already engaged in the topic, fits into this synthetic framework, developing a Functional Urban Area Index (FUAPI) in 2023 which allows us to represent ex-ante scenarios based on the spatial distribution of the local community and the density of urban functions.

The aim of the paper is to evaluate and compare FUAPI for the different stadiums of the national territory, in particular the eleven stadiums candidates for the European Football Championships 2032. This allows it to represent a picture of ex-ante scenarios, which play a role in the definition of urban planning and transport-mobility actions for the SMEs' organization.

Keywords: Spatial Proximity · Functional Urban Area · Sport Mega Events

1 Introduction

Nowadays, stadiums are not only simple structures designed to hold crowds for sporting events, but they also serve as spectacular frames for the events themselves.

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Through their dynamic evolution, stadiums evolved from modest playgrounds to multi-purpose arenas that host not only sporting events, but also artistic and cultural performances [1]. They therefore become, in addition to places where sporting competitions take place, cultural and social epicenters that demonstrate the unifying power of sport. The organization of Sport Mega Events (SMEs) is a complex process and includes multiple issues that must be addressed: definition, mediation, urban development, economics, politics, legacy, impact, and resistance to their acceptance. Moreover, the planning of such events is often incompatible with the principles of sustainability and the objectives of the 2030 Agenda [2, 3].

This manuscript is part of the research carried out by the authors in 2023 [4]. The aim of this paper is the application and evaluation of the Functional Urban Area Proximity Index (FUAPI) for the Italian stadiums candidates to host the European Football Championships of 2032. This index allows the representation of SMEs ex-ante scenarios, represented before mega sports events are realized, calibrated on the local population distribution and the density of the different urban functions, supporting urban planning and local public transport in choosing locations and/or improving urban services closely related to the residence.

The manuscript is organized as follows: Sect. 2 provides a literature review on the concepts of stadium and SMEs; Sect. 3 focuses on the method; Sect. 3.1 describes the study area and Sect. 3.2 provides the related data; Sect. 4 is dedicated to the case study and the application of the method; Sects. 5 and 6 discusses respectively results and conclusions of the study.

2 Literature Review

2.1 Stadium and Sports Mega Events in the Urban Context

After the crisis following the Covid-19 pandemics, many studies have focused on the enhancement of urban society and services closely related to residence [5–7]. These services are designed to ensure that everything you require daily can be reached within a 15–20 min walk [8, 9]. Spatial proximity has enabled the generation and/or consolidation of a proximity of neighbourhood relations: in fact, social relations, mutual care and the enhancement of common goods are the main result of the neighbouring city - the so-called city of 15 min. The theme of sports mega events is evident in this context: many studies have been carried out on the effects that they have on space and on the communities hosting them. By virtue of their scale, level of financial investment and media coverage they can produce positive effects (economic growth and urban regeneration [9]) but also negative effects on the host community [10]. The organization of a Sport Mega Event (SME) requires multiple issues to be addressed, including territorial governance, infrastructure planning, the related environmental impacts as well as the complex resistance to housing them [11]. Thus, the economic and social spheres are both affected by these events. These impacts are defined as those “that have a potential impact on the quality of life of local residents” [12]. Most of the SMEs, in fact, take place inside stadiums, located in urban contexts with consequent impacts on local communities. They play a fundamental role in the organization and success of the event itself: stadiums not only host competitions, but they also offer integrated services and facilities

to handle the large number of participants. Stadiums, in fact, were born as 'factories of sporting events' and have developed on the one hand with the evolution of sport, on the other with the growing interest in sport supported through the link between sponsor and media, but also as a consequence of the sport business industry [1, 13].

In the specific case of the Italian stadiums, Fig. 1 describes the three main phases [14] of the stadium model, which is closely related to the spatial settlement model.



Fig. 1. Italian stadium Generation (Author: Sinatra M., 2024; Source: Balletto, G., Borruso, G., Tajani, F., & Torre, C. M. (2018) [14]).

To ensure the safety and health of communities [15], sustainable mobility must contain environmental interference (noise, air etc.), which is an important challenge in the SMEs' organization [16–18], also in the management of vehicular and pedestrian flows, with a special focus on the management of accessibility.

The difficulty with assessing the latter arises from taking into account not only the average time for individual stages of the journey to access stadiums, but also the levels of congestion and/or traffic regulation systems.

3 Materials and Methods

The method is an advance of the research previously carried out by the authors. The aim of the research was to develop a proximity index, based on the distribution of the resident population, spatial proximity [4], and accessibility, which could support the planning of Mega Sports Events [4]. In this paper, the method has been improved: the aim, in fact, is to develop a methodological approach that allows the construction of a proximity index,

based on the distribution of the local residential community and the density of elements to which certain urban functions are attributed, identified through the FUA sub-units.

The point data model, in particular, was transformed into a three-dimensional continuous density surface by using the Kernel Density Estimation function. Therefore, the Functional Urban Area Proximity Index (FUAPI) represents the sum (*1-n*) of the Kernel Density Estimation area performed on the different functions of the i-th data set, and spatial proximity (k_i) all multiplied by the weight w_i [4]:

$$\text{FUAPI} = \frac{1}{n}\sum_{i=1}^{n} w_i k_i \tag{1}$$

Specifically, k_i can be described by the following formula:

$$k_i = \frac{cluster\ area\ of\ KDE_i}{spatial\ proximity} 0 \leq k_i \leq 1 \tag{2}$$

where:

- cluster area of KDE_i represents the area obtained through the Kernel Density Estimation of the i-th data set;
- spatial proximity is the buffer area with a radius of 1 500 m, calculated by the service from which attractiveness is evaluated.

The weight w_i can be expressed as the difference of the resident population within the spatial proximity area and the population living in the i FUA analyzed, all related to the population of spatial proximity:

$$w_i = \frac{\text{population of spatial proximity} - \text{population of} FUA_i \text{ class}}{spatial\ proximity} 0 \leq w_i \leq 1 \tag{3}$$

FUAPI provides an indication of the current situation of the proximity area from which the attractiveness of the service is assessed (ex-ante scenario).

To asses the scenario that would occur following the performance of a SME (ex-post scenario) it was evaluated, in percentage terms, the relationship between the people who could attract the event (turnout) and the resident population within the spatial proximity, defined as Carry Capacity:

$$CC = \frac{turnout\ of\ an\ event}{population\ of\ spatial\ proximity} 0 \leq CC \leq 100 \tag{4}$$

Table 1 shows different scenarios for FUAPI and Carry Capacity.

Table 1. Possible scenarios, classified for the respective level, FUAPI and Carry Capacity class (Authors: Balletto G. and Sinatra M, 2023).

Level	Functional Urban Area Index (FUAPI)		Carry Capacity (CC)	
	Class [0–1]	Scenario	Class [%]	Scenario
1	1–0.76	Positive	$60 \leq CC \leq 100$	Mid-high positive
			$60 < CC \leq 45$	Average positive
			$45 < CC \leq 30$	Average critical
			$30 < CC \leq 20$	Mid-high critical
			$CC < 20$	Critical
2	0.75–0.51	Average positive	$60 \leq CC \leq 100$	Mid-high positive
			$60 < CC \leq 45$	Average positive
			$45 < CC \leq 30$	Average critical
			$30 < CC \leq 20$	Mid-high critical
			$CC < 20$	Critical
3	0.50–0.26	Average critical	$60 \leq CC \leq 100$	Mid-high positive
			$60 < CC \leq 45$	Average positive
			$45 < CC \leq 30$	Average critical
			$30 < CC \leq 20$	Mid-high critical
			$CC < 20$	Critical
4	0.25–0.00	Critical	$60 \leq CC \leq 100$	Mid-high positive
			$60 < CC \leq 45$	Average positive
			$45 < CC \leq 30$	Average critical
			$30 < CC \leq 20$	Mid-high critical
			$CC < 20$	Critical

3.1 Study Area

The UEFA (Union of European Football Associations) European Football Championship 2032, more commonly known as EURO 2032, will be the 19th edition and will involve the male national teams of UEFA member associations. Between June and July 2023, Italy and Turkey will host the competition. For Italy it will be the fourth time that the matches of the European Championship will be played in its stadiums (EURO 1968, EURO 1980 and EURO 2020), while Turkey will host the championship for the first time.

For this reason, the study area is therefore represented by the Italian cities () candidate to host the European football championships 2032 (Bari, Bologna, Cagliari, Florence, Genoa, Milan, Naples, Palermo, Rome, Turin and Verona) (Fig. 2).

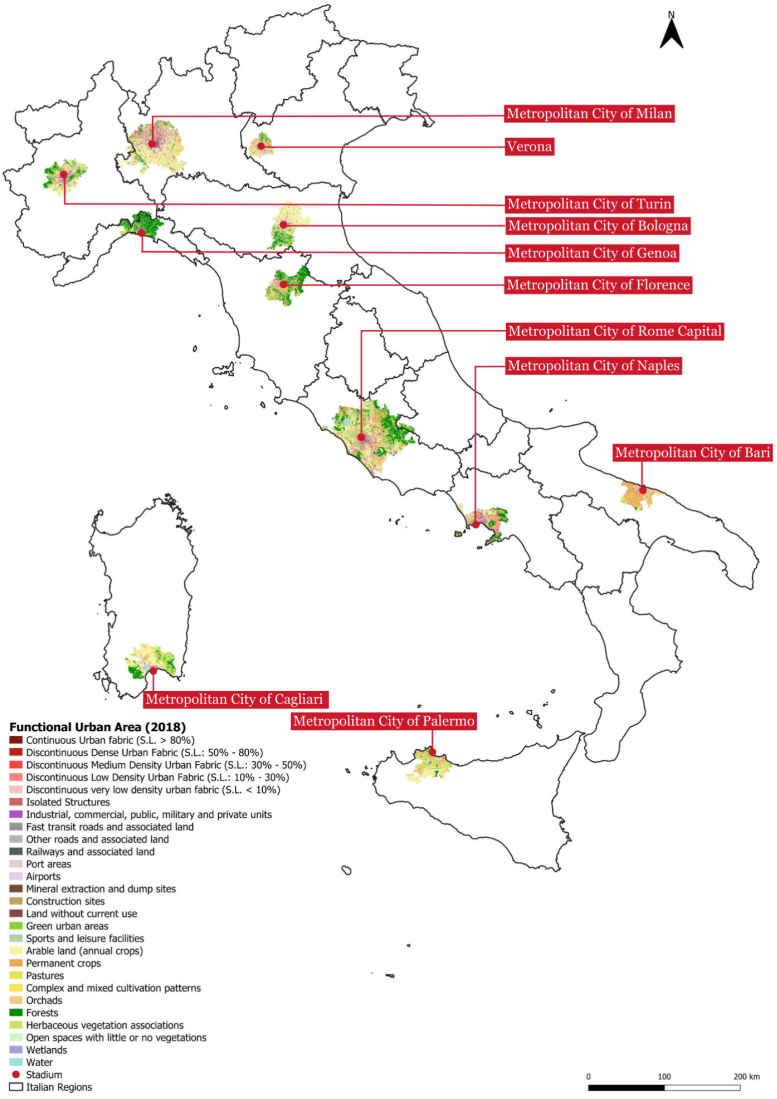

Fig. 2. Italian cities candidate to host the European Football Championship 2032 and related Functional Urban Area (Author: Sinatra M., 2024).

3.2 The Data

The dataset used in this manuscript consists of different layers (Table 2). In particular, following a careful review of the literature, the following data were used:

1. Urban Atlas - Copernicus: Functional Urban Area (2018 edition) [19]. Specifically, from this dataset it was possible to extract information about the urban fabric, classified according to 788 functional urban areas at European level. Italy's classification includes 27 functional urban areas.
2. Permanent census of population and housing [20]. This dataset was used to identify the resident population for different land use classes. Although the Copernicus dataset provides a population estimate, it was chosen to interpolate census section level data with land use classes in order to obtain more recent and reliable data. The following table summarizes the data used.

Table 2. Datasets.

ID	Dataset	Open Data	Source
01.1	Sports and leisure facilities	✓	FUA (Copernicus, 2018 Edition)
01.2	Continuous urban fabric (IMD > 80%)		
01.3	Dense urban fabric (IMD 30–80%)		
01.4	Low density fabric (IMD < 30%)		
01.5	Industrial, commercial, public and military units		
02	Permanent census of population and housing	✓	ISTAT, 2021

4 Case Study: Italian Stadiums Candidates for European Cup 2023

Italy submitted its candidacy for hosting matches in its stadiums together with Turkey for the 2032 European Football Championship. For this reason, it was chosen to apply the methodological approach to the 11 Italian candidate cities to host the EURO 2032 matches. Demographic statistics for metropolitan cities (Except for Verona, which is not a metropolitan city) [1], information on the urban/administrative fabricand the relative capacity of the stadiums can be found in Table 3.

Table 3. Summary of demographic statistics and urban/administrative infrastructure's information. Green indicates: metropolitan city, urban stadium and the presence of the metro or railway. Instead, red indicates: that the city is not a metropolitan city, the stadium is not an urban stadium and the absence of metro or railway.

City	Population (1/01/2023) [1]	Pop. density [pop/km^2]	Metropolitan City	Urban stadium and capacity	Train or Metro
Napoli	2 980 338	2 528		54 726	
Milano	3 228 006	2 049		75 817	
Roma	4 227 059	788		72 698	
Genova	816 606	445		36 599	
Cagliari	420 364	337		30 000	
Torino	2 204 632	323		41 507	
Bari	1 225 048	317		58 270	
Firenze	988 194	281		43 147	
Bologna	1 014 124	274		38 279	
Palermo	1 204 189	240		36 365	
Verona	256 049	199		39 211	

For the geospatial representation, the cities that presented the most significant results were chosen. The first selected city is Bari (Fig. 3) as the FUAPI turns out to be the lowest (FUAPI = 0.48 - level 3). The second city selected is Verona (Fig. 4), which has a high FUAPI level (FUAPI = 0.82 - level 1), even though it is not a metropolitan city. The following geospatial representations illustrate the different KDE and spatial proximity (R = 1 500 m). In particular, as regards the analysis of KDE, it was used a quadratic KDE with a radius of 500m and cell size of 25 m, applied to the following parameters and with the results as indicated:

- sports and leisure facilities (Fig. 3a and 4a);
- continuous urban fabric. S.L. > 80%(Fig. 3b, and 4b);
- discontinuous dense and medium density urban fabric- SL 50–80%) (Fig. 3c and 4c);
- discontinuous medium and low density urban fabric - 10–50%, (Fig. 3d and 4d);
- discontinuous medium and low density urban fabric - 10–50%, (Fig. 3d and 4d);
- industrial, commercial, public, military and private units (Fig. 3f and 4f).

5 Result and Discussion

The analysis was carried out on the candidate Italian cities to host the European Football Championship 2032. The proposed method based on FUAs made it possible to obtain a proximity index on the distribution of the local residential community and on the density of urban functions. The density was calculated using the Kernel Density Estimation function. The summary results for the cities (Bari, Bologna, Cagliari, Florence, Genoa, Milan, Naples, Palermo, Rome, Turin and Verona) are shown in Table 4. In particular, the cities that have FAUPI level 1 scenarios are: Genoa, Turin and Verona; level 2 are: Bologna, Cagliari, Milan, Naples, Palermo, Rome and Florence; the only city with a level 3 rating is Bari.

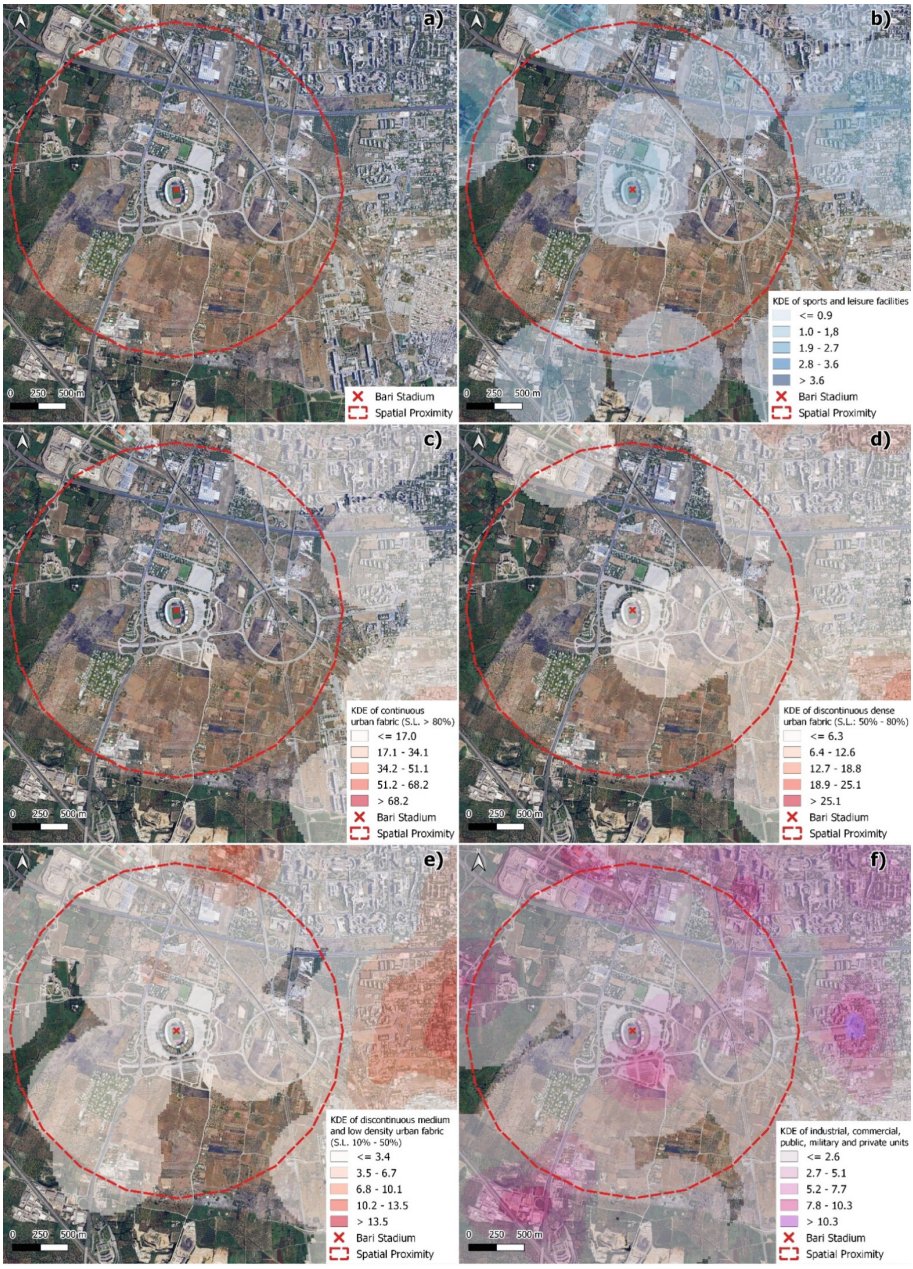

Fig. 3. Bari - Kernel Density Estimation and spatial proximity (Author: Sinatra M., 2024).

For each scenario we then proceeded to determine a set of policies (Table 5).

Table 4. Functional Urban Area Proximity Index results.

City	ID FUA_i class	Pop. of FUA_i	Pop. of spatial proximity	Stadium capacity	w_i	Cluster area of KDE [m^2]	Spatial proximity [m^2]	k_i
Bari	01.1	36	3 561	58 270	0.99	2 520 820	6 952 882	0.36
	01.2	0			1.00	199 169		0.03
	01.3	11			1.00	2 298 318		0.33
	01.4	11			1.00	5 338 959		0.77
	01.5	71			0.98	6 549 302		0.94
$FUAPI_{Bari}$		**0.48 (level 3)**						
Bologna	01.1	262	51 756	38 279	0.99	3 558 822	6 952 676	0.51
	01.2	11 662			0.77	5 546 669		0.80
	01.3	22 218			0.57	6 089 854		0.88
	01.4	6 456			0.88	6 892 694		0.99
	01.5	3 953			0.94	6 715 670		0.97
$FUAPI_{Bologna}$		**0.68 (level 2)**						
Cagliari	01.1	31	23 187	30 000	1.00	3 447 652	4 668 999	0.74
	01.2	5 960			0.74	3 882 587		0.83
	01.3	9 520			0.59	4 167 487		0.89
	01.4	3 784			0.84	3 950 009		0.85
	01.5	1 497			0.94	4 640 632		0.99
$FUAPI_{Cagliari}$		**0.70 (level 2)**						
Florence	01.1	437	59 519	43 147	0.99	3 796 317	6 952 671	0.55
	01.2	36 263			0.39	6 113 453		0.88
	01.3	16 525			0.72	6 659 877		0.96

(*continued*)

Table 4. (*continued*)

City	ID FUA_i class	Pop. of FUA_i	Pop. of spatial proximity	Stadium capacity	w_i	Cluster area of KDE [m^2]	Spatial proximity [m^2]	k_i
	01.4	1 631			0.97	5 477 742		0.79
	01.5	3 490			0.94	5 836 526		0.84
$FUAPI_{Florence}$		**0.63 (level 2)**						
Genoa	01.1	241	162 973	36 599	1.00	4 633 119	6 958 445	0.67
	01.2	51 770			0.68	6 829 103		0.98
	01.3	23 571			0.86	6 918 500		0.99
	01.4	4 341			0.97	6 016 318		0.86
	01.5	3 841			0.98	6 877 046		0.99
$FUAPI_{Genoa}$		**0.80 (level 1)**						
Milan	01.1	1 111	101 507	75 817	0.99	5 623 252	6 958 432	0.81
	01.2	14 596			0.86	4 694 074		0.67
	01.3	18 868			0.81	6 403 418		0.92
	01.4	7 772			0.92	6 492 690		0.93
	01.5	1 307			0.99	6 317 461		0.91
$FUAPI_{Milan}$		**0.78 (level 2)**						
Naples	01.1	148	117 821	54 726	1.00	5 422 923	6 925 684	0.78
	01.2	46 102			0.61	6 470 575		0.93
	01.3	13 976			0.88	6 239 064		0.90
	01.4	1 015			0.99	4 501 961		0.65
	01.5	2 156			0.98	6 583 886		0.95

(*continued*)

Table 4. (*continued*)

City	ID FUA_i class	Pop. of FUA_i	Pop. of spatial proximity	Stadium capacity	w_i	Cluster area of KDE [m^2]	Spatial proximity [m^2]	k_i
$FUAPI_{Naples}$		**0.74 (level 2)**						
Palermo	01.1	432	47 194	36365	0.99	3 709 653	6 933 679	0.54
	01.2	28 089			0.40	4 429 551		0.64
	01.3	11 470			0.76	4 769 843		0.69
	01.4	3 147			0.93	4 598 927		0.66
	01.5	706			0.99	5 776 911		0.83
$FUAPI_{Palermo}$		**0.55 (level 2)**						
Rome	01.1	328	33 957	72 698	0.99	5 018 614	6 944 412	0.72
	01.2	12 721			0.63	4 793 259		0.69
	01.3	12 222			0.64	6 309 382		0.91
	01.4	7 334			0.78	5 931 941		0.85
	01.5	511			0.98	6 944 412		1.00
$FUAPI_{Rome}$		**0.68 (level 2)**						
Turin	01.1	5	85 980	41 507	1.00	5 517 422	6 956 493	0.79
	01.2	7 272			0.92	5 971 570		0.86
	01.3	10 859			0.87	6 458 354		0.93
	01.4	6 571			0.92	6 187 469		0.89
	01.5	8 390			0.90	6 956 493		1.00
$FUAPI_{Turin}$		**0.82 (level 1)**						
Verona	01.1	637	75 095	39 211	0.99	5 690 633	6 954 391	0.82
	01.2	17 980			0.76	6 289 915		0.90

(*continued*)

Table 4. (*continued*)

City	ID FUA_i class	Pop. of FUA_i	Pop. of spatial proximity	Stadium capacity	w_i	Cluster area of KDE [m^2]	Spatial proximity [m^2]	k_i
	01.3	5 854			0.92	6 635 021		0.95
	01.4	994			0.99	5 336 743		0.77
	01.5	3 294			0.96	6 921 891		1.00
$FUAPI_{Verona}$		**0.82 (level 1)**						

Table 5. Summary results and Policy.

City	Carry Capacity (CC) [%]	FUAPI [0-1]	FUAPI level scenario	Policy
Genoa	78	0.80	1	Soft policy TPL
Naples	54	0.74	2	Soft policy TPL
Turin	52	0.82	1	Soft policy TPL
Verona	48	0.82	1	Soft policy TPL
Florence	28	0.63	2	Hard/soft policy TPL
Bologna	26	0.68	2	Hard/soft policy TPL
Milan	25	0.78	2	Hard/soft policy TPL
Palermo	23	0.55	2	Hard/soft policy TPL
Cagliari	-	0.70	2	Hard policy di TPL
Rome	-	0.68	2	Strong policy di TPL
Bari	-	0.48	3	Exclusion

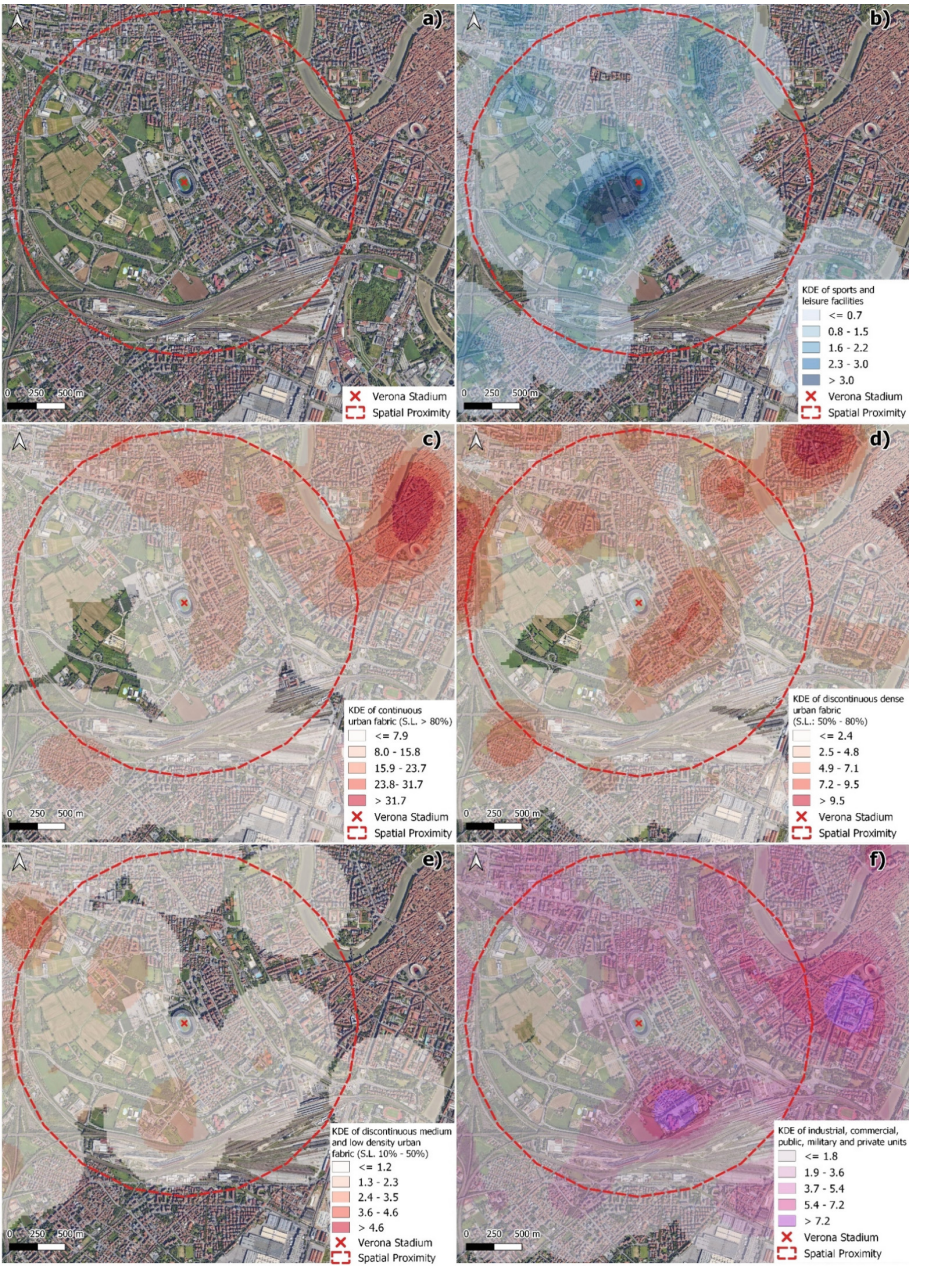

Fig. 4. Verona - Kernel Density Estimation and spatial proximity (Author: Sinatra M., 2024).

The analysis performed provides policy suggestions (Table 5) based on the scores gained by the different cities considered in terms of the FUAPI index and Carry Capacity. Cities like Genoa, Naples, Turin and Verona do not need important public transport policies, due to their configuration in terms of the sport facilities and level of services. More relevant interventions are needed in Florence, Bologna, Milan and Palermo, while the bottom of the table host Cagliari and Rome, that need harder policies, but still realizable. Bari, given its score, would be excluded from the selection.

6 Conclusion and Future Development

The present research was aimed at developing the FUAPI Index, based on an interdisciplinary approach, combining the 15-min city paradigm, the spatial distribution of the population and the concentration of urban functions.

As discussed previously, the focus in this document was on the area near the candidate Italian cities to host the European Football Championship 2032, assuming a buffer zone of approximately 15 min (radius 1,500 m) around the reference stadium and superimposing the density of residences and of urban services. This was achieved using various spatial analysis techniques, Kernel density in particular. A minimum unit of 25 m was used to collect and represent the results. The objective of future research is to continue in this line, using the Triple Access Planning (TAP) dataset, which is based on urban accessibility, which can be achieved through the transport system (physical mobility), the territorial system (spatial proximity) and the telecommunications system (digital connectivity). Digital connectivity, i.e. being connected, has in fact become an integral part of daily life, as important for communities and businesses as connection to service networks and therefore relevant in urban planning.

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