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Evaluating naturalness and functioning of urban green infrastructure[☆]

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ABSTRACT

Evaluating the state of urban green infrastructure (UGI) is a basic step to reach urban sustainability. Two indicators were used to evaluate 89 UGI sites in Zaragoza, a medium-sized city in NE Spain: Naturalness (Nat), related to the area covered by natural components; Functioning (Fun), related to the area showing natural hydrogeomorphological features. Complementarily, 15 biophysical and social variables were used to characterize these sites. A principal component analysis (PCA) was performed to group variables and types of UGI, while linear regressions and ANOVAs were applied to identify relationships between UGI characteristics, Nat and Fun.

The Zaragoza UGI was dominated by artificial regular sites. Most sites (73%) have low-medium values of Nat and Fun. They were mostly flat urban parks with very regular forms located in the most densely urbanized zones, and 20% of the sites have high values of Nat and Fun, corresponding to well-conserved natural areas, either unchanged or slightly transformed. Only 3 sites displayed high Nat values and low Fun values. No sites had high Fun values and low Nat values. These groups of UGI sites were mostly distributed along the first axis of the PCA which represented the natural and heterogeneous forms versus regularity and flatness features. The UGI sites scattered throughout the second axis represented a gradient from paved to vegetated sites. Both Nat and Fun were positively correlated with area, natural subsoil and the area covered by vegetation but negatively with artificial soil, regularity and flatness after the linear regressions and ANOVAs.

These results show that Nat and Fun are effective indicators to assess UGI sites. Minimizing regularity of design, preserving the natural topological relief, and restricting the area covered by artificial components are suggested to achieve a balanced representation of ecosystem processes, functions, and services within the UGI network of a city.

1. Introduction

The network of urban green zones, referred to as the urban green infrastructure (UGI), is an essential part of urban ecology, as it provides key multiple ecosystem services and certain urban resilience against climate change (Coutts and Hahn, 2015). There is a growing body of literature about the potential benefits of UGI as they perform important ecological functions for humans, such as climate change adaptation and mitigation (Pauleit et al., 2013) by ameliorating the meteorological conditions through the provision of shade, the lowering of solar radiation and the reduction of extreme temperature variations (Di Leo and Dubbeling, 2016), and subsequently by reducing energy use (Cheshmehzangi et al., 2019), among others. Properly designed UGIs can also help to manage and reduce disaster risk (Onuma and Tsuge, 2018) and boost biodiversity conservation (Hostetler et al., 2011). They also provide social and cultural benefits, such as increasing longevity (Jonker et al., 2014) and improving human health and well-being through the reduction of atmospheric pollution (Kim and Miller, 2019), the amelioration of the effects of heatwaves (Jonker et al. 2014), the promotion of mental wellness (e.g., stress relief), physical activity (Cohen et al., 2007), social communication (Cortinovis et al., 2018) and recreational opportunities (Terkenli et al., 2017), while also helping to build cultural vibrancy (Kumar and Vuilliomenet, 2021). UGI can also be considered as economic assets, as they can influence economic growth (Khoshnava et al., 2020) by increasing land and property values (Madison, n.d.) and food provision (Russo et al., 2017). The UGI physical and psychological benefits can also represent prominent economic benefits for the population (Center for Neighborhood Technology, 2010).

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During the present century, an increasing scientific interest in the study of UGI, following major environmental summits has been observed (Hanna and Comín, 2021). Given that the practical implementation of semi-natural solutions to improve UGI requires an evidence-based but cost-effective valuation, it is urgent to design simple but accurate valuation tools tailored to support the development of UGI (Van Oijstaeijen et al., 2020). Simultaneously, there has been a quick implementation of the so-called green zones in cities all around the world with an increase of about 4.11% during this century (Huang et al. 2017), which contributes to raise global environmental awareness on the role of urban areas for human well-being and the sustainable development of the planet (Davies and Lafortezza, 2018). Given the disconnection between policy, management, and science (Sutherland et al., 2013), improving the design and performance of UGI based on the best scientific knowledge is becoming one of the major challenges for urban policy makers because of the tight link between green zones and inhabitants' well-being (Panagopoulos et al., 2015), given that the UGI contribute to both ecosystem and human health (Tzoulas et al. 2007). For this, it seems necessary to develop representative and easy-to-use indicators of UGI design and performance in terms of ES.

To date, a variety of types of indicators has been used to assess UGI. The European Environmental Agency (EEA 2017) proposed a series of indicators: air quality, noise, water, sustainable land use and soil, waste and circular economy, nature and biodiversity, green growth and eco-innovation, climate change mitigation and adaptation, sustainable urban mobility, energy performance, environmental governance. These indicators displayed on an interactive map aim to help cities in assessing the quality of their UGIs. Furthermore, an indicator of the effectiveness of UGIs was proposed by Fernández de Manuel et al. (2021) based on the assessment of run-off retention, air purification, and cooling. To assess how effectively these 3 environmental processes are provided by various urban terrestrial and aquatic sites, their supply and demand imbalances were examined at the neighborhood scale through geospatial and statistical analysis. Tudorie et al. (2019) classified environmental indicators of UGI according to well-established ecosystem services frameworks. Carmen et al. (2020) asked stakeholders of four medium-sized European cities about the relevance of a set of indicators covering environmental, social, and economic aspects of green sites. In general, these studies suggested that it is essential to unify indicators and create integrated indexes to reach a real management tool that help cities to develop effective urban planning.

So, there is a lack of simple but integrative tools to evaluate the state of the UGI. Using indicators of multiple characteristics is a useful approach to describe and explain a series of features, although it does not ensure a synthetic evaluation of urban green sites use to compare sites (Wendler et al. 2022). Another problem is related to the spatial scale as it is difficult to evaluate all the sites composing the green structure of an urban zone using multiple characteristics because of the complex and sophisticated equipment required (Pakzad and Osmond, 2016). In addition, many of the approaches to evaluate UGI do not use quantitative data but just descriptive features (Hanna and Comin, 2021). These three common problems combined indicate that indexes synthetizing major features would provide a simple but useful evaluation tool of UGI sites. Most of the indicators use in many studies focus on environmental characteristics but not on the key features of the UGI sites. It is urgent to design simple but accurate valuation tools tailored to support the development of UGI (Van Oijstaeijen et al., 2020).

Our approach here is based on the hypothesis that the two major descriptive features of ecosystems, structure, and function, are good indicators of the state of UGI sites. Consequently, they should be used for their evaluation, as UGI sites can be considered ecosystems. As a result, descriptors of their structure and function are essential features to be used to describe their characteristics (Rowntree, 1984; Rowntree, 1986). The UGI is usually composed of different types of green spaces and a variety of structures which contain natural (trees, shrubs, herbs, natural water springs, natural rocks etc.) and artificial components (benches, tables, recreational components, architectural structures, etc.) (Andrade et al., 2013, Borelli et al., 2015). Less natural UGI, like urban parks, green roofs and facades, street trees, pocket parks, grassland, community gardens, canals and cemeteries often contain human-made components that facilitate their use by people (Shafer et al., 2013). Other UGIs are similar to undisturbed ecosystems mostly dominated by natural components such as rivers and forests, integrated in the urban area and more or less modified to facilitate recreational uses (Cvejić et al., 2015; Kowarik, 2011).

The state and performance of UGI can be indicated through the evaluation of its structure and functions, which can help to suggest cost-effective improvements to maximize the benefits for the population (Palliwoda et al., 2020).

The objective of this paper is to evaluate the structural and functional aspects of the urban green zones of a medium size city in Spain using two ecological indicators, Naturalness (Nat) and Functioning (Fun), defined by the degree of natural components and natural processes, respectively. Subsequently, we analyzed Nat and Fun in relation to a set of attributes represented by geomorphological, vegetation, soil, and social variables. These variables were selected to cover morphological components (regularity, flatness) and ecological characteristics of the UGI (plant material and vegetation cover), as well as features connected to citizen use (circulation, weekend or weekdays use of the UGI sites, time, day/night use of the green zones). This approach allowed us to study the potential of Nat and Fun to evaluate the structural and functional characteristics of urban green zones, which is useful both to improve the characteristics of individual sites and to assess the full set of green zones of a city.

2. Methods

2.1. Study area and sampling method

The study area corresponds to the urban zone of Zaragoza municipality (Spain, coordinates 41.6488° N, 0.8891° W), a medium-sized city (734,000 inhabitants; 167 km^2) (van den Berg et al., 2017), or an XL sized city according to "Cities in Europe, The New OECD-EC Definition" (2013). Zaragoza is the capital city of Zaragoza Province (972,000 inhabitants; 17,274 km^2) and of the autonomous community of Aragon (1, 332,000 inhabitants; 47,720 km^2) (Fig. 1). The residential enlargement of the city is taking place mainly in its North and South poles, with a few neighborhoods recently urbanized and others in the process of urbanization.

Zaragoza city (249 m above sea level) is located in the north-east of the Iberian Peninsula, in the middle of the valley of the Ebro River (average water discharge 230 m^3/s, with ordinary floods of 1200 m^3/s and extra-ordinary floods up to 2800 m^3/s; Ruiz-Bellet et al. 2015), a river which crosses the city in a northwest-southeast direction, receiving two tributaries (Huerva and Gallego) in the city. Zaragoza has a semi-arid Mediterranean climate. The average annual precipitation is 322 millimeters, and the rainiest seasons are spring (April–May) and autumn (September–November), with a relative drought in summer (July–August) and winter (December–March). It is characterized by high isolation and relatively extreme temperatures: hot in the summer reaching up to 44.5 °C and cool in the winter reaching < 0ºC (-2 ºC as minimum temperature). A cold and dry wind from the northwest blows frequently in the winter. During non-windy days of autumn-winter, fogs are frequent. The surroundings of the urban zone of Zaragoza are a typical steppe habitat with about 50% of shrub cover over gypsum soils (Comín et al., 2005).

During the last centuries, the Ebro River was transformed into a rectilinear stretch in Zaragoza city, but it maintains large floodplains upstream and downstream (Ollero-Ojeda et al., 2006). The Gállego River, one of the main tributaries, still preserves large floodplains in Zaragoza city and upstream. The other tributary, the Huerva River, is fully channelized and flows mostly underground. Apart from the

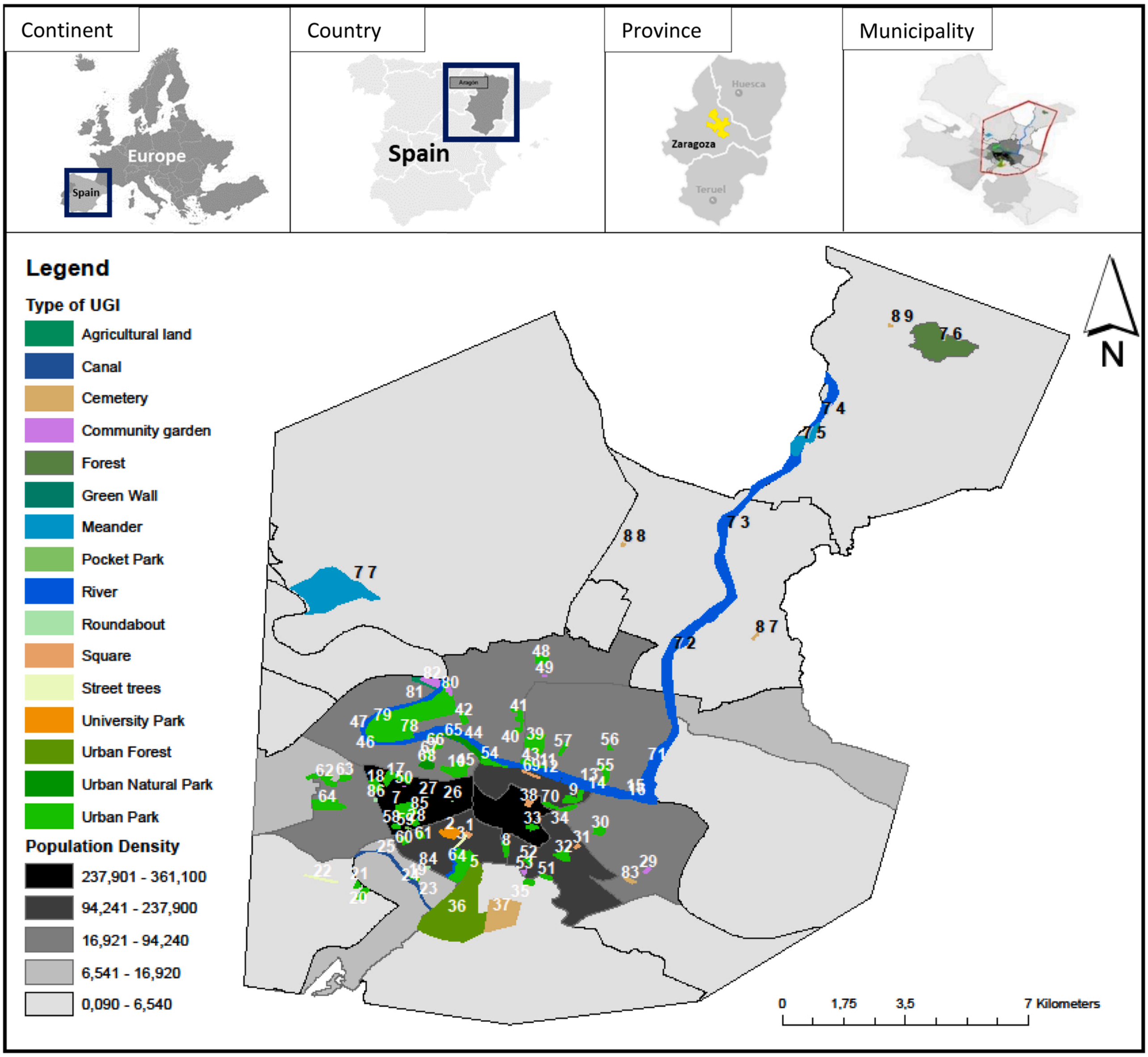

Fig. 1. Study area corresponding to the municipality of Zaragoza (Spain). This map shows the typology of the UGI elements that we visited and evaluated in relation with the population density of the city. (Check Fig. S1 in the Supplementary Materials for a zoom in on the city)

waterways, there are large natural green zones next to the city such as an oxbow lake and its floodplain (Galacho de Juslibol, 1.22 km^2), an abandoned meander of the Ebro River upstream but next to the city, and the steppe zone (332 km^2) in the southern part.

The UGIs of Zaragoza consist of natural, semi-natural, and artificially constructed sites, encompassing terrestrial and aquatic ecosystems. Some of them are small sites located in the most densely urbanized zone of the city whereas relatively large green spaces (river banks, forests, meanders) are mostly located in the peri-urban surroundings of the city.

Artificially constructed sites located in the urban area are relatively small UGIs: community gardens, urban parks, urban natural parks, pocket parks, green walls, cemeteries, squares, roundabouts, university parks, community gardens, irrigation canals, roundabouts, and street trees (note that this typology was developed by the European Commission, https://biodiversity.europa.eu based on Cvejić et al., 2015).

In this study, 89 UGI sites (Table S1) were visited and evaluated, 80 of them located within the city (urban parks, urban natural parks, university parks and urban forests, representing 81.7% of the total area of green zones in the city) and 9 in semi-urban zones on its periphery (Fig. 1). Environmental data were collected in-situ, from municipality data, observation and satellite imagery, encompassing 15 variables to characterize the degree of naturalness and artificiality and to detect the effects of natural dynamics (erosion, fire, strong wind, accumulation of organic matter, soil formation) in each UGI site. The set of UGI studied included community gardens, urban parks, pocket parks, green walls, squares, roundabouts, urban natural parks, university parks, urban forests, community gardens, irrigation canals, roundabouts, street trees, river banks, forests, cemeteries, rivers, meanders, and agricultural fields. Given that a few UGI sites (Parque Grande José Antonio Labordeta, Parque del Agua, the Ebro River banks, River Gallego) cover a large area and encompass a high spatial heterogeneity, they were divided into homogeneous zones according to their location, topography, and degree of artificiality. For instance, Parque del Agua (124.3 ha) encompasses a high spatial heterogeneity; it has a natural part with well-conserved native riparian ecosystems (human intervention is limited) (area = 45.1 (ha)) and an artificially designed part (area = 79.2 (ha)). Hence, it was divided into 2 units and each unit was evaluated separately.

2.2. Evaluation of the UGI sites

The overall approach used here to evaluate UGI sites aims to quantify their structural and functional characteristics through two complementary indicators called naturalness (Nat) and functioning (Fun) (Fig. 2). Nat indicates the degree of natural versus artificial components forming the UGI site. Similarly, Fun indicates the degree of natural versus artificial processes driving the functions of the UGI site. The methodological steps followed in this study can be seen in Fig. 2.

Additionally, 15 variables were selected to describe physical (area, flatness, regularity, artificial soil, natural subsoil), ecological (vegetated area, bare soil, native vegetation, artificial plantations, number of vegetation strata, plant pots and grouping), and social (circulation, daytime and weekend use) characteristics of the UGI sites (Table 1). Regularity, flatness, area, artificial soil, natural subsoil, bare soil, and vegetated area were estimated through Google Earth and ArcGIS (Vector) and calculations (formulas). We used the imagery available in Google Earth with a resolution less than 1 m/pixel and the imagery available in ESRI Basemap available in ArcGIS with a resolution less than 1 m/pixel. The imagery of Google Earth is from Maxar High Resolution Satellite Imagery. The imagery of ArcMap is from National Area Orthophotography Plan from National Geographic Institute (PNOA-IGN). Native vegetation, artificial plantations, number of vegetation strata, circulation, plant pots, and grouping through direct in-situ observations; daytime and weekend use through a combination of surveys performed weekly during peak-used periods; May, June and July 2020, by counting park users 3 times per day at three-hour intervals for a minimum of 3 days a week including two weekdays and one weekend day, also we used municipality data. These variables were correlated with Nat and Fun indicators to discriminate which were the variables most closely related to the two indicators and which groups of UGI sites can be distinguished. Area of the site with artificial soil or planted vegetation, the existence or not of plant pots, and plant groupings are related to their degree of naturalness and were used to describe the structure of UGIs. Other variables are related to functional aspects: how much of the UGI is occupied by regular forms or by flattened soil. More regular flat forms indicate a strong anthropogenic modification that control the site. In contrast, the dominance of irregular forms and irregular distribution of dead and decomposing organic matter, combined with sings of water and wind flows indicate that natural drivers regulate the functioning (e.g., active and/or natural geomorphology, primary production, soil formation). The remaining variables are related to social aspects (how much the site is used by people during work days or weekends, and how accessible it is for circulation) which are also linked to the anthropogenic influence. Daily used sites are more artificially managed in order to facilitate peoples´ use, while sites used principally during weekends tend to be more natural and well-conserved.

Nat was measured as the percentage of coverage of natural areas inside the UGI site. Natural areas can be covered or not by vegetation (there may be zones without vegetation, naked soil or rocks naturally established). Artificial areas are those established or built by humans, including planted vegetation, recreation, and service facilities, but not pedestrian or cycling routes through natural areas. Nat evaluation was done through fieldwork (UGIs in-situ characterization), visualization, and analyzing satellite images (Google Earth and ArcGIS). A similar scale to that of Machado (2004) was used to assign Nat values to each UGI site evaluated. A grading system ranking from completely natural (10) to completely artificial (0) sites was established (Table S2). A set of descriptive conditions defined each value; some of these conditions are optional. For example, to reach a Nat value of 1, a site can have 90–100% of the area occupied by artificial components, but built and ornamental structures not necessarily present. Decimal values were assigned accordingly. For example 3.4 means that only 34% of the site area, was covered by natural components. Therefore, Nat= (% of the area with natural components)/10.

An analogous scale was established to assign values for Fun, which was defined as the degree of natural processes driving the dynamics of the UGI site based on the classical concept of ecosystem functioning (Bürgi et al., 2004; Tiegs et al. 2019). It was measured as the area of the UGI site observed with natural dynamic features according to Table S3. These features were identified as signs of hydro-geomorphological drivers (wind and water flows, flooding, and erosion) and biological processes (organic matter accumulation) observed in the UGI sites. Marks and traces of wind and water flows can be identified easily in an ecosystem as dragged soil, bent trees, and organic matter which form irregular paths. Artificial processes used to shape regular accumulations of soil and paths. In a similar way, fallen herbs, leaves, branches and trunks are usually accumulated temporarily in more natural spots or removed from more artificial ones. The values of Fun ranged from 0 to 10, with 0 indicating non-functional sites highly influenced by humans,

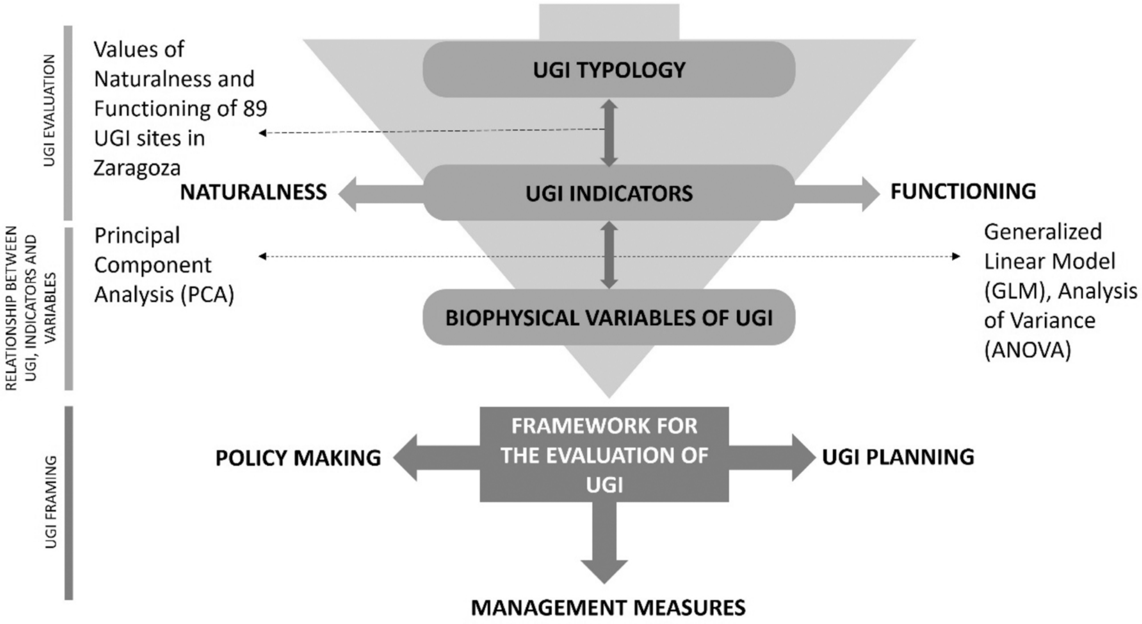

Fig. 2. Diagram illustrating the different steps followed in the methodology of this study.

Table 1

Type, definition and methodology of the 15 variables used to assess the UGI of Zaragoza (For more details, please check Table S4).

Type of Variables	Definition	Methodology	Formula
Regularity	It's the extent to which a site is designed using strict lines or well defined regular forms. For instance, a landscape designed park, containing symmetrical design and well defined shapes (strict lines of trees, round fountains, lines of pavement) in its design might have a value of 4 or 5 (depending on how artificial the park looks). On other hand, a natural forest is not artificially designed (because it is natural) have a value of 1 since strict lines of trees with equal spacing for example are rarely found in nature.	ArcGIS data; it is obtained by drawing a Polygon around the area of artificial design (with strict line or/and regular shapes), obtaining its area and dividing it by the total area of UGI	(Area of artificial design/Total area of the site) × 100
Daytime	The day and night use of the site	Survey and Municipality data	None
Weekend_Use	The weekday vs. weekend use of the site	Survey and Municipality data	None
Area	Total area of the site	Google Earth and ArcGIS data; it is calculated by drawing a Polygon around the UGI element and obtaining its area.	(Area of artificial components) + (Vegetation Area) + (Area of natural soil that is not covered by vegetation)
Artif_soil	Area of the site that is occupied by artificial components such as pavements, structure, fountains, houses, sport playgrounds etc.	ArcGIS data; it is calculated by drawing Polygons around the artificial zones inside the UGI element. Then obtaining the areas of the artificial zones (using Calculate Geometry inside the attribute table in ArcGIS). We added up the areas of the Polygons to obtain the total artificial area in the UGI element. Also it can be obtained with a formula.	(Area of the site) – (Vegetation Area) – (Area of natural soil that is not covered by vegetation)
Vegetation_Area	How much area is covered by vegetation	ArcGIS data; it is calculated by drawing Polygons around the vegetated zones inside the UGI element. Then obtaining the areas of the vegetated zones (using Calculate Geometry inside the attribute table in ArcGIS). We added up the areas of the Polygons to obtain the total vegetation area in the UGI element. Also it can be obtained with a formula.	(Area of the site) – (Area of artificial components) – (Area of natural soil that is not covered by vegetation)
Natural_Soil_No_Vegetation	The natural area of the site that is not covered by vegetation	ArcGIS data; it is calculated by drawing Polygons around the natural zones inside the UGI element that is not covered by vegetation. Then obtaining the areas of the zones (using Calculate Geometry inside the attribute table). We added up the areas of the Polygons to obtain the total natural area inside the UGI element that is not covered by vegetation. Also it can be obtained with a formula	(Area of the site) – (Area of artificial components) – (Vegetation Area)
Natural_Subsoil_Area	% of the total area of the site that is occupied by natural subsoil	ArcGIS data, Google Earth and observation. It is important to note that we did not measure the depth of natural	(Natural area/ Total area of the site) x 100

(continued on next page)

Table 1 (*continued*)

Type of Variables	Definition	Methodology	Formula
		subsoil. We are talking about the presence of natural subsoil and the% of area natural subsoil is present in the site. Thus, natural subsoil depends on the presence of natural area (vegetated + non vegetated area), for instance, a site that is occupied 100% by natural area (a natural forest for example) will have natural subsoil area= 100% because 100% of the total area of the site is occupied by natural undisturbed subsoil (no anthropogenic impact). On the other hand, low % of natural subsoil is found in designed UGI sites, such as artificially designed parks and street trees. The% of natural subsoil area is calculated by dividing the% of the natural subsoil area of the site (vegetated and non-vegetated) by the total area of site.	
Flatness	% of flatness in the sites	ArcGIS data, Google Earth and observation. It was calculated by drawing a Polygon around the flat zone, obtaining its area and dividing it by the total area of the UGI element.	(Area of the flat zone/Total area of the site) × 100
Nat_veg_plant	The existence or not of natural plantations	On site observation	None
Artif_planted	The existence or not of artificial plantations	On site observation	None
Plant_pots	The existence or not of plant pots	On site observation	None
Plant_group	The existence or not of plant grouping	On site observation	None
Veg_Strata	Number of strata in vegetation	On site observation	None
Circulation	How much the site is easily accessible and navigable	On site observation	None

and 10 pointing to complete preservation of natural hydro-geomorphological features and processes, and that artificial traits of anthropogenic processes were completely absent. For example, a value of 6.7, means that 67% of the total area of the site maintains its hydro-geomorphological and biological related features. Therefore, Fun= (% of the area with natural hydro-geomorphological features)/10.

2.3. *Ordination of UGI sites based on their physical, ecological, and social features and their relationships with Nat and Fun indicators*

A multivariate analysis was conducted to assess the characteristics of the UGI sites. In particular, UGI sites were ordered and grouped in a multidimensional space according to their socioecological features (15 variables) (Table 1), using a principal component analysis (PCA) followed by an agglomerative hierarchical clustering (Ward's criterion) and partitioning clustering (k-means algorithm to improve the initial partition obtained from hierarchical clustering) to automatically identify the optimum grouping of sites according to their shared environmental features (FactoMineR R package; Husson et al., 2014). Complementarily, individual linear regressions were performed to detect which variables were driving the variability of Nat and Fun. Similarly, ANOVAs, equivalent to linear regressions, were performed on categorical and binary variables. An automated selection procedure on General Linear Models (GLM) was performed to detect the best combination of variables to explain the Nat and Fun patterns based on small-sample corrected Akaike Information Criterion (AICc; best-fitting models were those with lower AICc and greater goodness of fit-R^2). Homoscedasticity and normality of residuals were checked visually. Prior to analysis, the variables "Area" and "Artif_soil" (Table S4) were log-transformed when necessary, to reduce skewness in the distribution of the explanatory variables. All quantitative predictors were Z-standardised (mean = 0, SD = 1) before PCA and GLMs, to allow for model coefficient comparison. The variance inflation factor ($VIF=1/(1- R^2)$) was calculated to check predictor collinearity (Zuur et al., 2010) and to remove excessively correlated variables ($r > 0.7$) prior to GLM.

All analyses were conducted in R (R Core Team, 2020) using the packages *glmulti* (Calcagno and Mazancourt, 2010), *ggplot2* (Wickham, 2011), and *FactoMineR* (Lê et al., 2008).

3. Results

3.1. *Naturalness (Nat) & Functioning (Fun) of UGI sites*

Most of the UGI units of Zaragoza, 65 out of 89 (73%), were characterized by low values (<5) of Nat and Fun (Fig. 3). Two of these sites were found to be extremely artificial, showing Nat and Fun values near 0. One of the sites is a (2 ha) square in downtown that was completely covered with artificial components, except for scattered small plant pots garnishing a few sitting benches; the other one is a cemetery (0.65 ha), also covered by artificial soil, except for isolated planted trees. The other

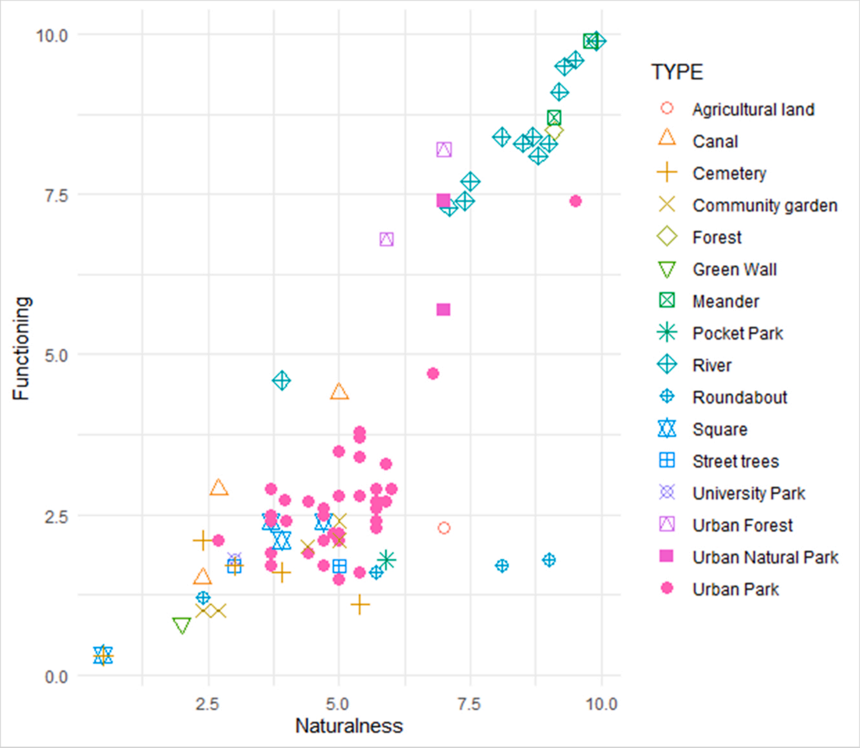

Fig. 3. Values of Functioning and Naturalness of 89 UGI sites in Zaragoza. Each symbol represents an UGI element.

sites of this group of low Nat and Fun values included a wide range of UGIs such as urban parks, university parks and squares, with a high proportion of artificial cover and, usually, planted flower pots or beds, combined with impervious surfaces, facilities for citizens' enjoyment (children's playgrounds, bar and restaurant terraces), and/or underground infrastructures (multi-story car park, petrol station). This group of UGIs also included community gardens which consisted of small urban agricultural lots with rest rooms, barbecue zones, and storehouses to stock agricultural items, as well as cemeteries (there are 9 cemeteries in the urban zone, this study evaluated 5 of them), human-made canals, and a small urban river area (Rio Huerva inside Parque Grande) with a low-medium value of Nat (3.9) and Fun (4.6) because its riparian area is very narrow and displayed a poor conservation status.

A group of UGI sites showed Nat values between 5 and 6, but low values of Fun, ranging between 1 and 4.6. These sites mostly represented urban parks and street trees (road alignment) with regular plantations of trees that maintain some natural components combined with above-ground artificial facilities for recreation and public enjoyment. The biggest cemetery in Zaragoza (51 ha), which was characterized by rows of trees on the sides of pathways, graveyards and architectural structures, also fell within this group.

Another group comprised 20% of the UGI sites (18 of them), characterized by high Nat and Fun values (>7) was dominated by natural sites that included rivers and riparian areas and forests, meanders, and a large urban forest (Pinares de Venecia, 318 ha). These sites displayed artificial components used for recreation, but their effect on Nat & Fun was minimal compared to the influence of existing natural components.

Three urban parks displayed intermediate values of Nat and Fun (4.7–7). They were characterized by artificial components (e.g. bar terraces, fountains, compacts walks, pedestrian boulevards), but maintaining key natural features such as the original topography and autochthonous vegetation (mostly planted).

Another three sites showed a high Nat (7–9) but a low Fun value (about 2), which corresponded to an urban agricultural land (82) and two roundabouts (85, 86) with a dominance of natural but ornamental components where natural dynamics were depleted. Roundabouts can have high Nat values since they are covered by lawn and plantation. However, they are artificially constructed so their Fun value was very low due to the lack of preservation of any hydro-geomorphological aspect (the presence of natural dynamics is negligible).

We did not find any UGI site with opposing extreme values of Nat (< 5) and Fun (> 5), which seems quite logical since high Fun values are driven by natural dynamics, and hence, should have also high Nat values.

3.2. Grouping Urban Green Infrastructure sites

The two first axes of the PCA analysis accumulated 47% of the data variability. A high difference between the 36.6% of the Principal Component (PC) 1 and the 10.7% of the PC2 was observed. The next PC represented less than 10% each of the remaining data variability (Table S5). Accordingly, we retained the two principal axes for interpretation of data variability.

Variables "Area", "Natural_Soil_No_Vegetation", "Natural_Subsoil_Area", "Vegetation_Area", "Daytime" or "Weekend_Use", "Nat_veg_plant","Naturalness", "Veg_ Strata" and "Functioning" were positively correlated with the PC1, while variables "Flatness", "Regularity", "Artif_soil" and "Plant_pots" were negatively correlated (Fig. 4a). The distribution of the UGI sites along the PC1 represented a gradient from natural to artificial. Three automated major clusters of UGI sites were detected (Fig. 4b). Cluster 1 was made of sites representative of river, meander and urban forest. Cluster 2 was mostly composed of urban parks. Cluster 3 contained highly artificially designed UGI sites as community gardens, cemeteries, squares and street trees.

The distribution of sites along PC2 represented a gradient from constructed and artificial UGI sites characterized by intense paving to more vegetated but architecturally designed UGI sites. Variables positively correlated with PC2 were "Circulation", "Artif_planted" and "Plant_ group", whereas "Weekend_Use" and "Natural_Soil_No_Vegetation" were negatively correlated (Fig. 4a). All the UGI sites distributed along this PC2 axis were in the negative side of PC1 axis since they corresponded to very regular shapes with artificial soil. UGI

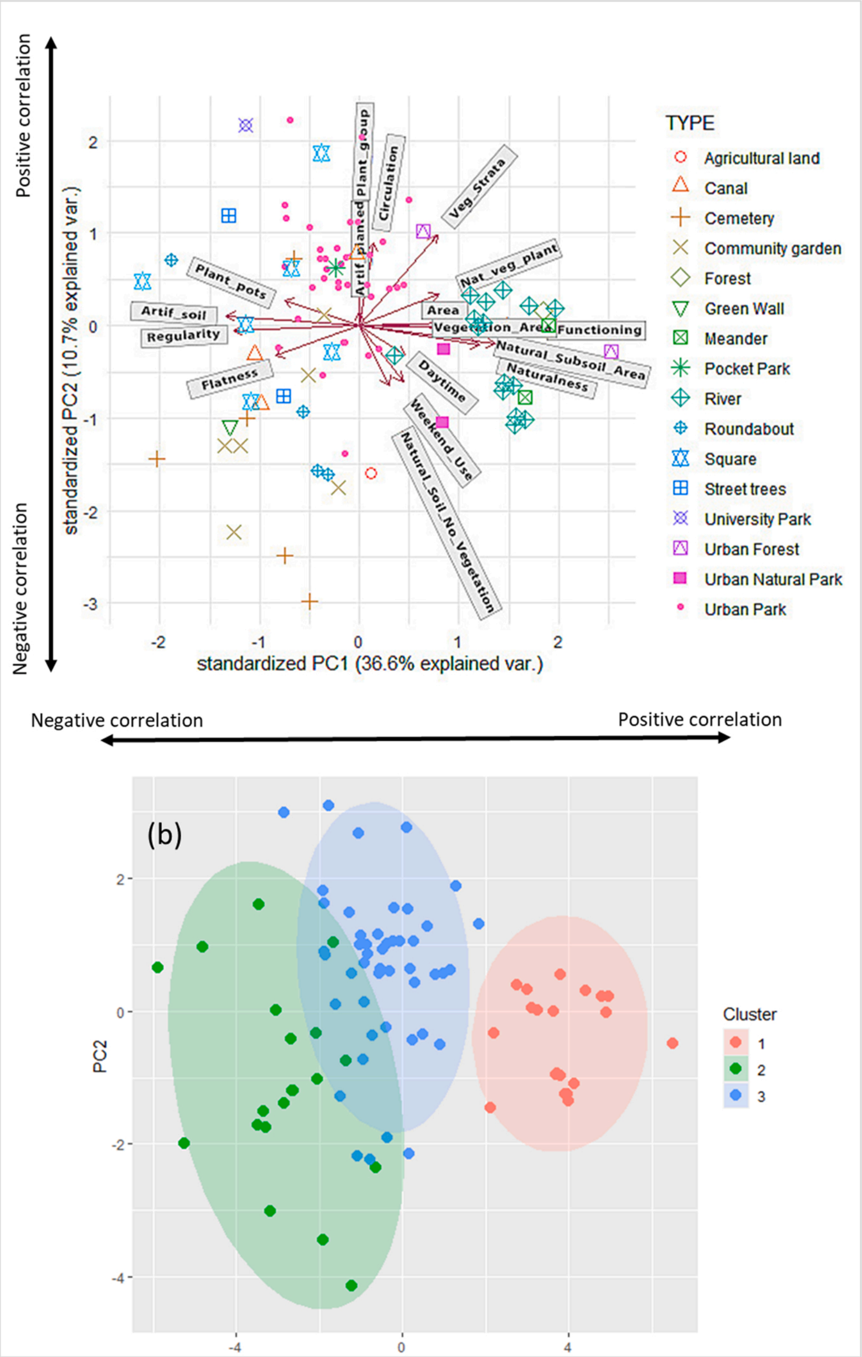

Fig. 4. (a): PCA ordination of UGI sites and variables studied in relation with the two first axes of variability. Each symbol represents an UGI element. “Nat” is the abbreviation of Natural, “Artif” is the abbreviation of Artificial, and “Veg” is the abbreviation of Vegetation. (b): Hierarchical clustering according to the shared features of UGI elements.

sites covered by artificially planted vegetation and other artificial components (e.g. sites number 2, 3 and 26 in Table S1) occupied the positive part of the PC2 axis while those flat units with regular shape (e.g. site number 53, 88 and 89 in Table S1), were distributed along the negative part of PC2.

3.3. Relationships between Naturalness and Functioning indicators and characteristics of UGI sites

Individual linear regressions showed that all explanatory variables resulted in highly significant Nat and Fun distribution patterns ($p < 0.001$ in all cases). Both, Nat and Fun indicators were positively related to “Natural_Subsoil_Area”, “Area”, “Vegetation_Area”, “Veg_Strata” and Nat_veg_plant, but negatively related to “Artif_soil”, Regularity, “Plant_pots” and “Flatness” (Fig. 5, Table 2). However, they differed in the amount of explained variance (goodness of fit -R^2). Nat was highly negatively related to “Artif_soil” (c in Table 2 and Fig. 5; $R^2 = 0.92$), and “Regularity” (g, $R^2 = 0.44$), but positively to “Area” (a; $R^2 = 0.44$).

Similarly, “Artif_soil” (l) showed the strongest negative relationship with Fun ($R^2 = 0.7271$). However, compared to Nat, Fun displayed a stronger negative relationship with “Regularity” (p) ($R^2= 0.6996$), followed by a positive relationship with “Natural_Subsoil_Area” (o) ($R^2= 0.663$) and “Area” (j) ($R^2 = 0.595$). “Vegetation_Area” was excluded

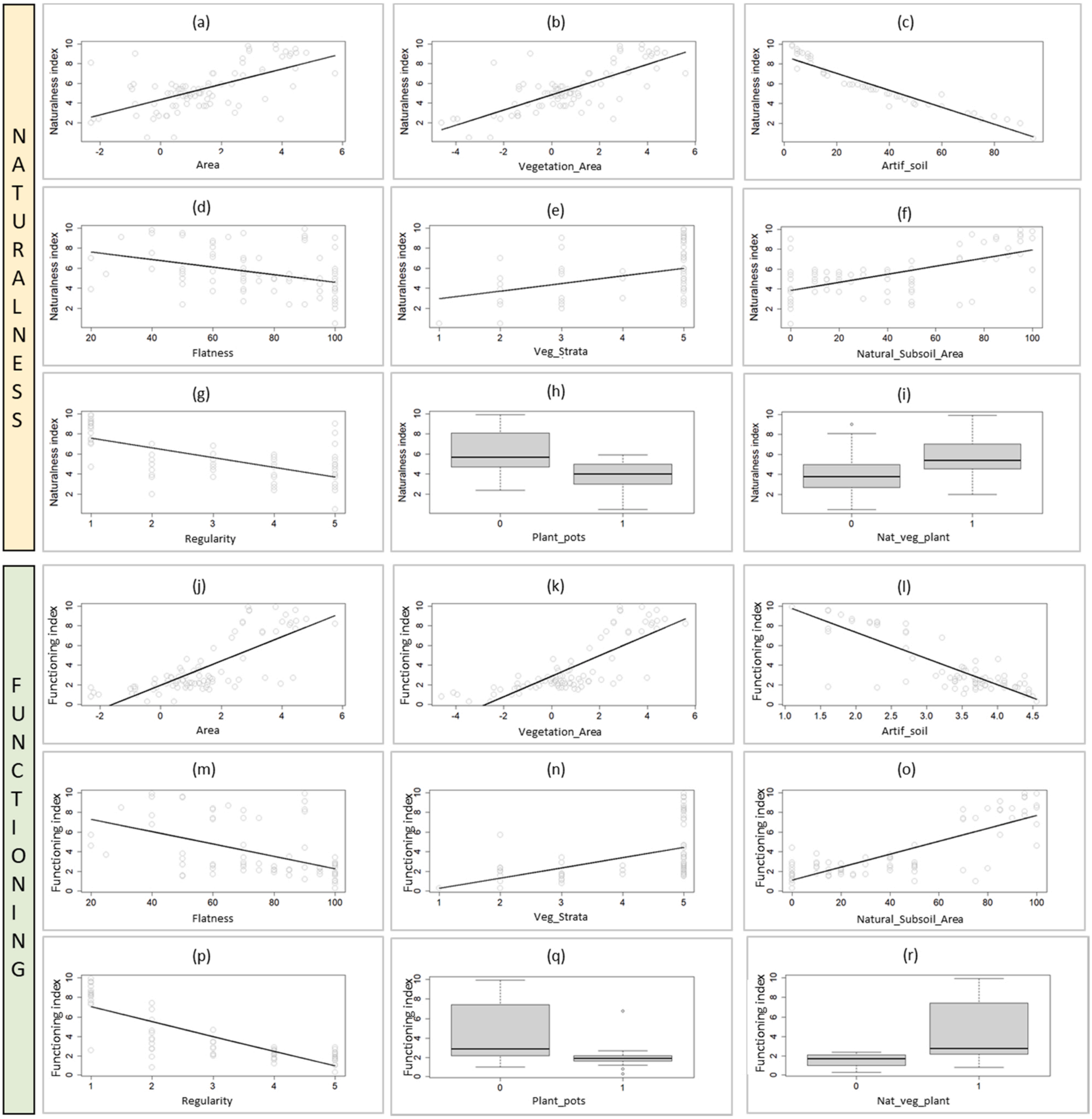

Fig. 5. Linear regression plots showing significant (p-value < 0.05) relationships between individual variables and Nat and Fun. Equivalent ANOVAs were performed for binary variables (h), (i), (q), (r), which were represented by boxplots (the median is denoted by the bold horizontal line, the box delimits the interquartile range, and the whisker lines extend to the observed maxima and minima, except for the outliers symbolized by points).

from the analysis to avoid multicollinearity, given the high correlation ($r = 0.98$) found between this variable and "Area".

Regarding the best combination of variables explaining Nat patterns, we found that the best-fitting model ($R^2 = 0.92$) included "Artif_soil" and "Regularity". However, the improvement in terms of explained variance is marginal in relation to that provided by the model just including "Artif_soil" ($R^2 = 0.9164$). The best-fitting model for Fun included "Regularity", "Area", and "Artif_soil" ($R^2 = 0.89$), improving substantially those resulting from individual regressions (Table 3).

4. Discussion

4.1. Characterization of UGI in the city of Zaragoza

The results of this study indicate that the UGI sites of Zaragoza city were distributed throughout the Nat & Fun combined range. UGIs of Zaragoza city were mainly characterized by low-medium values of Nat and low values of Fun, which corresponded to highly artificial UGIs with very regular shape and flat surface, located in the most densely urbanized zones of the city. Only 20% of the studied sites displayed high values of Nat and Fun, which corresponded to well-conserved natural areas (e.g. floodplains, hills), either unchanged (those located in the suburbs) or slightly transformed (surrounded by the urbanized parts of the city).

Table 2
Generalized Linear Model (GLM) summary of Naturalness (Nat) and Functioning (Fun) indicators with environmental variables representing major characteristics of urban green zones in Zaragoza city.

Indicator	Model	Variables	Adjusted R Square	Estimate	Std Error of the Estimate	p-value
Naturalness	(a)	Area	0.3662	0.7746	0.1076	2,022E-10
	(c)	Artif_soil	0.9164	-0.085416	0.002748	2,2E-16
	(d)	Flatness	0.1306	-0.03776	0.01001	0.0002952
	(e)	Veg_strata	0.1407	0.7579	0.1931	0.0001726
	(f)	Natural_Subsoil_Area	0.3927	0.040698	0.005348	3,054E-11
	(g)	Regularity	0.4383	-0.9709	0.1163	9,759E-13
	(h)	Plant_pots	0.1989	-2,2992	0.4810	7,062E-06
	(i)	Nat_veg_plant	0.1016	1,8369	0.5551	0.001363
Functioning	(J)	Area	0.595	1,2286	0.1076	2.2E-16
	(l)	Artif_soil	0.7271	-2,6626	0.1735	2.2E-16
	(m)	Flatness	0.2401	-0.06287	0.01171	6,568E-07
	(n)	Veg_strata	0.1737	1,0463	0.2370	2,887E-05
	(o)	Natural_Subsoil_Area	0.663	0.065802	0.004986	2.2E-16
	(p)	Regularity	0.6996	-1,5280	0.1065	2.2E-16
	(q)	Plant_pots	0.1337	-2,3901	0.6260	0.0002517
	(r)	Nat_veg_plant	0.1519	2,7641	0.6751	9,443E-05

Table 3
Results of mixed-effect models showing the best-fitting model equation, P-values (significant coefficients in bold type). *(R), "Regularity"; (A), "Area"; (As) "Artif_soil"; ns, non-significant coefficient.*

Indicator	Model Equation	(R)	(A)	(As)	R^2
Naturalness	$y = -0.26\ R - 0.96AS$	**0.00276**	ns	**< 2e-16**	0.92
Functioning	$y = -1.04\ R + 0.71\ A - 1.24AS$	**1.64e-10**	**1.06e-06**	**8.99e-14**	0.89

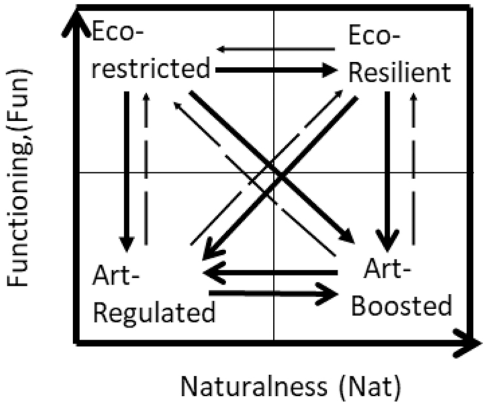

Fig. 6. Conceptual framework of alternative states of Naturalness (Nat) and Functioning (Fun) for UGI sites. The four squares in the figure correspond to UGI sites with either: high Nat and Fun (Eco-Resilient sites); high Nat and low Fun (Artificially boosted sites); high Fun and low Nat (Eco-Driven sites); low Nat and Fun (Artificially regulated sites); high Fun and low Nat (Eco-Restricted sites). The arrows show easily feasible changes of UGI sites characteristics (thick arrows) and difficult changes (thin arrows), and unlikely changes (broken lines).

Our approach based on Nat and Fun indicators encompassed the essential characteristics of ecosystems. Both Nat and Fun indicators were positively related to "Natural_Subsoil_Area", "Area", "Vegetated_Area", "Veg_Strata", and "Natural_veg_plant", but negatively related to "Artif_soil", "Regularity", "Plant_pots", and "Flatness" (Fig. 5, Table 2). We found a strong divergence in physical and social attributes between different types of UGIs (Fig. 4a) but a great convergence within the sites shaping them (Fig. 4b). Thus, UGI related to rivers and urban forests showed a greater size, more vegetation, undisturbed soils, naturalness and functioning than urban parks, and especially, compared to community gardens, squares, street trees and cemeteries, which were located in flat areas with artificial soil and vegetation and characterized by regular plantations with scattered trees and a reduced number of plant species.

The values of the Nat and Fun indicators were highly related between them, as shown in Fig. 3 and 4, which seem logical given that Fun could be considered as the ecological driver and Nat as an indicator of the components resulting from these functional drivers. Fully functional UGI sites seem incompatible with the absence of natural components; consequently, there were no UGI sites with high Fun values and low Nat values (Fig. 3). Conversely, the presence of natural components did not necessarily imply a high degree of functionality (e.g., UGI with a total absence of hydro-geomorphological functions but covered by planted vegetation).

Therefore, a city may have UGI sites highly regulated by hydro-geomorphological and other ecological drivers, including nutrient cycling via organic production and detritus decomposition (high Fun), which will facilitate the colonization and growth of natural vegetation (high Nat) and increase ecological resilience. However, they may be also artificially-regulated UGIs (Fig. 6), dominated by artificial components (low Nat) including recreational facilities, which will not be subjected to natural functioning processes (low Fun). In between, the city may have artificially-boosted UGI sites with a high cover of natural components (high Nat values due to the presence of several plant strata distributed more or less irregularly in mounds and hillocks), but not as the result of natural ecological processes (low Fun). Overall, a city cannot have long-lasting UGIs driven by natural processes (high Fun) with low cover of natural components (low Nat) because the drivers regulating the ecological functioning of the site would facilitate the colonization and development of plant populations and soil communities (ecologically-restricted UGIs, Fig. 6). However, there may be sites in transition states which temporarily present discordant (opposite) values of Nat and Fun. The framework defined by Nat and Fun can have a great potential for recurrent evaluations of UGI and monitor changes in their respective states (Fig. 6).

Different trajectories of changes of Nat and Fun for an UGI site can be identified in accordance with the services it provides. In Zaragoza city, most UGIs (45 out of 89) displayed low to moderate values of Nat and Fun. The dominance of this type of UGI is common in densely populated cities or in highly urbanized ones, as they are designed and constructed to provide mainly cultural services (O'Brien et al., 2017; Cheng et al., 2021), leading to the dominance of artificial components, and thus, lowering the values of naturalness and functioning (Lundholm, 2015).

4.2. Urban management and planning implications

Based on our results, we propose suggestions to be taken into consideration before, during, or after the planning of UGI in the city, at broader (city scale) and fine (UGI site) scale.

We detected a clear pattern in UGI features in concordance with that obtained for other cities worldwide (e.g., Rome, Capotorti et al. 2017) to be considered in urban planning: there is a clear separation between a group of natural sites located in suburban zones with an irregular distribution of plantations and tightly connected to hydro-geomorphological drivers as river flows, and most artificial UGIs in the most densely urbanized parts of the city, including new neighborhoods characterized by a very regular design and low functionality. This spatial segregation could be the cause of ecosystem disservices, such as biodiversity declines, given that the excessive aggrupation of very artificial sites and fragmentation of more natural remnants and UGIs can act as sink habitats (Lepczyk et al., 2017). Extreme clustering can also create a disharmony on biodiversity distribution between the UGIs sited downtown and those located in the surroundings of a city (Bötsch et al., 2018). Accordingly, it is advisable to keep natural remnants, which are still driven by ecological processes as UGI sites while a city enlarges (Snyman - Van der Walt et al., 2014), and to consider newly-built UGI as a useful tool to restore degraded zones and recover natural dynamics linked to hydro-geomorphological processes (Klaus and Kiehl, 2021). This strategy could contribute to a balanced provision of a full set of complementary ES at urban landscape scale. For example, the integration and conservation of riparian floodplains and forests in the urban landscape, as a population and city grow, can contribute substantially to the supply of ES and citys sustainability (Riis et al., 2020).

In this study, we covered most of the types of UGI elements referred to by Cvejić et al. (2015) and Kowarik (2011). Urban parks were the most common UGI type found in Zaragoza (in our case, 39 sites of 89), which seems logical, given that they are places of solace, recreation, and community fun in a stressful environment (Dunnett et al., 2002). Other types of UGI were barely present in the city; for instance, we found only one unit of green wall, even though green walls can create beneficial microclimates (buffering temperatures and increasing air humidity) and provide other environmental, social, and economic benefits such as regulating humidity, sound insulation, reducing heating and air conditioning expenses (Strumillo, 2021). We recommend urban planners to increase the type and variety of UGI, which would provide urban dwellers with a wider set of highly valuable ES that are especially affected by the reduction of diversity and surface of green infrastructure (Calderón-Contreras and Quiroz-Rosas, 2017).

The location of the majority of UGI units with high Nat and Fun values in peri-urban zones (Fig. 3), instead of in heavily populated neighborhoods, may indicate that the original geomorphology was not properly preserved during the expansion of the urban area. Thus, the land relief was changed, lowering the effect that ecological drivers can have on these UGI units. It is suggested to preserve the morphology of UGI sites incorporated to urban areas, or even imitate natural features if they are newly designed. Also, in the case of plantations, it is advised to have irregular groupings of trees and plants strategically disposed to enhance ecological connectivity, instead of scattered and isolated trees and plants without spatial continuity. Connectivity inside the site can be done using a gradual height plantation of indigenous trees and plants. The design of urban parks could be irregular, imitating in some way the English style of gardens and parks, and avoiding an excessively regular distribution of natural components (Allain & Christiany, 2006).

Furthermore, the strong negative relationship between “Artif_soil” and “Regularity” of the UGI units and the Nat and Fun indicators confirm i) the high potential of these variables to act as indicators of UGI performance, and ii) the idea that decreasing the area of artificial components and minimizing regular shapes in UGI design would favor functional processes and naturalness. Thus, we recommend the use of irregular shapes, asymmetrical distribution of vegetation, and mimicking nature in the arrangement of trees. The design should start with vegetation as the primary component and then specifying the artificial components in a way that do not disrupt the internal connectivity of plantations. Implementing these suggestions would increase the naturalness of UGIs while maintaining multifunctionality. However, improving the functional aspects of UGI sites requires keeping or recovering the influence of ecological drivers on the regulation of natural (hydro-geomorphological) dynamics (Mosler and Hobson, 2021). This may require both a broad consensus to design policies to obtain multiple ES from the set of UGI sites of a city and their systematic monitoring and assessment to ensure the accomplishment of the planned objectives. For this last purpose, the Nat & Fun indicators can be an efficient tool.

To achieve more natural and functional UGI, a shift in the mindset of decision makers and urban planners, as well as more ecological background and training in restoration ecology and environmental management, is required in their design. Up to date, UGI designers and planners have shown limited capacity to apply ecological principles to their work. The main professions involved in UGI design are landscape architecture, civil engineering, urban planning and design, with extensive involvement from lawyers, developers, and public officials. Nevertheless, environmental health and ecological processes have traditionally been omitted or marginalized by these disciplines, leading to negative impacts on urban economy and human well-being (Steiner et al., 2013).

4.3. *Advantages and drawbacks of the Nat and Fun approach*

Hanna and Comin (2021) performed a literature search to review types of studies of UGI characterization and evaluation and concluded that most approaches use methods requiring sampling and sophisticated analytical methods. The advantage of the Nat & Fun indicators and the analysis provided in this study lies in its simplicity, as it can be applied without sophisticated methods. Thus, Nat & Fun can be generalizable and help to increase the cost-effectiveness of UGI evaluations, as no expensive equipment is required and, at the same time, they provide an acceptable accuracy (the approach was able to detect meaningful groupings of UGI according to their environmental features). Previous studies used numerous ecological indicators (12 in the case of the European Environmental Agency (European Environmental Agency EEA, 2017) to assess UGI performance and focused on ES assessment (Fernández de Manuel et al., 2021), very time-consuming and expensive procedures were required to obtain the data needed to assess ES properly (Brouwer et al., 2003). The Nat & Fun indicators also satisfy the need for the unification of indicators (Tudorie et al., 2019) in order to assist cities in developing objective and adequate urban planning of UGI. Complementarily, the further assessment of ES provided by the UGIs of Zaragoza and its relationship with Nat and Fun indicators will allow a complete overview of the performance of Nat and Fun, not only as a surrogate of the UGI performance but also on the potential supply of valuable ES.

The use of complex methods is minimal in our approach but is mainly focused on an ecological perspective. Further development of this approach could also include social and economic variables and their relationship with the Nat and Fun indicators used here. Additionally, this study didn’t incorporate the use of remote sensing even though remote sensing is responsible for producing a virtual explosion of growth in ecological investigations and applications (Cohen and Goward, 2004). Future research can substitute the use of Google Earth and ArcGIS (Vector) by using image classification in remote sensing (e.g. Xu et al., (2020)). Moreover, the number of variables used in this study could be considered high (15) and could have been reduced. Further investigation is needed analyzing a smaller number of variables representing other characteristics than the ones presented in our study.

5. Conclusion

The UGI of Zaragoza city was mostly characterized by sites designed with regular shapes and a dominance of artificial components distributed throughout the densely urbanized area of the city. However, there was also a small group of sites, covering a large area, with a high cover of natural components and driven by natural processes (river meanders, floodplains, forests), mostly located in suburban zones. A similar pattern has been found in other European cities (Capotorti et al. 2017), so the framework proposed here for the assessment of the UGI network could be applicable in other cities and countries. The evaluation of Nat and Fun indicators seems an efficient tool to obtain an overview of the characteristics of the green zones of a city, the potential changes to be implemented in existing UGI sites and the design of new ones, to reach a more balanced representation of ecosystem processes, functions and services within the UGI network of a city.

A strong negative relationship was observed between the proportion of artificial area and of regular design and the Nat and Fun indicators, which suggests a high potential of these variables to act as indicators of UGI performance. Our results indicate that the improvement of naturalness and functioning of UGI sites can be achieved by minimizing regularity (regular design), hence preserving the natural topological relief and decreasing the area of soil covered by artificial components.

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CRediT authorship contribution statement

Elie Hanna: Investigation, Data curation, Visualization, Writing – original draft, editing, review. **Dani Bruno:** Writing – review & editing, Methodology. **Francisco A. Comín:** Investigation, Writing – original draft, editing, review, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2022.127825.

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