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Innovation, green infrastructures and urban form

Towards regenerative city models

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Many shades of green: intrinsic and network properties of urban green areas

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Abstract

Urban green spaces are a vital component of public infrastructure, yet their evaluation often relies exclusively on either qualitative descriptions, aggregate metrics or basic quantitative thresholds. Thus, research frequently overlooks intrinsic attributes, spatial integration, functional accessibility, and the broader impact on urban liveability. This paper critically re-examines the legacy of Italy's urban planning standards – specifically the Ministerial Decree 1444/1968, which introduced minimum green space requirements – to assess whether the prevailing metric-based paradigm has marginalized qualitative and locational dimensions. Through a comparative case study of three mid-sized Tuscan cities – Pisa, Lucca, and Grosseto – this research develops and applies an original methodology that integrates both intrinsic characteristics (typological, geometric, and structural) and extrinsic features (accessibility and configurational properties) of urban green spaces. Drawing on field surveys, spatial analysis, and Space Syntax techniques, the study constructs a composite evaluative framework to assess the actual usability and functional performance of green areas within the urban context. Findings reveal that a substantial proportion of green spaces are either residual or inaccessible, and are often poorly connected to the urban fabric despite formal compliance with legal standards. While national planning requirements have increased the quantity of public green space, these areas are frequently located on the urban periphery or insufficiently integrated into movement networks, thereby limiting their effectiveness. The proposed approach offers a lightweight yet robust tool for quali-quantitative assessment, enabling more nuanced evaluations and supporting context-sensitive planning practices. The study advocates for a renewed emphasis on design quality and locational integration in green infrastructure policies to enhance the equity, usability, and liveability of urban environments.

Keywords

Green public areas; Accessibility; Space syntax; Quantitative assessment; Composite Index

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1. Introduction

A few years ago, when interviewed on the topic of territorial facilities, Edoardo Salzano recalled the two etymological roots of the term "standard", assuming curiously different meanings: one referring to a model, a minimum reference value, a mandatory requirement, a performance threshold; and the other, etymologically more immediate (from the French *estandart*), meaning a banner, a flag.

It is undeniable that in 1967, the Italian law 765, and the following year, the ministerial decree 1444, made these two meanings to overlap and align: the legal recognition of the right to territorial provisions of a predetermined and non-negotiable minimum amount, as something to be celebrated by proudly raising a flag on a difficult yet victorious battlefield.

However, more than fifty years after the introduction of urban planning standards, it is equally undeniable – as Salzano himself, along with several other urban planners, acknowledged – that the pride evoked by the second meaning quickly faded, giving way to the accounting practice for which the first meaning – a minimum numerical reference – has commonly become both an expression and an operational tool.

Among territorial provisions, public green spaces are the most prominent – not only because of the minimum extension granted to them in 1968, but above all due to the significance of the values they symbolically represent. Unlike spaces for parking, education, and activities of common interest, public green areas do not merely serve functional needs; they also embody elements of nature within the urban environment, recognized as an indispensable resource for the community. These spaces fulfil a variety of roles, spanning ecological-environmental, social and recreational, cultural, and hygienic-health purposes.

For these reasons, the planning of public green areas was a central subject in 20th-century urban planning and design manuals, where it was widely and extensively addressed, accompanied by a detailed set of technical guidelines and design recommendations.

Enrico Tedeschi's essay (1947), published by Metron in the immediate post-war period, provides a clear example: it offers highly detailed technical guidelines for collective services, categorized into various types, outlining their dimensions, location in relation to residential areas, and influence based on settlement density. A similarly meticulous focus on the topic can be found in later manuals, from Piccinato (1947) to Rigotti (1947), and from Dodi (1953) to the Manuale dell'Architetto (CNR, 1946), across its different post-war editions. It is difficult to find such an extensive discussion and analysis on the subject in the late 20th and early 21st centuries.

All this highlights how sensitivity and attention to the issue of urban green spaces – both in terms of their intrinsic characteristics and their location – were widely shared and deeply rooted in the early years of post-war urban expansion. Paradoxically, however, this attention waned when, in 1967, a minimum provision of public green space was legally established, and the following year, this provision was strictly quantified across the different homogeneous zones into which municipal territory was divided.

In other words, the legal recognition of public green space as an inalienable and non-negotiable right for every resident – a glorious achievement marked by the banner of Law 765 – paradoxically seems to have diminished interest in the intrinsic nature of this provision and its specific locational characteristics. It is as if the cultural and political struggle to secure the right to green spaces (and other public services, of course) had absorbed all attention, diverting focus away from the design solutions necessary for their actual implementation in terms of structure and location. Once the political and legislative victory had been achieved, much of this attention seemingly evaporated: all guidance on the creation of public green areas became encompassed within and absorbed by the definition of the minimum standard, an unavoidable threshold whose fulfilment came to represent the entirety of the issue.

It is perhaps even more surprising how this attention has remained weak and marginal, even when, starting from the 1980s, the inadequacy of urban planning standards as a factor and guarantee of settlement quality became evident, sparking a lively debate on ways to move beyond them – a debate that, despite its breadth, has largely remained unproductive.

Indeed, while over half a century of experience has clearly shown that the issue of territorial provisions – and urban green spaces in particular – has been reduced in practice to mere compliance with an accounting obligation, amounting to nothing more than a simplistic numerical verification, discussion and testing of alternative strategies for ensuring an adequate provision of public green spaces in urban areas are still on going. Beyond addressing entirely heterogeneous needs and aspects, ranging from the ideas of green city, healthy city to ecosystem services, which struggle to be synthesized into a single integrated approach, the fundamental issue remains unresolved: how to translate the control of these aspects into rigorous procedures – ideally objective and, if possible, not overly complex – so that they can be easily applied in planning practice. These very qualities – perhaps the only ones – that the Legge Ponte standards certainly did not lack are precisely what ensured their primacy for over half a century of widespread and consistent use.

In such a context of persistent uncertainty, it becomes particularly relevant to examine a diverse sample of Italian urban settlements in order to analyse the intrinsic characteristics of public green spaces and their configurational properties, with special attention to those created after the introduction of regulations on standards. The discussion of the results of this exploration will allow assessing the actual suitability of green areas for the various needs they are intended to serve and, conversely, the effectiveness of law 765 in meeting the requirements for green spaces aimed at social and recreational, cultural and health-related purposes for which it was enacted.

To reach these result, three subgoals are stated: (a) analyse the amount and the intrinsic characteristics of green spaces within the city; (b) analyse the extrinsic characteristics of the green spaces, with a particular focus to their accessibility; (c) discuss the overall suitability of green public spaces by combining intrinsic and extrinsic features, proposing a lightweight analytical tool designed for preliminary but effective quali-quantitative assessment – going beyond the simplistic use of general or aggregated values. The case studies analysed in this paper are the three historical Italian settlements of Pisa, Lucca and Grosseto, selected because of their demographic size, quite similar, which enables a reliable comparison of the results.

In this vein, the paper is structured as follows. Section 2 provides a background about studies analysing the impact of green areas features on liveability, especially focused on quantitative approaches. Section 3 presents the three case study areas – Pisa, Lucca and Grosseto, in Tuscany (Italy) – by briefly discussing their main characteristics from a morphological, demographic and historical perspectives. Section 4 illustrates the datasets and methods employed. Section 5 presents the results and their discussion, providing interpretative tools and cutting-edge infographics to assess the overall suitability of green public spaces. Finally, Section 6 provides the general conclusions.

2. Background

Urban green spaces are a central concern in contemporary urban planning, as they significantly influence both the psychophysical well-being of residents and the environmental resilience of cities (Li et al., 2005). Numerous studies have demonstrated how the presence of green areas contributes to stress reduction, increased physical activity, and social cohesion, as well as to the mitigation of climate change effects, such as urban heat islands and hydrogeological risks (Biernacka & Kronenberg, 2018). Urban greenery is thus not merely an aesthetic or recreational resource, but a vital ecological and social infrastructure (Mihinjac & Saville, 2019). In fact, the value of green spaces extends beyond their physical and ecological characteristics to include perceived and symbolic dimensions, such as visual quality, sense of safety, mental well-being, and the urban identity they help to construct (Zhang et al., 2021). This symbolic and functional diversity is further confirmed by recent research highlighting the spatial heterogeneity of green space values across cities (Giannakidou &

Latinopoulos, 2023), and the varying capacity of green spaces to support biodiversity and ecosystem services depending on local planning approaches (Lazzarini et al., 2024).

Over time, methodological approaches to urban green space analysis have evolved. Traditional qualitative perspectives have been increasingly complemented by quantitative methods aimed at supporting qualitative analysis and developing composite indicators to capture the many characteristics, multifunctionality, and impacts of green spaces. As discussed by Haaland & van den Bosch (2015), the increasing adoption of the compact city model – driven by rising urbanization trends over recent decades and reinforced by the concrete and inevitable projections for the future (UN Habitat, 2022) – underscores the need to develop multidimensional assessments of the impact of green infrastructures, including from an environmental perspective, given the ongoing climate crisis and the need for systemic adaptation strategies (Ceci et al., 2023; Isola et al., 2024).

Among these multidimensional assessments, green types have been defined (for a review, see Kabisch et al., 2015), and several significant indicators have been developed, including tree canopy coverage (Nowak and Greenfield, 2012), biodiversity (Aronson et al., 2017), and proximity (Rigolon, 2016).

Accessibility, overall, has emerged as a relevant dimension in assessing green space performance. It must be understood not only as the physical ability to enter a green space – sometimes limited by physical, social, or cultural barriers (Pantaloni et al., 2024; Bocca, 2023; Wolch et al., 2014) – but also in terms of its strategic spatial location within the urban fabric, known as, in configurational terms, spatial centrality (Hillier, 2007), which can be used to determine whether the green spaces are easily connected within the urban grid (pathways, cycleways, or road network) or not.

In this regard, Space Syntax has proven to be an effective methodology for analysing the spatial structure of cities and revealing the integration and connectivity potential of green spaces. Several contributions (Hillier, 2007; Karimi, 2012; Cutini, 2016) have shown how syntactic measures – such as integration, choice, and depth – offer a novel perspective on the legibility, accessibility, and attractiveness of open spaces, moving beyond simple physical distance metrics.

More than this, recent applications of Space Syntax in the study of green areas have further expanded its relevance in this field, showing its correlation with some actual and perceived phenomena. Tannous et al (2021) showed how urban planning can strongly influence accessibility, highlighting how large parks often follow spatial logics aligned with integration patterns – given their proper planning process – while smaller ones tend to emerge from irregular land availability, weakening spatial coherence and their accessibility. Moreover, studies have confirmed that green spaces with higher syntactic integration are not only objectively more accessible but are also perceived as such by users, reinforcing the connection between spatial form and lived experience (Gomaa et al 2024), fostering as a consequence social interaction. In a similar manner, accessibility and spatial configuration impact on perceived security, with low visibility and poor connectivity resulting in risky perception of green areas (Farkhondeh et al., 2023), once again highlighting the connection between form, position, access, and liveability, and thus proving Space Syntax ability to enhance spatial equity (Wang et al., 2022).

Finally, Space Syntax proved an useful tool not only in extracting intrinsic characteristics of urban spaces or in helping to discover hidden correlations, but also in identifying and addressing inequities in green space accessibility among different social groups (Huang et al., 2023), and to propose interventions for improving the usability and attractiveness of campus green spaces (Li et al., 2019). Collectively, these studies illustrate the versatility of Space Syntax as both an analytical and a design-support tool for rethinking urban greenery as a structurally integrated, socially inclusive, and perceptually meaningful component of the urban fabric.

Building on these insights, this paper proposes an integrated approach that encompasses both the intrinsic characteristics of green spaces – such as typology, form, dimension, barriers – and their extrinsic dimensions – such as accessibility, centrality, and localization. The aim is, as stated in the introduction, to offer a multidimensional framework for the quali-quantitative analysis of urban greenery, going beyond simple and aggregated quantitative analysis, thus exploring the "many shades of green".

3. Case studies

This study examines three cities located within Tuscany, Italy: Pisa, Lucca, and Grosseto. These all are three historically founded urban centres in Tuscany, each with comparable population sizes – approximately 90,000 inhabitants in Pisa and Lucca, and around 80,000 in Grosseto. Despite these demographic similarities and a shared process of modern suburban expansion radiating from historically walled cores, these urban areas differ in terms of historical development, urban morphology, and spatial characteristics, providing diverse contexts for analysing urban quality and accessibility of public spaces and thus allowing the exploration of green public areas dynamics and the identification of potential trends among the three case studies.

All three historic centres are densely built and enclosed by preserved – or partially preserved, in the case of Pisa – fortification walls. However, the physical dimensions of these cores differ: Pisa and Lucca possess similarly sized historic centres (approximately 2 km^2), while Grosseto's is comparatively smaller (approximately 0.3 km^2). The character and role of the city walls also vary: in Lucca and Grosseto, the walls are walkable and integrated into green infrastructure, whereas in Pisa, they function primarily as a boundary element, although they adjoin the unique green space of Piazza dei Miracoli – one of the largest open areas within the city.

The relationship between each city and its river system further illustrates morphological divergence. In Pisa, the Arno River serves as a central yet divisive element in the urban fabric. In Lucca, the Serchio river lies at the periphery, marking the edge of suburban development. Grosseto, lacking a river within the city itself, is nevertheless marked by the presence of a pre-existing reclamation canal, later covered over, whose area significantly constrained urban expansion, particularly regarding green spaces, since the culverting has, in fact, created a wide opportunity for their development.

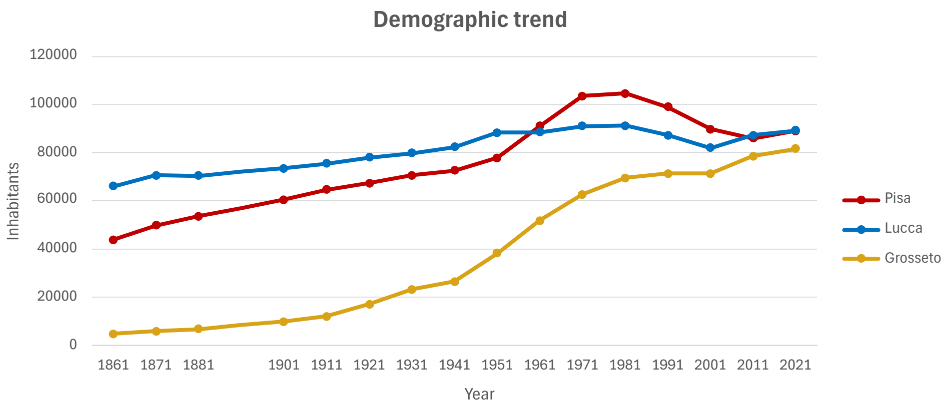

Fig.1 Demographic trends in Pisa, Lucca, and Grosseto from 1861 to 2021.

Patterns of suburban growth also differ markedly. Lucca has developed according to a radial and somewhat organic mode, while Grosseto and Pisa's development was addressed by the planning strategies of two master plans by Luigi Piccinato: predominantly northward along a defined infrastructural axis Grosseto, primarily toward the east Pisa. It is worth noting that, despite the current similar size of the three cities, a marked difference distinguishes the recent urban development of Grosseto from that of Lucca and Pisa – one that also has implications for the current provision of green spaces. For historical reasons, Grosseto underwent significantly greater physical and demographic growth throughout the twentieth century compared to the other Tuscan cities (see Fig.1), resulting in a settlement that is, for the most part, of recent (or very recent) origin. Furthermore, this development followed a compact urban pattern with relatively high density, setting it apart particularly from the expansion of Lucca, which in recent decades has experienced low-density sprawl, largely devoid of public spaces within it.

Based on this contextual understanding, the boundaries of the study areas for spatial analysis were delineated to include both the historic centres and the adjacent suburban zones extending to the edge of the first rural belt, as Fig.2 shows. This delineation was guided by the continuity of the built environment rather than by a priori standardized area sizes. As a result, the study areas encompass approximately 20.8 km^2 in Pisa, 14.7 km^2 in Lucca, and 13.3 km^2 in Grosseto.

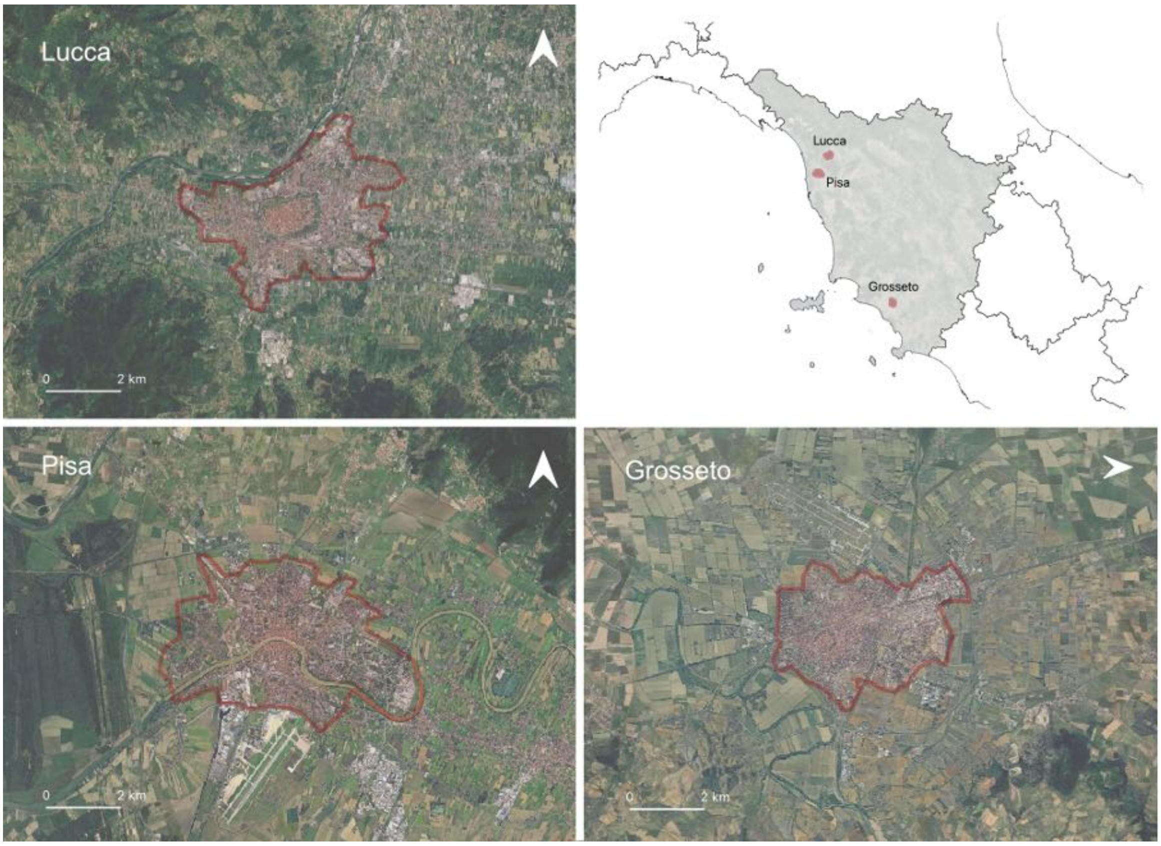

Fig.2 General overview of the case studies: location and geographical extent of Lucca, Pisa, and Grosseto (Tuscany, Italy).

4. Datasets and methods

To assess public green areas intrinsic and extrinsic characteristics, three primary datasets were employed.

First, the Regional Cartography (CTR 2k Regione Toscana), which served as the spatial reference layer for all analyses conducted. It provided a detailed cartographic base onto which the collected data through the on-field survey of (a) Green Areas, (b) Access Points, and (c) Urban Cycle Paths were digitized and spatially integrated.

Second, the OpenStreetMap (OSM, 2025) road data. Following extraction, the dataset underwent a process of categorization and data cleaning to ensure accuracy and consistency. Specifically, road segments with an *fclass* value corresponding to the following categories were retained: "living_street", "motorway", "motorway_link", "primary", "primary_link", "residential", "secondary", "secondary_link", "tertiary", "tertiary_link", "trunk", "trunk_link", "service", "cycleway", "footway", "pedestrian", "steps", "track". From this dataset, Normalised Angular Choice (NACH) values at two different radii (Rn and R800m) were calculated in the software DepthmapX in accordance with Space Syntax theory (Hillier 2007; Turner 2007; Cutini 2016). These values offer insights into the movement potential and accessibility patterns of urban spaces, aiding in the assessment of the positional values of green areas and the intrinsic relation with the urban fabric, as detailed in Section 5.

Third, the Orthophoto Cartographic from the *Istituto Geografico Militare* (OFC 1965 IGM-RT, OFC 1975-76 IGM-RT), downloaded from the Geoscopio Toscana (Regione Toscana, 2019), and Piccinato Urban Plans have been used to add a diachronic analysis of the green public areas. The following paragraph details the collected data and how the georeferenced dataset of green areas has been elaborated.

4.1 Survey and data collection methodology

The dataset of green areas, access points, and urban cycle paths have been created from scratch for this research. In particular, three subsets were created: a polygonal layer comprehending the urban green areas, a point layer containing the access to the gated urban public areas, and a linear layer representing the cycle paths. For each subset, a comprehensive set of attributes was recorded, then integrated within one single polygonal layer through GIS spatial tools. Several parameters were selected to comprehensively represent the actual qualities of the current urban green areas. As mentioned above, those parameters can be distinguished in intrinsic features, inherent to the local, geometric and functional aspects of each area, and its locational characteristics, or extrinsic features, referring to the relationships with its surroundings and the whole settlement as well. The final parameters are listed and described here below, and summarized in both Fig.3 and Tab.1, with the first one focusing on the methodological framework and the second one on the specific attributes included within the final georeferenced dataset of green areas. Green public areas were thus identified and georeferenced with the following fields:

- ID code: unique identification code, for each polygon, with the information about the municipality where it is located and a progressive counting, in the format *MUN_nnn*;
- Year: whether the green public space was already in place before the 1968 or not [ante 1968; post 1968];
- Class: the type of green public space, depending on its use [Park/Public Garden; Equipped; Sporting; Associated with other services; Traffic-enclosed (e.g., median strips, roundabouts, railway-adjacent greenery), which is non-accessible; Residual; Other];
- Area: the dimension of the green area, expressed in square metres;
- Compactness: the ratio between the area and the square perimeter, expressed by the formula $C = 4\pi A / \Pi^2$, inspired by the Visibility Graph Analysis Isovist Compactness metric. It has the ability to estimate how compact (close to a circle) a shape is;
- Gated: whether the public green area is fenced or not [yes; no];
- Public accessibility: the physical accessibility to the green public space, whether it is open, closed, or restricted in some periods or subject to the payment of a fee [free; limited (in time or under payment); inaccessible];
- Local centrality: the positional value – according to the configurational concept of centrality – of the green area within the urban environment in a logic of pedestrian movement, calculated using NACH 800m, with R=800m meaning the walking distance of an elderly person in 15 minutes;
- Global centrality: the positional value in a logic of vehicular movement, calculated using NACH Rn (Van Nes and Yamu, 2021);
- Cycleways: whether a cycleway serves the public green space or not [yes; no];
- Parking: whether a parking is present nearby, within a radius of 50 metres [yes; no].

Please note that all the fields were automatically detected within the on-field survey, then obtained in their final form just by combining the punctual, linear and polygonal layers information. The only exceptions are represented by the year information, retrieved from the OFC 1965 IGM-RT, OFC 1975-76 IGM-RT (Regione Toscana, 2019) and urban plan of Piccinato for Pisa and Grosseto – from which it was possible to distinguish green public areas already present from those not yet realized through cartographic overlapping and critical analysis in a GIS environment – and the centrality fields, which required the association of NACH measures to the public green areas. In particular, once calculated the Space Syntax metrics (NACH Rn and NACH R800, weighted by length according to Turner 2007) on the municipal areas, the value of the highest-integrated street facing the green area has been associated to it.

This choice was made to retain the strongest configurational affordance of each space and avoid potential distortions that could arise from averaging surrounding values, especially in cases where highly integrated segments are flanked by poorly integrated ones. For fenced green areas, the closest street segment to the actual access point has been considered.

This method permitted the association of both global and local measure of configurational accessibility to each public green area. Once the aforementioned dataset was constructed, a cross-spatial analysis was conducted integrating the various collected parameters, in order to perform a quali-quantitative assessment of urban greenery across the three case studies.

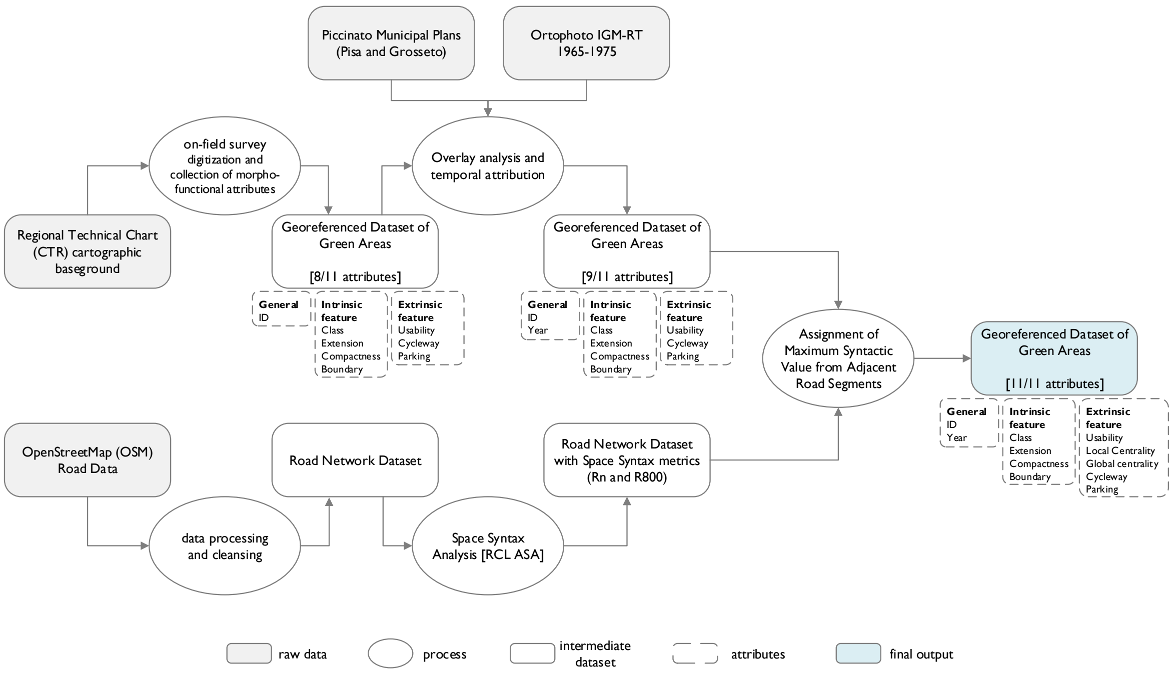

Fig.3 Methodological workflow of the research.

General info		Intrinsic features				Extrinsic features				
MUN_ID	Year	Class	Extension	Compactness	Boundary	Usability	Local centrality	Global centrality	Cycleways	Parking
PI_xxx LU_yyy GR_zzz	Pre 1968 Post 1968	Park/Public garden Equipped Sporting Assoc w services Traffic-enclosed Residual Other	Value [sqm]	Value	Yes No	Free Limited Inaccessible	Value NACH R800	Value NACH Rn	Yes No	Yes No

Tab.1 Summary of the parameters included in the georeferenced dataset of green areas, grouped in General Information (ID, Year), Intrinsic Features (Class, Extension, Compactness, Boundary) and Extrinsic Features (Usability, Local centrality, Global Centrality, Cycleways, Parking).

5. Results and Discussion

Following data processing, quantitative analyses of urban green spaces were conducted, structured – as already said – around a tripartite discussion: intrinsic features, extrinsic features, and an integrated assessment of both, with the ultimate aim of evaluating the effective suitability of urban greenery, highlighting somehow the distinction between quantity and quality. The three selected case studies thus provide a common baseline for a comparative analysis of how intrinsic urban characteristics – such as specific land use, surface area, and spatial form – and extrinsic elements – such as levels of public accessibility and transportation infrastructure – contribute to urban environmental value.

Given the similar structural origins of Pisa, Lucca, and Grosseto – with, as this section will highlight, quite different outcomes among them – it becomes particularly meaningful to investigate not only the total amount of urban green space, but also its typology, spatial distribution, and accessibility. This enables a more comprehensive and quantitative assessment of green infrastructure that moves beyond a purely numerical or superficial approach, which – as the analysis will show – can often be misleading or devoid of real significance.

Emerging trends have been synthesized into summary infographics, designed to facilitate immediate visual comparison among the three case studies, thereby enhancing both accessibility and interpretability of the findings.

5.1 Intrinsic features

The analysis of intrinsic features provides a geometrical-functional characterization of urban green areas, offering insights into their spatial distribution and, to a limited extent, their diachronic evolution – specifically between the pre- and post-1968 periods. These data are summarized in Fig.4, which presents a spatial comparison of green spaces distribution and morphological characteristics across the three case studies on the left side – categorized by class – and, on the right side, a set of diagrams for each case. These include a quantitative distribution diagram by class, and four bar charts reporting on geometric attributes (extent and compactness), the presence of fencing, and the year of establishment. All charts present values as percentages of total green space surface, rather than by number of individual green areas, in order to provide a more meaningful and quantifiable metric that avoids misleading interpretations due to fragmentation or size variance.

In absolute terms, the total surface area of urban green space is relatively comparable across the three cities: 2.45 km² in Pisa, 2.16 km² in Lucca, and 2.87 km² in Grosseto. However, their spatial distribution patterns reveal distinct differences. In Pisa, green areas are more fragmented and dispersed across the urban fabric. In Lucca, they are more clustered – most notably around the historic city wall park, which stands apart as a prominent and singular green landmark. In contrast, Grosseto presents a more zone-based and visually cohesive distribution, with green areas appearing as integral parts of residential neighbourhoods, even though internally composed of smaller, discrete units.

From a typological standpoint, the classification of green spaces by class reveals notable trends across the three case studies. A striking observation is the substantial presence of residual green areas in all three cities, accounting for 30% in Pisa, 15% in Lucca, and 22% in Grosseto – representing, respectively, the first, third, and second highest values within each city's typology profile. Conversely, the most "valuable" types of green space – parks/public gardens and equipped green areas – constitute nearly half of the total green public space in Lucca (49%), 45% in Grosseto, but only 30% in Pisa.

Although the relative proportion of small-scale green spaces (i.e., those smaller than 200 m²) remains fairly limited – accounting for 4% in Pisa, 3% in Lucca, and 2% in Grosseto – Grosseto exhibits the largest average green area size, suggesting a more deliberate and consolidated pattern of land allocation for greenery. This impression is further supported by Grosseto's high compactness index, with over 90% of green areas scoring above 0.12, and the predominance of the park/public garden typology, which represents 38% of the city's green space stock. This contrasts sharply with Pisa, where the same category accounts for only 24%.

Fig.4 Intrinsic features representation in the three case studies and infographics on the specific features.

Temporal distribution patterns reinforce these distinctions. Grosseto exhibits a more recent green space development trajectory, consistent with the demographic and urban growth discussed earlier: 84% of its public green areas were established after 1968, compared to 49% in Pisa and 43% in Lucca. This suggests a more modern and possibly master-planned green infrastructure strategy in Grosseto, aligned with its urban expansion phases.

In general, spatial compactness confirms the greater fragmentation of Pisa and Lucca compared to Grosseto, based on data related to the urban form of green spaces. In Grosseto, green areas tend to be more geometrically regular, followed by Pisa (80%) and Lucca (76%). These differences reflect not only morphological characteristics but also potentially divergent planning approaches. While compactness is undoubtedly a rough metric, it still enables the identification of green spaces that, due to their irregular geometric configurations, are functionally inadequate as recreational or social environments. These often correspond to residual spaces – byproducts of other land uses – particularly marginal areas adjacent to vehicular infrastructure.

The analysis of enclosure conditions further reveals that approximately one in four public green spaces is gated. This is a significant factor affecting also accessibility, as these areas often impose temporal or group-based access restrictions – or both – thereby reducing the proportion of green spaces that are effectively usable by the public.

A particularly insightful aspect of the analysis is the relationship between green space typology and year of establishment. As shown in Fig.5, a network-based representation captures both the temporal evolution and the spatial clustering of recently developed green areas. These patterns are further clarified in Fig.4, which synthesizes the typological shifts across time periods using a radar chart. Notably, Pisa is the only city in which the three categories with the highest percentage increases are all medium-to-high qualitative types: sporting areas (+554.7%), parks/public gardens (+205.7%), and equipped green spaces (+139.1%). In contrast, Lucca shows the highest increase in sporting areas (+294%), followed by green spaces associated with services (+114%) and residual green (+94%). Interestingly, the smallest increase in Lucca is in the park/public garden category (+48%), which nonetheless still represents a substantial portion (approximately 46%) of the city's current green public areas – largely due to the historical city wall park. Conversely, Grosseto shows its three highest percentage increases in equipped green spaces (+2172%), residual green areas (+1725%), and traffic-enclosed green (+570%). This pattern reflects the city's extensive urban expansion after 1968, which resulted in a considerable growth in public green areas. However, this growth was driven by lower-quality green space typologies, despite the overall substantial increase across all categories.

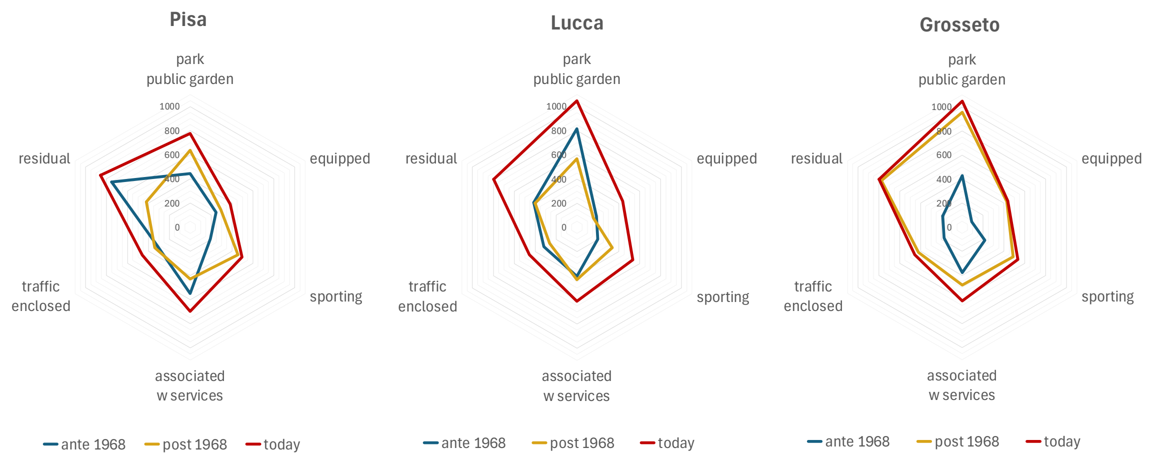

Fig.5 Radar charts comparing the class proportions of the three case studies [square root of the amount] before 1968, after 1968, and across the entire period.

Ultimately, this multidimensional examination of the intrinsic characteristics of public green spaces offers a far more nuanced and informative perspective than conventional aggregated quantitative assessments – such as those commonly featured in planning reports or statistical yearbooks. By incorporating considerations of form, function, and temporal layering within the urban fabric, the analysis provides deeper insights. Nonetheless, one critical dimension remains underexplored: the accessibility of public green areas. This factor fundamentally shapes, in a cascading manner, the overall suitability of green spaces – understood here as their actual value in contributing to urban liveability and explored in the following sections.

5.2 Extrinsic features

The analysis of extrinsic features focuses on characteristics external to the green spaces themselves – specifically, those dependent on the surrounding urban systems and external conditions. In particular, the study emphasizes usability and spatial accessibility, including pedestrian, vehicular, and cycling access.

As discussed in Section 2, accessibility is often overlooked in green space assessments, despite its significant role in determining the actual impact of urban greenery. Extensive green areas located at the urban periphery may offer far less contribution to everyday well-being, air quality, or liveability than a centrally located urban park that is easily reachable by large portions of the population. The findings are summarized in Fig.6, which is organized into two main parts.

On the left, a spatialized comparison of green areas across the three case studies is presented, with each area categorized by usability, understood here as the type of public access. In the background, the road network is hierarchized based on spatial centrality. Red segments represent streets with high local centrality (top 20% of Normalized Angular Choice, NACH, at radius R800); yellow segments indicate streets with high global centrality (top 20% of NACH at global radius Rn); grey segments correspond to segregated parts of the network that do not fall within either category. Finally, dashed green lines represent existing bicycle lanes.

On the right, a series of bar charts present quantitative indicators – expressed as percentages of total green surface – regarding: public usability levels; centrality class (local/global/segregated); presence of bicycle infrastructure nearby; and availability of dedicated parking facilities.

A brief methodological note is warranted on how centrality and accessibility data were processed. The goal was to produce a clear and legible visualization that captured the configurational accessibility of individual urban green areas and offered a more nuanced evaluation of their extrinsic features. This classification was developed through the construction of a unified Centrality Index, derived from Space Syntax analysis, enabling the synthesis of multiple dimensions of spatial integration into a single accessibility metric. Based on this index, three levels of centrality were defined:

- Locally Central: green spaces associated with the top 20% of road segments in terms of Normalized Angular Choice (NACH) at a local radius (R800), indicative of high pedestrian accessibility;
- Globally Central: green spaces associated with the top 20% of segments based on NACH at a global radius (Rn), reflecting broader vehicular accessibility and spatial integration;
- Segregated: green areas associated with street segments that do not fall into either of the previous categories, characterized by low configurational accessibility.

This classification provides a foundation for the subsequent qualitative analyses of green space actual suitability, discussed in the following section, and serves as a key interpretive layer for assessing the broader urban performance of green infrastructures.

Fig.6 offers an overview of green space accessibility, addressing the often-overlooked dimension of extrinsic features – the external conditions that determine how green spaces are experienced and used.

Beginning with physical accessibility, the data show that in all three cities, at least 30% of green spaces are subject to access restrictions, with Pisa reaching the highest value of 39%. This category includes museum parks and privately managed sports facilities, as well as green areas linked to public or institutional services, just to give a few examples.

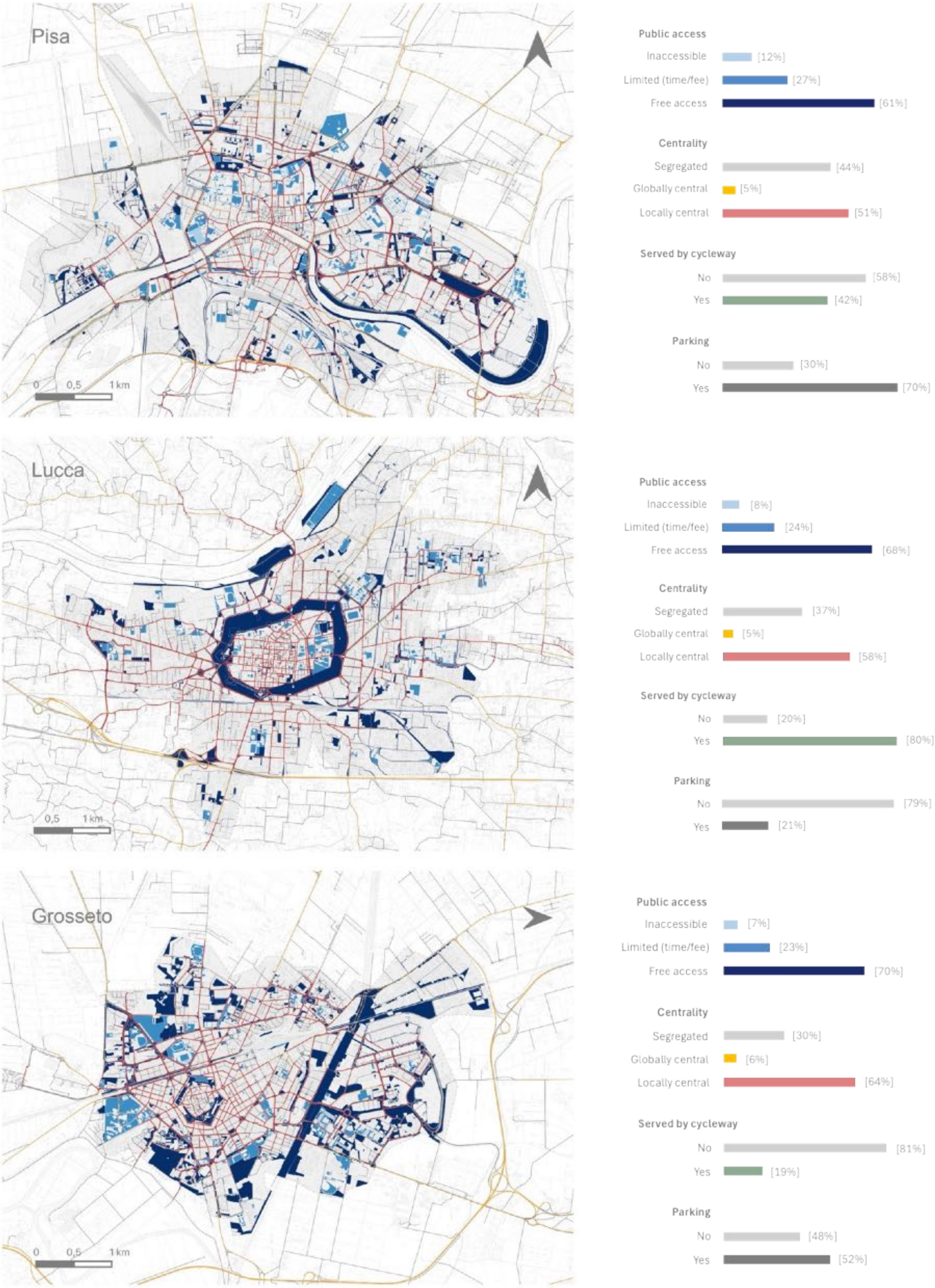

Fig.6 Extrinsic features representation in the three case studies and infographics on the specific features.

Also included are public green areas that are currently inaccessible due to construction, renovation, or neglect. However, the most common contributors to inaccessibility are traffic-enclosed green areas – spaces embedded within or surrounded by road infrastructure.

While such areas may serve ecological or aesthetic functions, they are functionally unusable by the population, despite being counted as public green space. Specifically, the share of completely inaccessible public green areas amounts to 12% in Pisa, 8% in Lucca, and 7% in Grosseto.
However, accessibility extends beyond direct physical access to include what may be termed spatial or relational accessibility – that is, the centrality of green areas both locally (in terms of walkability and proximity to residential areas) and globally (in terms of connection to major vehicular flows). The spatial configuration analysis reveals that a significant portion of green spaces is located in areas with low local centrality – 49% in Pisa, 42% in Lucca, and 36% in Grosseto – often as a consequence of high-density urban areas where space for green infrastructure is either unavailable or deprioritized. Furthermore, considering the results, even when green areas were developed in peripheral zones, little consideration was given to their integration with major vehicular flows. As a result, these spaces are often situated in low-visibility, low-accessibility locations, requiring intentional effort from users to reach them, rather than emerging as natural components of daily urban routines. This lack of integration is further supported by the high proportion of segregated green areas, as measured by configurational analysis indices. Specifically, 44% of green areas in Pisa, 37% in Lucca, and 30% in Grosseto are not located along routes with high local or global betweenness – meaning they do not even lie along commonly used paths or strategic urban connectors.
A notable exception is Lucca, where 80% of green spaces are served however by cycling infrastructure, largely due to the strategic role of the city wall circuit. In contrast, the corresponding figures are significantly lower in Pisa (42%) and Grosseto (19%), contributing further to the spatial detachment – and functional disconnection – of green spaces from the everyday lives of residents.
Altogether, these findings provide a radically different perspective on urban greenery. They underscore the importance of integrating the intrinsic characteristics of green spaces, previously discussed, with their extrinsic conditions to form a more holistic assessment. The following section presents an integrated evaluation framework aimed at discussing the overall suitability – and, in terms of urban liveability, the functional value – of public green areas.

5.3 Integrated assessment

In addition to the separate evaluation of intrinsic and extrinsic characteristics, and the corresponding analyses presented in the two preceding subsections, this section proposes a combined assessment approach aimed at enabling a streamlined, quantitative evaluation of urban green space actual suitability. This is achieved through the prior definition of standardized 'quality ranges'. The process begins with the selection – according to the prior analysis – of parameters impacting green space usability. For each selected parameter, threshold values, classification codes, and typological characterizations were defined and are presented in Tab.2.
Specifically, for the parameter "Class", it was deemed reasonable – within the scope of this assessment – to group certain categories according to their functional and experiential value. The "Park/Public Garden" and "Equipped" features, which typically offer the highest levels of usability and public amenity, were grouped under Category A. Under Category B, of intermediate quality, were included "Sporting" and "Associated with Services" features, as their accessibility is often restricted and their use generally limited, thus not ensuring full or inclusive enjoyment. Finally, Category C encompassed the "Residual", "Traffic-Enclosed", and "Other" features, representing green areas that are either not usable or are of marginal recreational value.
Regarding spatial extent, a minimum area threshold of 200 sqm was confirmed from the intrinsic features analysis. Green spaces below this threshold were considered episodic, minor fragments not indicative of planned or significant public green infrastructure, thus with a lower positive impact on liveability. For compactness, a threshold value of 0.12 was employed, consistent with the findings from the earlier subsection on intrinsic features; this value delineates minimally compact green areas, with an irregular and inconsistent

shape which limits the fruition or the contiguous visibility, thus impacting on the way people can live and perceive them.

	Parameter	Base category	Derived Category	Label	Potential combinations		
Intrinsic features	Class	Park/Public garden Equipped Sporting Assoc w services Traffic_enclosed Residual Other	Park/Public garden Equipped	A	A-hA-hC A-hA-lC A-lA-hC A-lA-lC	B-hA-hC B-hA-lC B-lA-hC B-lA-lC	C-hA-hC C-hA-lC C-lA-hC C-lA-lC
			Sporting Assoc w services	B			
			Traffic_enclosed Residual Other	C			
	Extension	Value [sqm]	> 200 sqm	hA			
			< 200 sqm	lA			
	Compactness	Value	> 0.12	hC			
			< 0.12	lC			
Extrinsic features	Usability	Free Limited Inaccessible	Free	F	F-lc-pk F-lc-npk F-gc-pk F-gc-npk F-s-pk F-s-npk	L-lc-pk L-lc-npk L-gc-pk L-gc-npk L-s-pk L-s-npk	I-lc-pk I-lc-npk I-gc-pk I-gc-npk I-s-pk I-s-npk
			Limited	L			
			Inaccessible	I			
	Centrality	Value (NACH R800) Value (NAC Rn)	Locally central	Lc			
			Globally central	Gc			
			Segregated	s			
	Mobility amenities	Cycleways Parking	Parking	Pk			
			No parking	npk			

Tab.2 Parameters selected for the qualitative assessment, categorization and possible combinations for green public areas.

In terms of extrinsic features, existing categorizations for Public Access ("Free", "Limited", "Inaccessible") and Parking Availability ("Yes", "No") were maintained, as for the measure of accessibility, categorized again into three classes: Locally central, Globally central, and Segregated. In summary, for each green area, Space Syntax quantiles were verified: if the area was within the top 20% quantile of NACH R800, it was categorized as Locally Central; if within the top 20% of NACH Rn, as Globally Central; otherwise, the area was classified as Segregated.

Tab.2 presents the summary of the considered categories and also illustrates the possible combinations of them, delineating the full range of green space typologies emerging from the selected categorizations. In total, 12 types of green areas according to intrinsic properties and 18 types of green areas according to extrinsic properties were identified, which in theory generate a potential number of 216 combinations. Compared to the original dataset (Tab.1), the information on the year of realization was excluded, as it is not qualitatively relevant for assessing current green space quality. Similarly, the presence of cycling paths was omitted, which may initially seem counterintuitive given their role in accessibility. However, in the context of this simplified tripartite classification – Low Suitability (LS), Medium Suitability (MS), and High Suitability (HS) – the presence of a cycling path was not considered a decisive factor in comparison to the more impactful features of Class, Public Access, and Centrality – thus just valuable in a logic of further more in-depth and granular studies. Fig.6 presents the matrix of all possible combinations between intrinsic and extrinsic features of green spaces.

Fig.8 Integrated assessment of the three case studies through the *overall suitability value* categorization and connected infographics.

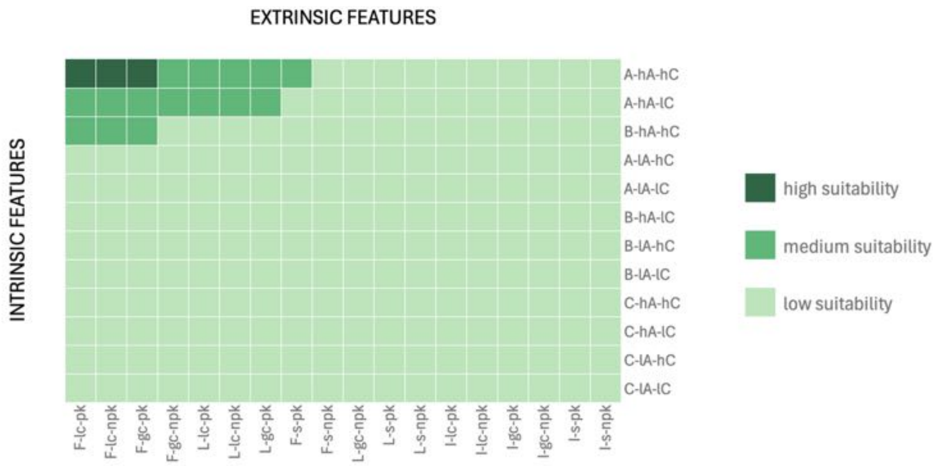

Fig.7 Waffle suitability chart representing the matrix used to categorize the green public areas in High Suitability (HS), Medium Suitability (MS) and Low Suitability (LS).

Intrinsic features are represented along the horizontal axis, while extrinsic features are organized along the vertical axis. High Suitability (HS) combinations are highlighted in light purple (n = 3), Medium Suitability (MS) in purple (n = 15), and Low Suitability (LS) in blue (n = 197). The spatial distribution of this classification is visualized in Fig.8, which allows for a comprehensive evaluation of the overall suitability of public green spaces by integrating both intrinsic and extrinsic characteristics. Additionally, a grouped bar chart illustrates the distribution of HS, MS, and LS green areas across the three case-study cities, expressed both in percentage terms relative to each city's total and in absolute values.

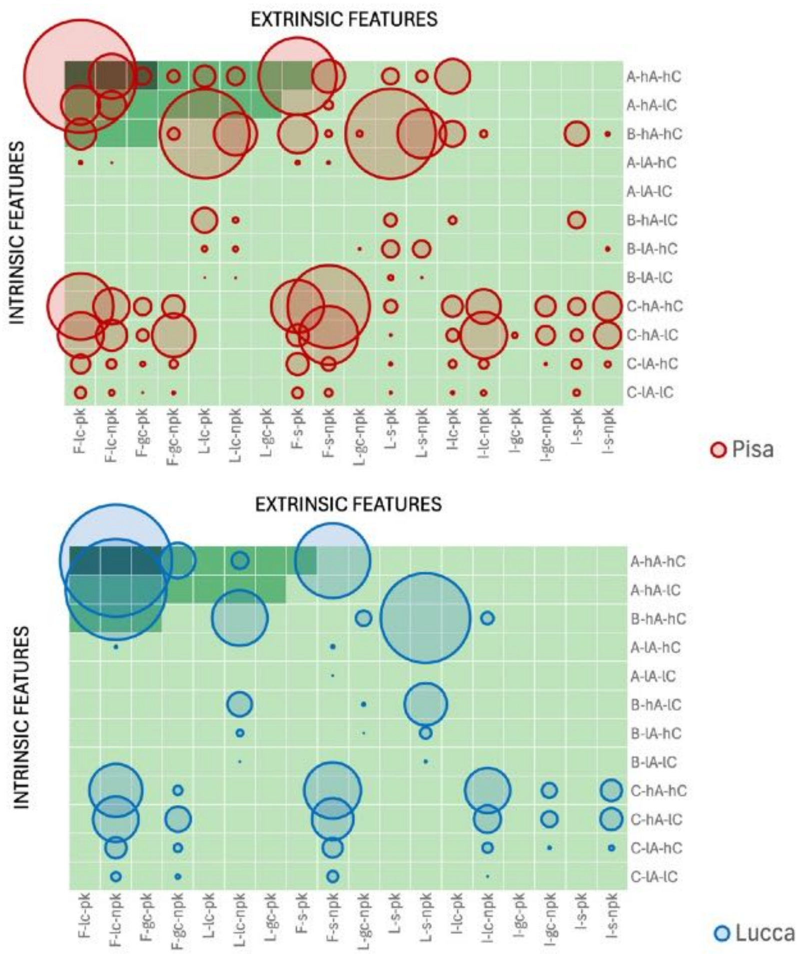

Fig.9 Bubble charts resuming the quantitative amounts (total area) per typology of green areas, obtained by considering both intrinsic and extrinsic features. The overlap with the waffle suitability chart highlights the clustering and prevalent typologies of green public spaces for each case study.

What emerges from this analysis is that only a low amount of urban green space can be considered high valuable in terms of liveability. Specifically, only 16.5% of green space in Pisa, 20.3% in Lucca, and 31.5% in Grosseto falls into the High Suitability category. In contrast, a substantial proportion – 71.8% in Pisa, 60.6% in Lucca, and 58.9% in Grosseto – is classified as Low Suitability, indicating that a significant share of public green areas exerts limited or negligible positive impact on urban liveability.

To provide a final, integrative layer of analysis, Fig.9 overlays variable-sized circles onto the Waffle Chart presented in Fig.7. The size of each circle is proportional to the total surface area associated with each suitability category, enabling a rapid visual interpretation of the typological composition of green spaces across the urban landscape. This visualization also reveals distinct spatial clusters, further highlighting the differentiated distribution of green space types – considering both intrinsic and extrinsic characteristics. By replacing traditional tabular formats, this representation offers a more intuitive and immediate understanding of the combinations of green space properties, serving as a valuable tool for interpreting complex spatial patterns in urban green infrastructure.

6. Conclusions

This contribute proposes an expeditious methodology for assessing the quality of green spaces, defined in terms of the effectiveness of their performance as services for health, recreational, and social activities of the inhabitants. The assessment of such effectiveness was evaluated both with reference to the intrinsic properties of individual areas designated as public green spaces and to the positional properties they actually assume in relation to the urban network and their actual accessibility.

The analyses, carried out on the three case studies of Grosseto, Lucca, and Pisa, showed that the provision of green areas, expressed solely through the numerical values of their extension, is entirely insufficient to provide a reliable indication of their actual performance quality. It emerged in all three cases that a large portion of public green space is of low 'quality' (categories: traffic-enclosed, residual, other), often corresponding to leftover areas along the edges of road infrastructure – spaces that are sometimes inaccessible due to being cut off by road networks, or generally residual elements in relation to built-up areas. The presence of urban parks, actually implemented in accordance with the standards imposed by Ministerial Decree 1444, is yet frequently marked by conditions of segregation from the street grid.

Interesting insights also emerge from the diachronic trend analysis, which shows that after 1968 – despite diverging planning priorities driven by each city's unique historical, urban, and morphological evolution – the typological composition of newly introduced green spaces varies significantly across cities. While Pisa demonstrates a marked shift toward higher-quality green typologies, such as parks, equipped areas, and sports facilities, Lucca experienced more substantial growth in sports areas. Grosseto, within the broader context of general expansion, saw an increase across all typologies, including large areas designated as parks or public gardens. This pattern appears to reflect an attempt to compensate for the limited usability of green spaces by planning extensive park, equipped, or sports areas – even though these are often characterized by poor accessibility relative to their urban context. The findings from the analysis of extrinsic characteristics reinforce this interpretation, highlighting the limited integration of green areas into the urban path network. This is due to their peripheral locations, restricted (or even absent) accessibility, and very weak connections to the cycling route network.

The construction of a composite quality index, integrating both intrinsic and extrinsic characteristics, results in a distribution largely dominated by areas of low quality. The research offers the opportunity for further developments and exploration in various directions – for example, by integrating proximity-based indicators such as NAIN to assess potential supply-demand imbalance, or by assessing the amount of green space available to each resident within a certain distance from their home through the use of ISTAT census data, or by extending the analysis beyond green areas to include linear tree plantings and shaded walkways, thus accounting for green corridors and microclimatic comfort, also in relation to different population groups. These possible extensions would be particularly relevant in relation to the targets and principles outlined in the emerging Nature Restoration Law, which emphasizes ecological connectivity, social inclusion, and equitable access to high-quality green infrastructure.

All of this, while still far from offering a definitive interpretation of the issue, nevertheless provides some useful insights and, above all, highlights the need for a careful and detailed assessment of the settlement and performance quality of green areas – both for evaluating their actual conditions in specific contexts and, especially, for assessing and addressing their provisions within urban development or regeneration plans.

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