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Reading Urban Green Morphology to Enhance Urban Resilience: A Case Study of Six Southern European Cities

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Abstract: A loss of natural capital within cities and their surrounding areas has been noticed over the last decades. Increasing development associated with higher sealing rates has caused a general loss of Urban Green Spaces (UGS) within the urban environment, whereas urban sprawl and the improvement of road networks have deeply fragmented the surrounding landscape and jeopardized ecosystems connectivity. UGS are an essential component of the urban system, and their loss has a greater impact on, e.g., ecological and hydrological processes, threatening human well-being. Different types and spatial configurations of UGS may affect their own ability to provide ecosystem services, such as biodiversity support and water regulation. Nevertheless, the study of UGS spatial patterns is a research branch poorly addressed. Moreover, UGS analyses are mainly focused on public and vast green spaces, but seldom on informal, private, and interstitial ones, returning a myopic representation of urban green areas. Therefore, this study investigates the UGS spatial patterns within six Southern European cities, using the urban morphology analysis to assess all urban vegetated lands. Results revealed three main Urban Green Spatial Patterns (UGSPs): *Fragmented*, *Compact*, and *Linear Distributions*. UGSPs taxonomy represents a novelty in the urban morphology field and may have important implications for the ability to provide ecosystem services and, thus, human well-being.

Keywords: Urban Green Spaces (UGS); Urban Green Spatial Patterns (UGSPs); Green Infrastructure (GI); Informal Urban Greenspace (IGS); urban morphological analysis; sustainable urban development

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1. Introduction

Urban areas represent a highly complex ecological, social, and economic system constantly undergoing change and evolution [1]. During the last century, urban growth has deeply impacted natural capital, jeopardizing the surrounding landscapes and threatening urban green spaces. On one hand, the urban sprawl into peri-urban areas (e.g., agricultural lands, forestlands, and natural wetlands) and the improvement of the road networks have fragmented green spaces into small patches, reducing the natural landscape and modifying its connectivity [2–4]. On the other hand, within the urban areas, the infill development for new housing and business has put pressure on urban green spaces, causing their general loss [5,6].

Urban Green Spaces (UGS), defined as all vegetated lands within the urban environment [7], represent an important component of the urban system, providing a vast array of ecosystem goods and services relevant for human well-being [8]. Ecosystem services can be defined as the "benefits that people obtain from ecosystems or their direct and indirect contributions to human well-being" [9]. In urban environments, UGS can supply provisioning services (e.g., water supply), regulating services (e.g., filtering air pollutants, mitigating urban heat islands, facilitating water infiltration and storage, regulating water quality), supporting services (e.g., water cycling and provisioning of habitat for species), and cultural services (including recreational, spiritual, religious, esthetic, and psychophysical benefits) [10–13].

The loss of urban green capital driven by the infill development not only undermines residential satisfaction and health [8], but also the resilience against climate change [14]. Increasing soil sealing rates have deeply influenced ecological, hydrological, and geomorphological processes, enhancing natural disaster risk [15–17]. For instance, a lot of research has demonstrated that urban development enhances flood hazard [18] due to lower rainfall infiltration into the soil, increasing surface runoff [19] and decreasing evapotranspiration [20,21], besides leading to higher air temperatures and the well-known urban heat islands phenomenon [22]. More frequent and/or intense weather and climate-related hazards such as heavy precipitations and heat waves—along with relevant socio-economic damages—have been recorded worldwide and they are expected to increase [16,23].

Due to the growing vulnerability of urban areas to disaster risk, the concept of resilience has emerged in recent decades as an attractive ability that a city should develop to face global changes (urbanization and climate change). A comprehensive definition of urban resilience proposed by Meerow et al. [24] refers to the ability of an urban system (and its social, ecological, and technical networks) to maintain or rapidly return to previous functions after a disturbance, and to adapt to change, quickly transforming the systems that limit its adaptive capacity. Because of their multifunctional character, UGS are recognized to have an important role to ensure resilience and adaptation, thus, providing livable cities to future generations [25]. However, to build sustainable and resilient cities namely through the increase of UGS, a "strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings" is required [26]. Therefore, it is the network, the connected vegetated patches, that ensures the provision of several ecosystem services [27]. Extensive studies have demonstrated that the spatial patterns of UGS are closely related to the ecosystem services that they can deliver [28–30]. For instance, a study by A. Trihamdani [31] shows that large and centralized UGS can be less effective to mitigate urban heat islands if compared to equally distributed green spaces. On the other hand, larger urban green areas offer greater exposure to nature, positively impacting citizens' health and well-being [32]. Greening cities not only enhance resilience but also improve the well-being and livelihood of urban residents [33–35]. Hence, UGS need to be considered as an integral element of the urban system.

The combination of streets, plots, open spaces, and buildings, commonly term as "urban tissue", or "plan unit", displays a rich array of repeating arrangements in the urban space, called patterns. Urban morphology analysis identifies and describes the distinct urban patterns (elements position, shape, size, proportions) and the processes effective in their formation to understand the urban system and to plan future changes. For instance, applying an urban morphology analysis to built-up elements, the position and the outline of the buildings (the footprint) are highlighted in a two-dimensional plan view, while open spaces and street spaces are just separators. In this way, homogeneous built-up patterns can be detected. Then, these patterns can be classified according to their distribution (i.e., matrix of the urban pattern) and grain (i.e., fragmentation grade of the urban pattern). Performing this analysis at different levels of resolution, commonly the building/plot, the street/block, the city, and the region, allows to study various aspects of the urban system [36,37].

Over the last ten years, the morphological approach has received increasing attention to analyze UGS [38]. Quantitative measures that reflect some aspects of urban green spatial configuration include the ratio of green spaces to the total urban area [39], the amount of urban green space per inhabitant [39–42], the average distance between residential areas and UGS [8,39,40], and green patch size and shape [43]. However, these measures are mainly applied to formal, public, and vast urban green areas, thus, excluding informal, private, and interstitial UGS, returning a partial representation of urban green. Further research is needed to quantify small-scale and private UGS [44,45] since they also represent inestimable elements in UGS connectivity [46]. Besides, with a focus on UGS spatial patterns, many studies investigated UGS spatiotemporal changes [47,48], or applied landscape metrics to describe fragmentation processes [49,50] and to evaluate UGS connectivity [51]. However, no morphological analyses have been carried out yet to identify, classify, and describe the distinct UGS spatial patterns [38].

Hence, this study investigates the spatial patterns of UGS, intended as all urban vegetated land within cities [7], in Southern European cities. The specific aims of the research are: (1) identifying the UGS spatial patterns and define an Urban Green Spatial Patterns (UGSPs) taxonomy; (2) investigating the frequency of different UGSPs; and (3) exploring if the investigated UGSPs are characterized by a recurrent percentage of green cover. The study is focused on six study sites selected in the urban center of six ancient cities in Italy and Portugal.

2. Materials and Methods

2.1. Study Areas

This study investigates the UGS spatial configuration in Italian and Portuguese cities. We considered a city as "a Local Administrative Unit (LAU) where at least 50% of the population lives in one or more urban centres" [52]. The selection of cities included those characterized by a historic and dense center along or crossed by a river course since their resilience to natural risks such as flooding is particularly crucial. Thus, the study focuses on six cities: the Italian cities of Turin, Verona, and Parma, and the Portuguese cities of Lisbon, Oporto, and Coimbra (Figure 1).

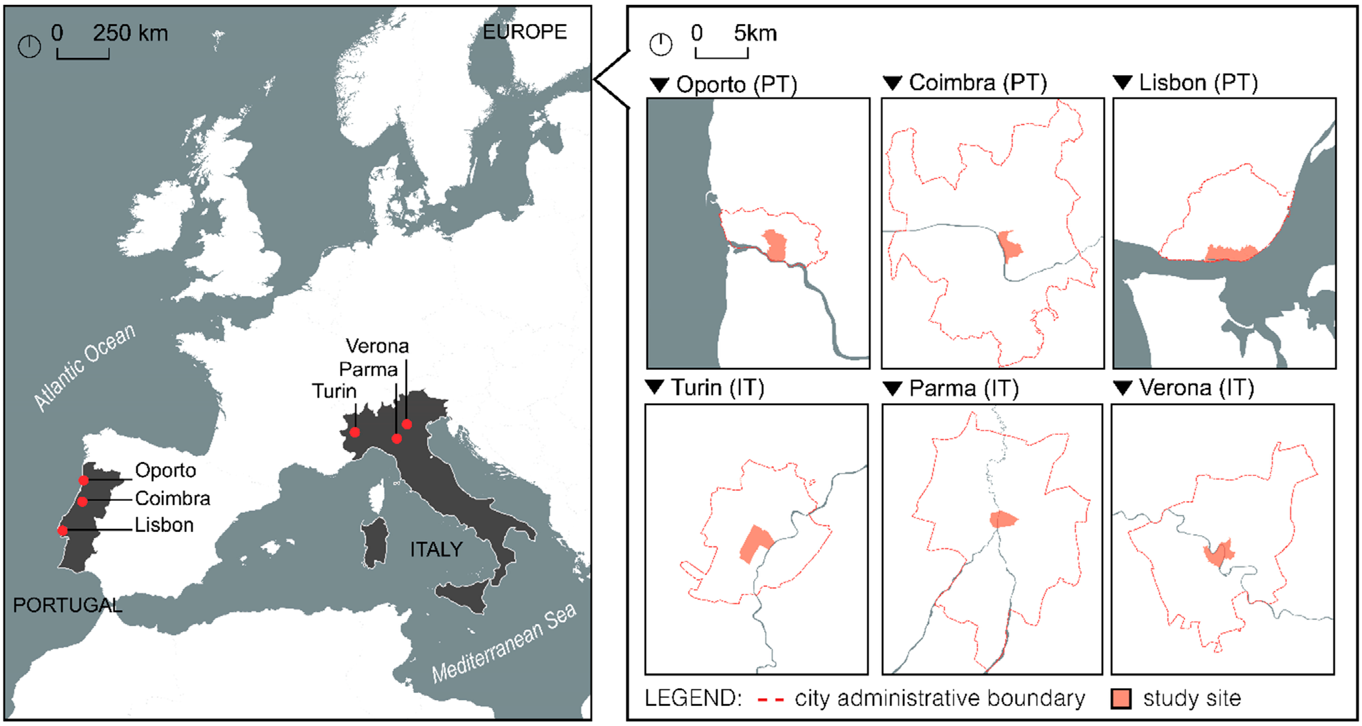


Figure 1. Location of the Italian (IT) and Portuguese (PT) cities and identification of the study areas investigated.

The UGS morphological analysis was restricted to study areas comprising a smaller portion of the cities (Figure 1 and Table 1), due to time constraints to manually identify and map all the small green areas (see Section 2.2.1). The study sites were selected considering districts (in Italian *quartieri* and *circoscrizioni* and in Portuguese *freguesias* or *união das freguesias*) characterized by the presence of a river and a historical center. The high percentage of imperviousness and the presence of the river are aspects that make ancient city centers more vulnerable to the increasingly frequent meteorological extreme phenomena. Due to the lack of unsealed soil to convert into green areas, as well as the need to preserve historical and artistic values of these places, a more careful and in-depth knowledge of the existent green infrastructure is desirable, in order to fully exploit the few opportunities to create new green areas and provide the ecosystem services required (e.g., floods and heat islands mitigation).

Table 1. Main characteristics of the cities and selected study sites.

City	Population (inhab.)	Area (km^2)	Study Site Population (inhab.)	Study Site Area (km^2)	Historical City Center (km^2)	River	Study Site's Information
Turin (IT)	872,367 (2011)	130.0	78,523 (2011)	6.9	~3.5	Name: Po Total length: 652 km	Historical origins: roman District: Circoscrizione 1 Landscape: plain Location with respect to the river: along Po River
Parma (IT)	175,895 (2011)	260.6	28,235 (2011)	3.5	~3.5	Name: Parma Torrent Total length: 92 km	Historical origins: roman Districts: Quartiere Parma Centro, Quartiere Oltretorrente Landscape: plain Location with respect to the river: crossed by Parma torrent
Verona (IT)	252,520 (2011)	198.9	30,577 (2011)	4.2	~1.5	Name: Adige Total length: 410 km	Historical origins: roman District: Circoscrizione Centro Storico Landscape: plain to hilly Location with respect to the river: crossed by Adige River
Lisbon (PT)	547,733 (2011)	100.0	61,321 (2011)	6.6	~1.4	Name: Tagus Total length: 1007 km	Historical origins: phoenician Districts: Freguesias of São Vicente, Santa Maria Maior, Misericórdia, Estrela Landscape: hilly Location with respect to the river: along Tagus River
Oporto (PT)	237,591 (2011)	41.4	40,440 (2011)	5.3	~0.5	Name: Douro Total length: 897 km	Historical origins: roman Districts: União das freguesias of Cedofeita, Santo Ildefonso, Sé, Miragaia, São Nicolau and Vitória Landscape: hilly Location with respect to the river: along Douro River
Coimbra (PT)	143,396 (2011)	319.4	13,971 (2011)	3.7	~0.5	Name: Mondego Total length: 258 km	Historical origins: roman Districts: União das freguesias de Coimbra (excluding the non-urban areas north of the street N17 and south of the A31) Landscape: plain to hilly Location with respect to the river: crossed by Mondego River

Hence, in Turin, the district called Circoscrizione 1, which partially opens on the west shore of Po River, is investigated. In Parma, the two districts are separated by the Parma Torrent: Quartiere Parma Centro, on the east shore, and Quartiere Oltretorrente, on the west shore. In Verona, the district called Circoscrizione Centro Storico is crossed by the Adige River. In Lisbon, the districts of São Vicente, Santa Maria Maior, Misericórdia, and Estrela run along the north shore of the Tagus River. In Oporto, the União das freguesias of Cedofeita, Santo Ildefonso, Sé, Miragaia, São Nicolau, and Vitóriais nestled on the north shore of Douro River and extends northward. In Coimbra, the União das freguesias of Coimbra, which runs along the east shore of Mondego River, is considered. The focus on districts rather than historical city centers allows to characterize and compare the population and extent between the six study areas.

2.2. Investigating Urban Green Spatial Patterns (UGSPs)

The study uses the urban morphological approach, typically applied to investigate built-up areas, to analyze UGS. Hence, the location and the configuration of UGS are highlighted, instead of considering those of the buildings. Buildings and non-vegetated open spaces are treated as separators. UGS analysis was processed with a Geographical Information System (GIS), using QGIS software.

In order to define the UGSPs, the analysis consists of two main stages (Figure 2): (1) the identification of UGSPs as recurrent UGS distributions (macroscale analysis); (2) the evaluation of UGSPs peculiarities in relation to the diffusion of the patterns (microscale analysis/sample survey).

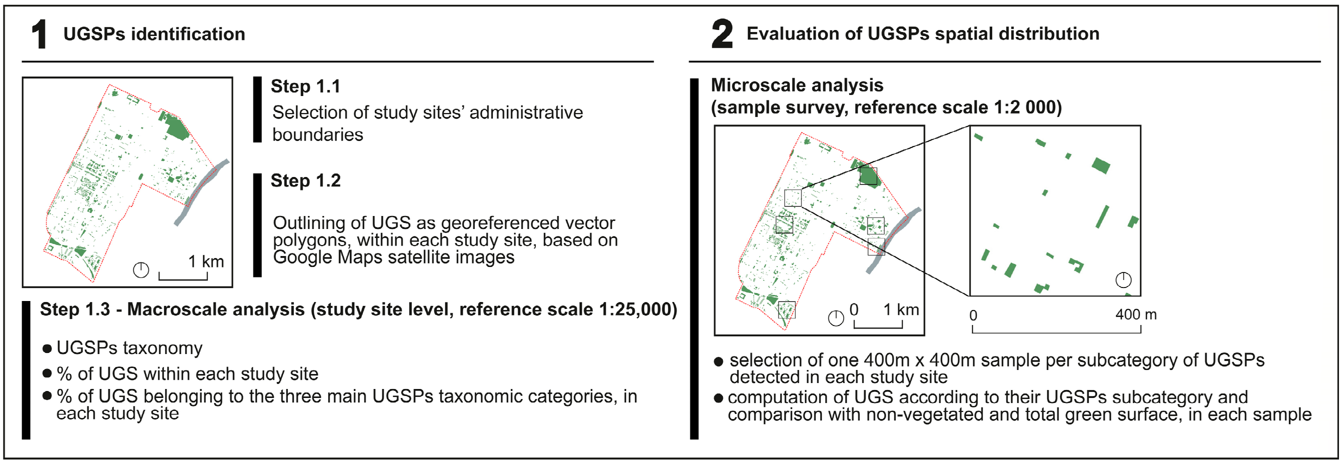


Figure 2. Graphical overview of the workflow.

2.2.1. UGSPs Identification

Districts' administrative boundaries were extracted from maps freely accessible on national and municipal websites of the selected cities. In Coimbra's case study, the borders of the historical district also included a rural area. Since the research is focused on urban areas, Coimbra's rural area was excluded from the analysis (Table 2).

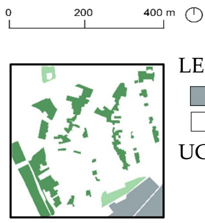
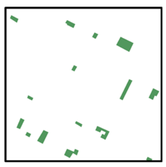
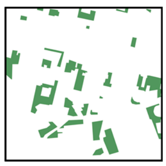
Table 2. Source and type of data used to delimit the study sites in the six selected cities (websites links can be found in the section "Data Availability Statement").

City	Study Site	Administrative Boundaries Reference	Data Type	Original Reference Scale
Turin (IT)	Circoscrizione 1	Municipality Website	pdf (boundaries description)	-
Parma (IT)	Quartiere Parma Centro, Quartiere Oltretorrente	Municipality website	shapefile	1:10,000
Verona (IT)	Circoscrizione Centro Storico	Municipality website	web map	1:10,000
Lisbon (PT)	Freguesias of São Vicente, Santa Maria Maior, Misericórdia, Estrela	Government website of statistical data	shapefile	1:25,000
Oporto (PT)	União das freguesias of Cedofeita, Santo Ildefonso, Sé, Miragaia, São Nicolau, Vitória	Government website of statistical data	shapefile	1:25,000
Coimbra (PT)	União das freguesias de Coimbra (excluding the rural areas north of the street N17 and south of the A31)	Government website of statistical data	shapefile	1: 25,000

Referring to the traditional morphological approach and its taxonomy, which is based on the description of streets, plots, and buildings recurrent arrangements (i.e., urban patterns), the present research proposes a taxonomy of UGS arrangements. The taxonomy was defined by observing UGS spatial distributions and grains, and detecting repetitive configurations of UGS, termed Urban Green Spatial Patterns (UGSPs).

The UGSPs identified within the investigated study sites are classified into three main taxonomic categories: *Linear Distributions* (LD), green areas characterized by a stretched and irregular shape; *Fragmented Distributions* (FD), describing spread and more or less scattered green areas; and *Compact Distributions* (CD), large green areas with a low level of fragmentation (Table 3). Hence, in every study site, UGS were measured and compared to the non-vegetated surface and according to their UGSPs category.

Table 3. Urban Green Spatial Patterns (UGSPs) taxonomy considered in this study.

UGSPs Taxonomy	Description	UGSPs Subcategory	Description	Graphical Example (1:2000 Reference Scale)
Linear Distribution (LD)	Green areas characterized by a stretched and irregular shape	Vertical (V) and Horizontal (H)	The term *vertical/horizontal* is related to the disposition of the green string with respect to the direction of the watercourse: *vertical* is used to define a crosswise direction; *horizontal* is used to define a parallel direction	 LEGEND: water; non-vegetated surface; UGS: LD-V; other distributions
		Belt shaped (B)	The term *belt shaped* is used to addresses a green component that encloses a city portion	 LEGEND: water; non-vegetated surface; UGS: LD-B; other distributions
		Along the Stream (ATS)	The term *along the stream* is used to addresses a green component that extends along the river	 LEGEND: water; non-vegetated surface; UGS: LD-ATS; other distributions
Fragmented Distribution (FD)	Spread and more or less scattered green areas characterized by regular or irregular shapes	Fine-Grain (FG)	Based on the extent of green, the term *fine-grain* addresses groups of small-sized green components	 LEGEND: water; non-vegetated surface; UGS: FD-FG; other distributions
		Coarse-Grain (CG)	Based on the extent of green, the term *coarse-grain* addresses groups of large-sized green components	 LEGEND: water; non-vegetated surface; UGS: FD-CG; other distributions
Compact Distribution (CD)	Large green areas characterized by a low level of fragmentation	-	-	 LEGEND: water; non-vegetated surface; UGS: C; other distributions

2.2.2. Analysis of UGSPs Spatial Distribution

In order to better comprehend the attributes of each UGS pattern, in particular to investigate if each UGSPs category is characterized by a recurrent percentage of green cover, a sample survey was conducted at a reference scale of 1:2000 (Table 3). Considering the detailed scale and the extent of the study sites (Table 1), sample plots were randomly selected. The dimension of the sample plots was defined based on the grain of the UGS tissues included in the study sites. In our study, a sample of 400 m × 400 m was considered adequate since it includes also the vastest *Linear Distributions* pattern detected in Verona.

In every study site, one random sample plot per each UGSPs category was intended to be selected. During the selection process, variations in UGS grain and spatial distribution were noticed within *Linear* and *Fragmented Distributions*. Hence, based on the grain and the spatial distribution, three *Linear* and two *Fragmented* subcategories were defined. A complete summary of the proposed UGSPs taxonomy is shown in Table 3.

According to the type of UGSPs identified in each case study, the number of samples per study site was variable (Table 4), and a total of 36 samples were investigated in the six cities. In each sample, UGS were measured according to the belonging pattern subcategory and compared with the non-vegetated and the total green surface.

Table 4. Number of samples investigated per study site and per UGSPs subcategories.

Study Site	Linear Distribution (LD) Subcategories				Fragmented Distribution (FD) Subcategories		Compact Distribution (C)
	Vertical (V)	Horizontal (H)	Belt Shaped (B)	Along the Stream (ATS)	Fine-Grain (FG)	Coarse-Grain (CG)	
Turin (IT)	x	x	-	x	x	x	x
Parma (IT)	x	-	-	x	x	x	x
Verona (IT)	x	x	x	x	x	x	x
Lisbon (PT)	x	x	x	-	x	x	x
Oporto (PT)	x	x	-	-	x	x	x
Coimbra (PT)	x	x	x	x	x	x	x
Number of samples	6	5	3	4	6	6	6

3. Results

The morphological analysis of UGS performed at the macroscale (1:25,000) identified similar UGS percentages between the cities investigated, with average and standard deviation values of green cover of 25 ± 13% in Italian and 21 ± 10% in Portuguese cities. The cities of Verona and Coimbra present the highest percentage of UGS, 41%, and 34%, respectively, whereas Lisbon (11%) and Turin (9%) are the ones with the lowest values (Figure 3a).

Most importantly, the analysis revealed the existence of distinct UGSPs, namely UGS repetitive configurations, and provided a taxonomy. This study represents a first step on UGSPs analysis and we are aware of the limited statistical value of the results due to the small number of samples analyzed. Hence, it was preferred to present the results with a more comprehensive description. The UGSPs identified at the macroscale are: the *Fragmented Distributions* (FD), the *Linear Distributions* (LD), and the *Compact Distributions* (CD). Generally, the *Fragmented Distributions* (FD) are the most representative within the study sites, followed by the *Linear Distributions* (LD) and *Compact Distributions* (CD) (Figure 3b).

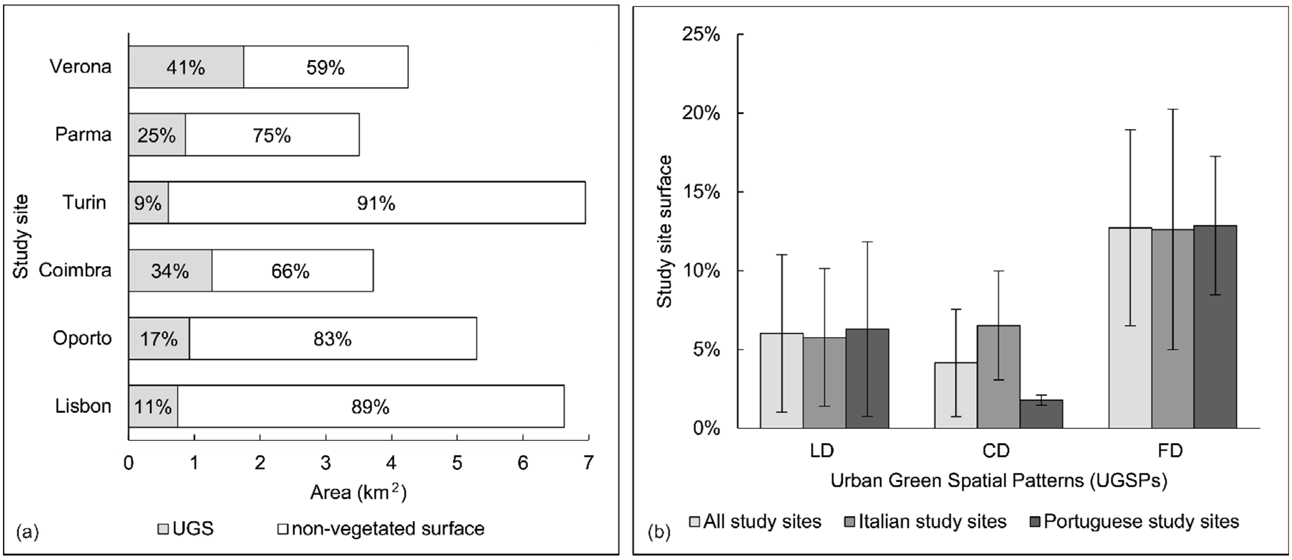


Figure 3. (**a**) Percentage of UGS and non-vegetated surface within each study site; (**b**) Mean percentage values of study sites' surface occupied by the three main UGSPs taxonomic categories.

The microscale analysis (1:2000) based on sample plots (400 m × 400 m) provided more detailed information of UGSPs taxonomy.

The *Fragmented Distribution* was identified in every study site. Nevertheless, different UGSPs subcategories were recorded, with *Fine-Grain* (FG-FG) being mainly detected in the historical center of the cities investigated, whereas the *Coarse-Grain* (FG-CG) being more diffused along the periphery. The vegetation cover within the *Fragmented Distribution* is higher in *Coarse-Grain* (17 ± 5%) than in *Fine-Grain* (4 ± 2%) patterns (Figure 4e,f).

The *Compact Distribution* was identified in every study site. However, each study site features just few examples of this pattern. Within the samples with a *Compact Distribution*, on average, 60% of the sample's area is occupied by the *Compact Distribution*, with differences between Italian and Portuguese study sites (Figure 4g).

Whereas *Fragmented* and *Compact Distribution* are easily detectable in all study sites, the *Linear Distributions* seem to be more site-specific. The *Linear Distribution* (LD) is present in all study sites, covering 1–39% of the sample's area. Its distribution within the study sites, however, seems to be more site-specific than in the other two UGSPs categories, since not all its subcategories are present in every study site (Figure 4a–d). The *Horizontal* (LD-H) pattern is not present in the study site of Parma; the *Belt shaped* (LD-B) is not present in Oporto, Turin, and Parma's study sites; and the *Along the Stream* (LD-ATS) is not present in Lisbon and Oporto.

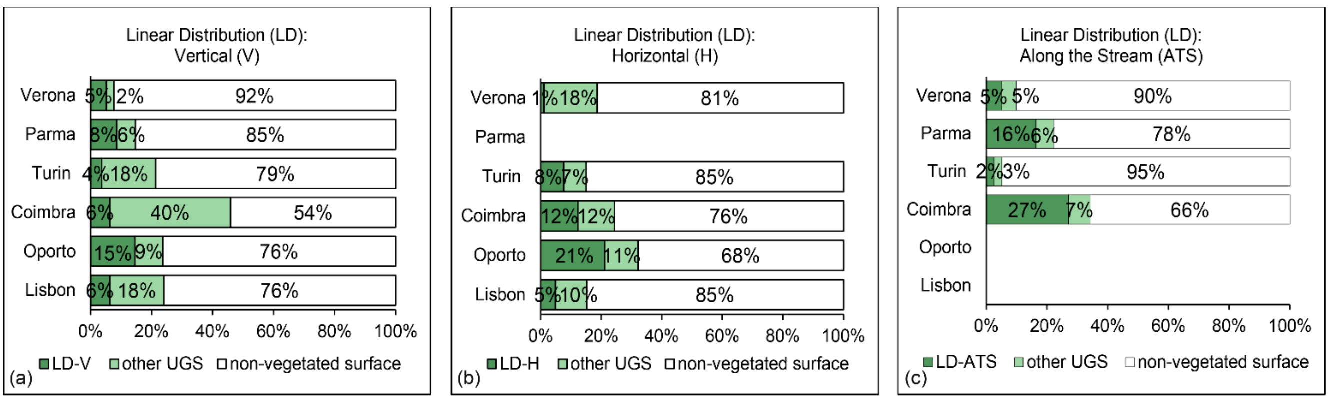


Figure 4. *Cont.*

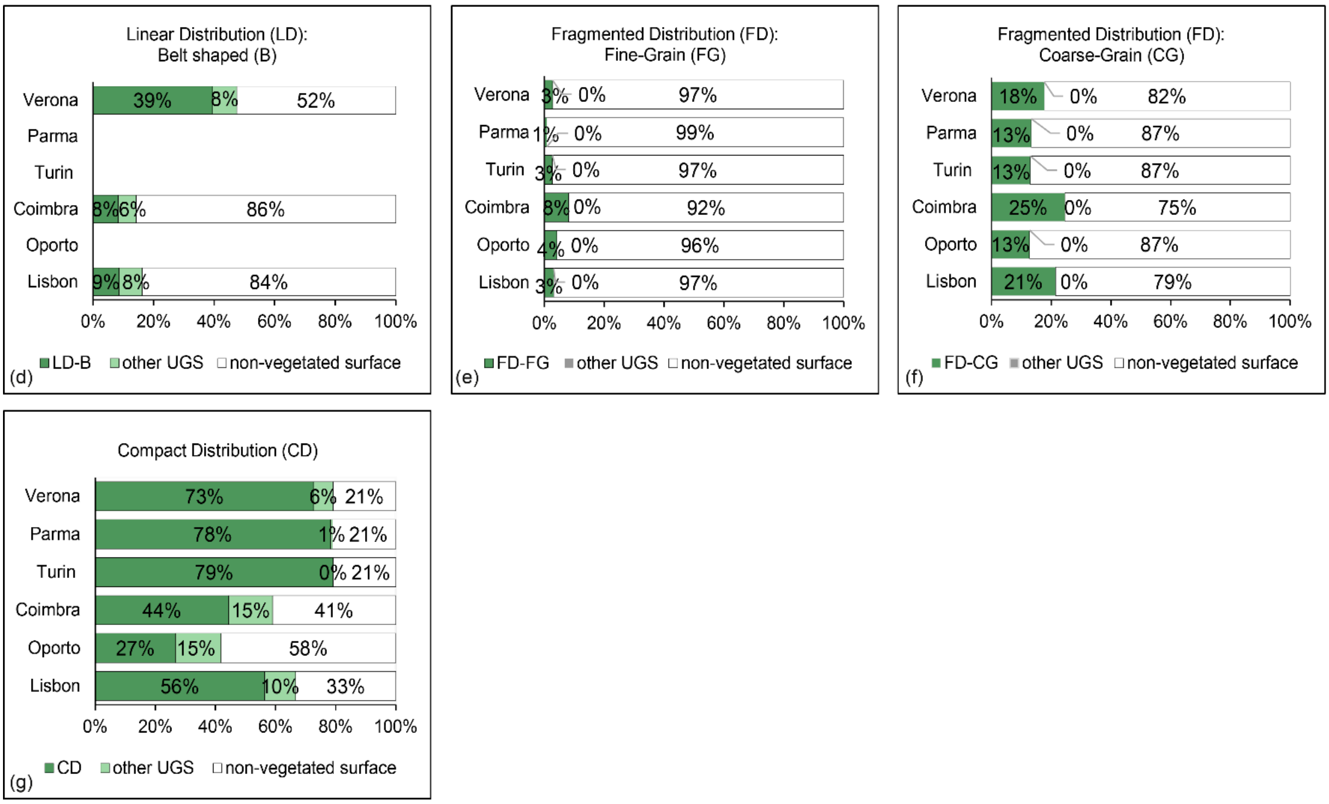


Figure 4. Percentage of sample surface occupied by the UGSPs taxonomic subcategories within each sample: (**a**) *Linear Distribution* with *Vertical*; (**b**) *Horizontal*; (**c**) *Along the Stream*; (**d**) and *Belt Shaped* patterns; (**e**) *Fragmented Distribution* with *Fine-Grain*; (**f**) and *Coarse-Grain* patterns; (**g**) *Compact Distribution*.

4. Discussion

4.1. Types of UGSPs in Southern European Cities

UGS are multifunctional areas able to enhance urban resilience [35], but according to previous studies, there is a strict relationship between UGS patterns and urban ecosystem services delivered. For example, several research studies demonstrate that a particular spatial configuration of UGS can better mitigate floods [53], heat island effect [41,54], or can better guarantee biodiversity preservation [55] and spatial equity [56]. However, although in the last decade urban green space morphology has gained more relevance among the scientific community, studies focusing on classification and description of the UGS spatial patterns are still limited [38].

Hence, our research provides a step forward in the field of UGS analysis by performing a morphological lecture of the urban areas covered by vegetation within six Southern European cities and assessing their spatial configuration.

Several mapping techniques have been applied to green spaces analysis, including informal, private, and interstitial UGS, which are disregarded in most studies [44,45]. For instance, Haase et. al. [45] applied a mixed method of RapidEye imagery and GIS-data combined with random forest models to detect private front and backyard green spaces within the city of Leipzig, Germany. Mathieu et al. [57] used object-oriented classification techniques and very high-resolution multispectral Ikonos imagery to automatically map the extent of >90% of private urban gardens within the city of Dunedin, New Zealand. Nevertheless, the manual mapping operation performed in the present study has been preferred since: (1) a sufficiently detailed cartography was not available (1:2000); (2) it determined a better definition of the UGS perimeter, allowing us to perform a detailed morphological analysis.

Such detailed morphological analysis of UGS has captured a relevant aspect of the complexity of the UGS: several small UGS define particular configurations, repeated within the cities and among different urban systems. Therefore, the UGS repetitive configurations were identified, defined as UGSPs, and classified into three main taxonomical categories: *Fragmented Distributions*, *Compact Distribution*, and *Linear Distributions*.

The results show that the fragmentation of green areas is a peculiarity of dense city portions, which is consistent with previous research elsewhere [49,50]. As a matter of fact, historical city centers are compact built-up areas, thus, the most common UGSPs is the *Fragmented Distribution*, which mainly consists of residual and interstitial green spaces. This *Fragmented Distribution* is generally characterized by a *Fine-Grain* pattern mostly detected in the city centers, and a *Coarse-Grain* pattern more common along the periphery of the study sites. This distribution of patterns is clearly manifest in Lisbon, Parma, and Verona.

The *Compact Distribution*, which is characterized by vast public parks or private yards, has been also detected in all study sites but represents the lowest percentage of the UGS investigated (Figure 3b). This aspect underlines the importance of an analysis of urban green spaces that includes residual, interstitial, and private green patches.

The microscale analysis (1:2000) used to investigate the UGSPs subcategories, although focusing on quite limited portions of the study areas, is qualitatively significant for the definition of the proposed method of UGS analysis. Differences between the two countries can be noticed. On one hand, the Portuguese study sites feature a slightly higher range of green in both subcategories of *Fragmented Distributions*, on the other hand, in the Italian study sites the *Compact Distributions* are generally vaster. Differently from *Fragmented* and *Compact Distributions*, *Linear* ones do not appear in every study site but are rather site-specific. In some cases, they are the footprint or the buffer area of ancient city walls (*Belt shaped* subcategory); in others, they are the sum of small private gardens, traffic green areas, or parks with a strip configuration (*Horizontal* and *Vertical* subcategories); whereas in some other cases, they are green lines along the stream (*Along the Stream* subcategory). Moreover, *Linear Distributions* are highly variable in dimension, depending on the built-up tissue, ranging from small patches of traffic green areas to vast parks along the ancient city walls.

In order to better understand UGSPs specific characteristics and contribute to city resilience, comparisons with other case studies would be desirable. Nevertheless, as far as we are aware, no similar researches are present in literature. Comparisons could unleash the most diffused green patterns and the patterns' variations, allowing to realize morphologic abaca. Along with statistical analysis of green patterns' diffusion and scale, the green patterns morphologic abaca could represent the starting point for further studies on the contribution of UGSPs in mitigating, e.g., urban floods and heat islands, to answer the questions: "Which benefits can this particular green pattern provide?", "How can these benefits be maximized?" and, consequently, "Which management strategies could be applied?".

4.2. Application of the UGSPs Approach for Planning and Management Purposes

The detection and taxonomical classification of UGSPs developed in this study are a novelty in the urban morphology field and may have important implications for UGS planning/management and research paths.

Given that UGS represent the counterpart of the built-up areas in the urban system, the application of a common approach can not only better explicit the spatial relationship between urban green space and urban form, but could also be the bridge between urban planning and urban ecology. Borgstrom et al. [58] contend that there is a "mismatch of scales" in urban landscapes, namely between the scale of monitoring and decision making and the scale of ecological patterns and processes. For instance, the interconnection of private gardens and their interaction with surrounding public green areas are demonstrated to represent a unique resource for assessing the ecological connectivity and helping biodiversity conservation within the urban system [46,59–61]. Nevertheless, private UGS are often viewed as separate entities managed by the householders instead of being integrated into city-wide ecological strategies. Certainly, a key challenge to this aim is that the sense of privilege related to the ownership of a garden in the urban landscape is deeply rooted within the society. To overcome this issue, different top-down and bottom-up methods to incentivize householders into a "wildlife-friendly" management of gardens could be applied. For instance, in addition to regulation, municipalities may influence the behavior of inhabitants by showing a good example or by actively involving citizens and local associations, supporting private or community proposals on public green spaces, and helping them in defining local actions that householders can take to reduce negative impacts and implement the urban ecological framework [59,62,63].

UGSPs may represent the basic tool to ensure the coordinated management of UGS at multiple scales and to support the achievement of urban resilience. The following reasonings attempts to explain their role.

It is proved that UGS can regulate the microclimate of their surroundings mitigating urban heat islands [64]. Typically, the large urban parks, thus, the *Compact Distributions*, are recognized to have a higher level of thermal comfort than other urban spaces, but how can this cooling effect be maximized? Several studies show that a higher density of trees, in comparison with areas with grasslands and/or low density of trees, and some plant species are more efficient in the cooling island effect due to the shading and evapotranspiration effect of the trees [64]. Likewise, also the *Fragmented* and the *Linear Distributions* can be fully exploited when cooling effects are needed. In fact, a study by Sodoudi et. al. [54] demonstrates that: (1) if planted with broad-leaf trees instead of trees with small canopies, hedges, or grass, scattered green spaces can provide more shade, cooling down the surrounding environment; (2) if the direction of the linear configurations of green is parallel to the prevailing winds, wind channels are more likely to be formed and ventilation conditions improve with the presence of trees; a perpendicular direction would instead cause the airflow to be blocked by the canopy of vegetation, and ventilation conditions to be worse. Hence, based on the climate zone, accurate selection and distributions of plants could be proposed as measures to maximize the cooling effects within the UGS of each urban green spatial pattern. Furthermore, if, besides temperature regulation, also biodiversity and stormwater management are considered, UGSPs can be designed and improved in order to simultaneously maximize several benefits. In fact, when analyzing the disposition of the UGSPs, measures to implement the green network could be included. For instance, some studies deem that, although UGS are mainly fragmented, if located nearby an ecological corridor they can be reached and host several urban species, working with the corridor as an interconnected habitat within the residential ecosystem [59,60,65]. Hence, knowing the species hosted by an ecological corridor can best address the choice of plant species to be included within the UGS of a *Fragmented Distribution* located nearby. Urban green patterns have also been analyzed in stormwater management studies. Researches provide interesting results on the impact of patterns of pervious and impervious surfaces on stormwater runoff [66] and some studies analyze the influence of urban green patterns [67–69], but this research path is still little addressed and further analysis is needed. Although urban green patterns seem to represent a key point to enhance urban resilience, further studies are needed to better understand their impact on ecosystem services.

If measures to maximize the ecosystem benefits are listed for each UGSPs, a "guidebook" of actions to apply to the individual UGS might be developed (hence, involving the single householder), whether formal or informal, public or private, vast or interstitial, but also all the UGS within the neighborhoods or to the entire UGSPs (involving entire communities). Moreover, the use of a GIS software would allow to link specific attributes to each UGS (dimensions, pattern, ecological, and social values, etc.), as well as an array of feasible mitigation and adaptation actions according to the UGSPs to which they belong (Figure 5). In this way, UGS would no longer be considered as isolated green patches, but would be designed and implemented as an integral part of a more complex system. This kind of approach can help urban planners and urban ecologists, as well as policymakers, to better adapt the urban systems to climate changes and, hence, to enhance urban resilience.

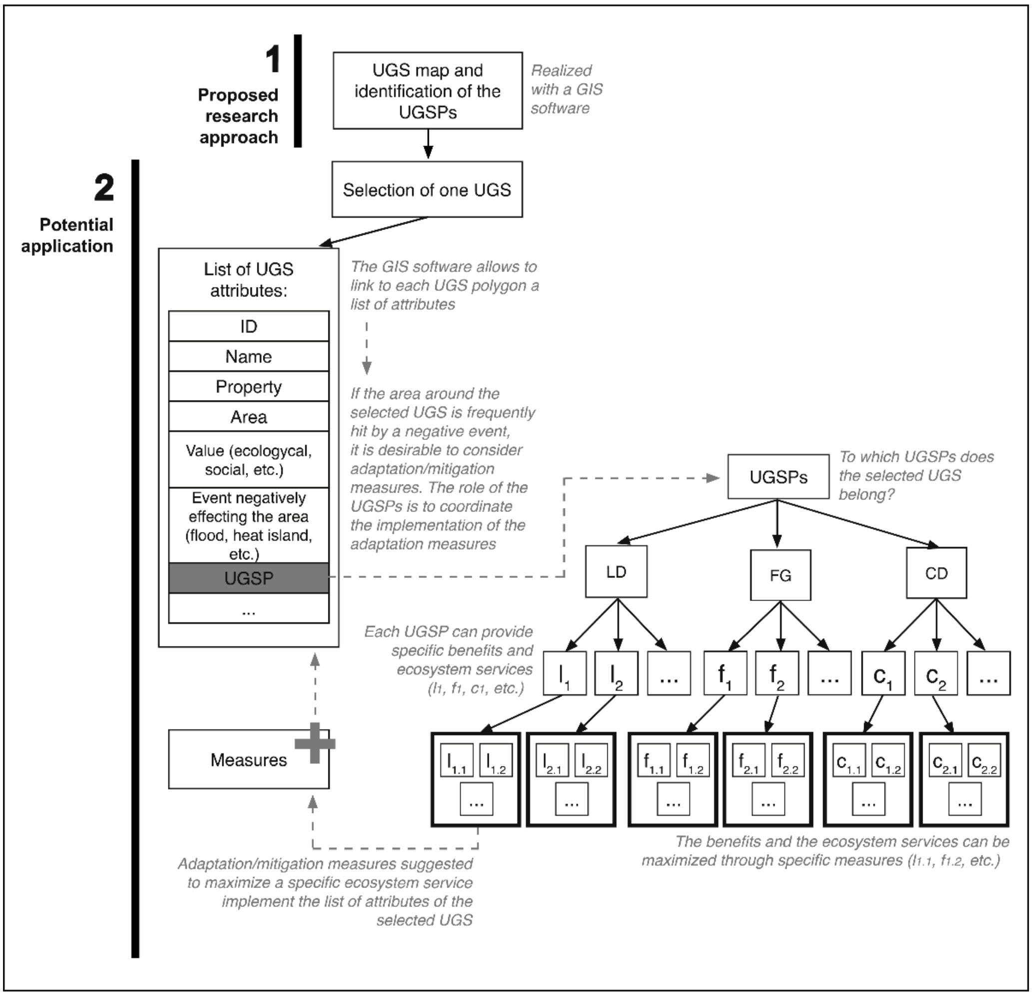


Figure 5. A potential application of the UGSPs approach in UGS management.

5. Conclusions

In the last decade, there have been a profound re-evaluation of UGS, which are no longer considered merely for their aesthetic and social functions, but also for their ecological and technological potential. Urban infrastructures have undermined ecosystems' integrity and the derived fragmentation of the green capital represents a paramount issue within the urban environment.

Several research paths have been already traced to better assess the role of UGS (e.g., in mitigating flood events and heat islands), but various aspects of the UGS still need to be investigated. The urban morphological analysis of streets, plots, and buildings has represented the basic tool to study the urban system and now, applied to UGS, can lay the foundation for a more comprehensive analysis of the role of UGS within the urban environment.

The spatial pattern of UGS is related to many urban ecosystem services, but scientific research has not assessed yet if repetitive spatial configurations of UGS do exist. Therefore, this study was intended to deepen the theme of urban green distribution considering not only public and vast green spaces, but also informal, private, and interstitial green areas.

A morphological analysis of UGS was performed within the historical center of six European cities (three Italian and three Portuguese) and provided the following conclusions.

Firstly, the sum of informal and formal, private and public, interstitial and vast UGS defines repetitive urban green configurations, nominated in this study as Urban Green Spatial Patterns (UGSPs). UGSPs can be classified into three main taxonomical categories: *Fragmented*, *Compact*, and *Linear Distributions*.

Secondly, the *Fragmented* and the *Compact Distributions* are the most diffused UGSPs within the study sites, whereas the *Linear Distributions* are site-specific.

Thirdly, the *Fragmented Distributions* feature small and scattered UGS in city centers and a concentric gradual augmentation, in terms of size and amount of green spaces, moving towards the periphery of the study sites.

Lastly, even though *Compact Distributions* are common, they comprehend the lowest percentage of the UGS considered.

UGSPs can represent a relevant tool not only to consider informal, private, and interstitial green areas as an integral part of the urban green system, but also to unleash and manage their potential contribution to the development of more resilient cities.

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