# From Fragments to Systems: Mapping Urban Spatial Potential for X-Minute City Planning

Chiara Anselmi(✉), Camilla Pezzica, and Federica Deri

Department of Energy, Systems, Territory and Construction Engineering, University of Pisa, Largo Lucio Lazzarino, 56122 Pisa, Italy
chiara.anselmi@ing.unipi.it

**Abstract.** In contemporary urban planning, fragmented suburban contexts and limited public resources require operational tools able to identify where public spaces and facilities can be introduced with limited conflict, cost, and land consumption. This paper proposes a parcel-based computational decision-support framework for mapping urban spatial potential in X-minute city planning. Taking cadastral parcels as the elementary unit of transformation, the model evaluates land suitability for two distinct targets – open public spaces and built public facilities – through a multi-criteria structure addressing morphology, regulatory framework, ownership and accessibility issues, lot coverage and uses, environmental and landscape constraints. The framework is applied to the suburban area of Massa (Italy), a heterogeneous territory characterized by strong spatial fragmentation, low service provision, and high dependence on private mobility. These conditions make it a particularly relevant testing ground for proximity-based planning approaches, where the challenge lies in activating and interconnecting dispersed spatial resources. Results highlight differentiated spatial potentials for public spaces and facilities, confirming that proximity planning cannot rely on a single transformation logic. At the same time, private interests and ownership emerge as critical structural constraints, emphasizing the need to explicitly integrate property conditions into computational planning tools. The study also outlines how parcel-level suitability can support a network-based interpretation of urban systems, enabling the identification of strategic nodes and connections. This work provides a foundation for future research aimed at adapting the model to different policy scenarios and integrating advanced network analytics, supporting more flexible and context-sensitive implementations of proximity-based planning.

**Keywords:** Urban Spaces · Parcel-based Approach · 15-min city

## 1 Introduction

Ensuring equitable access to public spaces, services, and everyday opportunities has become a central concern in contemporary urban planning, particularly in contexts shaped by dispersed urban growth and increasing pressure on public resources. Within this broader framework, a persistent challenge is the fragmentation of public spaces, which often appear as isolated "islands" within the urban fabric [1]. These disconnected

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areas suffer from severe pedestrian and vehicular accessibility issues, often compounded by parking shortages [2]. At the same time, the debate on public space provision has highlighted the inadequacy of traditional minimum planning standards, which in practice often reduce public amenities to residual green areas or parking lots within private subdivision plans, without any broader city-wide vision [3, 4].

In response to these spatial inequalities, proximity-based planning and the "15-min city" have gained increasing attention [5]. This paradigm is particularly relevant in the suburban contexts of Italian cities, which are often characterized by residential monofunctionality and a strong dependence on private mobility for access to essential services [6, 7]. Within this perspective, the emc2 model provides a useful reference, proposing the transformation of main streets in low-density suburban areas into linear pedestrian corridors enriched by a mix of public and private services, with the aim of enhancing accessibility and revitalizing peripheral neighborhoods [8].

Despite the theoretical appeal of proximity models, a significant research gap remains in the operational tools available for their implementation. Municipalities are increasingly constrained by limited public resources and frequent conflicts with private stakeholders [9, 10]. As a result, implementing the proximity city is not only a morphological issue, but also a matter of property and ownership. Effective local planning cannot ignore existing land uses and ownership structures, since neighborhood-scale regeneration must be grounded in the socio-economic reality of land. This perspective is consistent with the interpretation of cities as complex adaptive systems rather than as products of top-down design [11, 12]. Urban form emerges through the aggregation of localized decisions, many of which take place at the scale of the individual cadastral parcel, which becomes a crucial operational unit, enabling planners to mediate between private rights and collective interests under real spatial and economic constraints [13, 14].

Building on these premises, this study operationalizes the concept of "urban vocation" through a parcel-based computational decision-support model. Rather than prescribing fixed outcomes, the model evaluates current land profiles in order to identify parcels whose existing morphological, regulatory, environmental, accessibility, and ownership conditions make them more suitable for future public transformation. By incorporating legal and economic constraints, the framework supports the identification of opportunities for public intervention while reducing costs and potential land-use conflicts, thus linking bottom-up urban dynamics with strategic planning choices [15].

At the same time, operationalizing the emc2 model requires transformed parcels to function not as isolated opportunities, but as parts of a connected spatial system supporting accessibility, continuity, and daily mobility. For this reason, the study complements parcel-level suitability with a network-based perspective that explores how suitable parcels can relate to one another within a wider proximity system. Relying on network-based measures such as shortest paths or configurational metrics [16, 17], the proposed approach supports the identification of candidate nodes, the evaluation of their connectivity, and the exploration of scenarios capable of maximizing spatial coverage while limiting intervention costs. This ultimately translates the "latent potential" of parcels into operable spatial strategies.

The methodology is tested on the case study of Massa, Italy, a sprawling suburban area between the mountains and the coastline, characterized by fragmented settlement patterns and a marked deficit of public spaces and services.

The remainder of this paper is organized as follows. Section 2 discusses the main issues related to cadastral datasets. Section 3 presents the methodological framework. Section 4 describes the case study area. Section 5 reports and discusses the results of the suitability analysis, and introduces a preliminary facility-facility graph. Finally, Sect. 6 concludes by summarizing the main findings and outlining future developments.

## 2 Dataset-Related Issues

The aim of this contribution is to engage with local-level implementation planning by bringing public regulations into alignment with private action and its management. This requires a fine-grained analysis of urban form, in which the cadastral parcel is treated as the actual decision-making unit of urban transformation.

Recent studies have demonstrated that plot configurations play a decisive role in shaping patterns of physical change, as they constitute one of the main determinants of urban form and actively guide its evolution [18, 19]. Within parcels, form, ownership, land use, and planning rules converge as structural conditions of urban action [20]. Parcels therefore become a policy instrument aimed at balancing individual property rights with collective environmental and spatial well-being.

Although cadastral data represent the official legal reference for taxation and regulatory constraints, they are often outdated and spatially inconsistent with other topographic and open datasets. These discrepancies may result in positional inaccuracies that affect both administrative processes and planning decisions [21–23]. To address this issue, the proposed model does not rely on strict spatial overlaps between datasets. Instead, it introduces tolerance thresholds and rule-based tolerances for each indicator, allowing for a more flexible and robust integration of heterogeneous data sources. This results in a quasi-fuzzy evaluation framework, in which suitability is derived from degrees of proximity and compatibility rather than exact geometric coincidence. Moreover, cadastral parcels do not always reflect the current physical configuration of the urban environment, particularly where land subdivision has already occurred to accommodate infrastructures such as roads, without corresponding updates in cadastral classification or geometry. To resolve this mismatch, the cadastral layer has been reinterpreted through its integration with additional datasets and orthophotography.

Furthermore, the analysis focuses exclusively on parcels within the urban fabric that are realistically susceptible to transformation. Accordingly, the original dataset has been refined by excluding roads, water bodies, and already structured natural elements, which do not constitute ordinary transformation units. Existing public spaces (such as streets, squares, parks, and service facilities, as defined by the Municipal Urban Plan of Massa) are also excluded from the pool of candidate parcels. However, they are not removed from the model; rather, they are retained as structural components of the system and as essential benchmarks for the subsequent network analysis.

## 3 Methods

The proposed decision-support model focuses on identifying suitable locations for public spaces and public facilities in suburban areas, where such provisions are often limited (see Sect. 4). The model distinguishes between transformations into open public spaces and those into built public services, as these two categories respond to fundamentally different spatial and functional logics. While open public spaces are flexible and multifunctional, supporting both social and environmental roles, built public facilities require full compliance with building and infrastructural conditions, including direct accessibility, service connections, and regulatory constraints, resulting in a more limited and structure-dependent locational potential. Within the category of open public spaces, the model considers the allocation of collective outdoor activities, such as public squares and urban parks. Areas explicitly designated for ecological corridors are not treated as a separate output category. Instead, urban greenery is reinterpreted not merely as a residual or standard-based provision, but as a structurally integrated system. In this sense, urban green spaces are conceived as interconnected elements capable of enhancing accessibility and the quality of public space, while simultaneously supporting ecological functions.

The resulting suitability model captures the inherent predisposition of land to accommodate public transformations, avoiding a deterministic interpretation that may fail to capture unfavourable local conditions, potentially affecting the feasibility of the resulting interventions. It adopts a compromise-based approach, in which no configuration is strictly excluded from the set of possible transformations. Lower suitability values indicate increasing levels of implementation complexity, higher costs, or the need for regulatory adjustments, rather than infeasibility. This reflects the incremental and adaptive nature of urban transformation processes, where multiple suboptimal conditions can still be negotiated within a broader decision-making framework.

### 3.1 Suitability Analysis Criteria

The multicriteria decision-making model is based on a set of eight criteria capturing the main spatial conditions influencing parcel transformation. These criteria are designed to represent a different dimension of urban feasibility, including:

- morphological characteristics,
- accessibility and network integration,
- land ownership conditions,
- urban context,
- regulatory constraints,
- environmental factors.

Each criterion is articulated through a set of descriptors, which are subsequently translated into quantitative parameters defining thresholds and spatial relationships (see Table 1). Together, they provide a multi-dimensional representation of the conditions that enable or constrain the transformation potential of each parcel. In the following paragraphs each criterion will be analysed.

**Morphological Development Potential.** This criterion assesses whether parcel form is compatible with feasible urban transformation. Since spatial constraints directly affect

costs and implementation complexity, small, narrow, or irregular plots are generally less adaptable than larger and more regular ones [18, 19]. Feasibility is operationalised through a minimum buildable footprint of 300 m2, calculated after applying a 10-m setback from buildings in accordance with Italian regulations concerning windowed façades (Art. 9 DM 1444/68). Distances from roads and parcel boundaries are not considered fixed constraints, as they can be adjusted within implementation-level planning processes. Additionally, a compactness index ($I_c$ calculated from area and perimeter, following the normalised formulation in Eq. 1) is used to capture the geometric regularity of parcels, with a threshold of 0.25 excluding highly elongated or irregular plots that are less compatible with efficient and standard development conditions [24, 25].

$$I_c = \frac{4\pi A}{P^2} \tag{1}$$

**Regulatory Development Potential.** Beyond morphological constraints, development potential is also shaped by regulatory restrictions unrelated to parcel form. The model therefore includes buffer zones associated with major transport infrastructures, such as highways and railways (30 m), as well as other locally regulated areas and site-specific protected zones, including cemeteries, protected green areas, and DOC/DOP agricultural land. While these conditions may considerably limit private development, they can, where compatible, open opportunities for public intervention.

**Land Ownership.** Adopting a realistic approach, ownership is treated as a structural condition of urban change rather than as a simple contextual attribute, since it determines decision-making power and the actual possibility of transformation [20, 26]. Given the financial limits of public land acquisition and the widespread fragmentation of private property, publicly owned parcels represent a strategic starting point for expanding a continuous and interconnected public urban network [27].

**Road Network Accessibility.** This criterion evaluates the relationship between parcels and the existing mobility network, assuming accessibility to be a necessary condition for effective public intervention. Proximity to roads improves usability and reduces the need for additional infrastructure, although excessive proximity may create safety or environmental concerns for recreational and ecological uses [28–31]. In this study, accessibility is prioritised: parcels with direct or near-direct access receive higher suitability scores, with a 5-m tolerance for geometric inconsistencies and distances beyond 100-m considered poorly accessible.

**Lot Coverage.** Lot coverage is used as a proxy for settlement saturation and, more broadly, for the degree of soil sealing and land artificialisation (LR Toscana 65/2014). In line with the objective of limiting further land consumption, already developed areas are generally considered more suitable for reuse, although no distinction is made here between different types of built occupation. A reference threshold of approximately 30% is adopted as a benchmark for high land occupation ($S_c$), with lower values generally associated with higher transformation potential.

**Land Use.** Land use influences both the feasibility and the appropriateness of intervention, as it reflects existing development conditions, ecological value, and potential acquisition costs. Already artificialised areas are generally more suitable for new public

facilities, whereas agricultural, semi-natural, and natural areas may require preservation, careful management, or lower-impact forms of collective use. Parcels are therefore classified into four categories—artificial surfaces, agricultural land, semi-natural green spaces, and natural areas—representing a gradient of transformation potential.

**Environmental Constraints.** This criterion incorporates the most restrictive and generally non-derogable conditions affecting land transformation, including flood hazard (PGRA), geological hazard (PAI), and protected areas such as the Natura 2000 network. Because these constraints impose significant limits on land-use change, especially in high-risk areas, parcels subject to them show substantially lower transformation potential, particularly for built interventions.

**Landscape and Heritage Constraints.** Site-specific conditions related to landscape quality, cultural value, and spatial identity are addressed through the framework of D.Lgs. 42/2004 (*Codice dei beni culturali e del paesaggio*). These include buffers around lakes, rivers, and coastal areas, as well as forests, woodlands, parks, and listed heritage buildings. Unlike environmental constraints, they do not necessarily prevent transformation, but rather condition its form, scale, and compatibility with existing landscape and cultural values. Parcels not affected by constraints are assigned the highest suitability.

### 3.2 Suitability Analysis Workflow

The model adopts a multi-criteria aggregation procedure to derive parcel-level suitability values from the previously defined criteria. As mentioned above, rather than defining strict suitability thresholds, the approach is designed to capture varying degrees of feasibility, reflecting the incremental and context-dependent nature of urban transformation processes. Each descriptor within a given criterion is assigned a score on a scale ranging from 0.25 to 1, according to its contribution to the suitability for a specific target use. Lower values indicate increasing levels of implementation complexity, cost, or required intervention. No criterion is treated as a strict constraint and no score equal to zero is assigned. Table 1 shows the scoring assessment for all the criteria.

Although each criterion is evaluated independently, their effects on urban transformation are not independent. The feasibility of intervention depends on the combined presence of multiple conditions rather than on their additive contribution. The aggregation is performed through a geometric mean (2) that avoids full compensability between criteria and preserves sensitivity to low-performing conditions without excluding transformation entirely. This results in a compromise-based suitability structure in which all criteria contribute jointly, without generating exclusionary effects. The formulation is applied independently to each target use, namely public space and public facilities, producing distinct suitability outputs. No additional weighting scheme is introduced, as all criteria are conceptualised as "should-have" conditions and are therefore treated as equally contributing factors.

This ensures a non-hierarchical aggregation structure and avoids the introduction of arbitrary prioritisation among criteria. To complement the aggregated suitability score, the model retains information on the most limiting condition affecting each parcel. While the geometric mean provides a synthetic measure of overall suitability, it does not

**Table 1.** Suitability scoring assignment for public spaces and facilities

| Criteria | Descriptors | Parameters | Public Space Score | Public Facilities Score |
|---|---|---|---|---|
| Morphological Development Potential | High development suitability | $A \geq 300$ mq, $Ic \geq 0.25$ | 0.25 | 1.00 |
| | Moderate development suitability | $A \geq 300$ mq, $Ic < 0.25$ | 0.50 | 0.75 |
| | Low development suitability | $A < 300$ mq, $Ic \geq 0.25$ | 0.75 | 0.50 |
| | Unsuitable configuration | $A < 300$ mq, $Ic < 0.25$ | 1.00 | 0.25 |
| Regulatory Development Potential | No constraints | overlap = 0% | 0.25 | 1.00 |
| | Partially constrained | overlap < 40% | 0.50 | 0.75 |
| | Significantly constrained | 40 < overlap ≤ 90% | 0.75 | 0.50 |
| | Fully constrained | overlap > 90% | 1.00 | 0.25 |
| Land Ownership | Private | overlap > 70% | 0.25 | 0.25 |
| | Religious institutions | overlap > 70% | 0.50 | 0.50 |
| | Local government | overlap > 70% | 0.75 | 0.75 |
| | Publicly owned | overlap > 70% | 1.00 | 1.00 |
| Road Network Accessibility | Direct access | $0 < d \leq 5$ m | 1.00 | 1.00 |
| | Limited accessibility | $5 < d \leq 100$ m | 0.625 | 0.625 |
| | Poor accessibility | $d > 100$ m | 0.25 | 0.25 |
| Lot Coverage | High coverage | $Sc \geq 0.3$ | 0.25 | 0.25 |
| | Low coverage | $0 < Sc < 0.3$ | 0.625 | 0.625 |
| | Vacant lot | $Sc = 0$ | 1.00 | 1.00 |
| Land Use | Artificial surfaces | Main use | 0.25 | 1.00 |
| | Agricultural land | Main use | 0.50 | 0.75 |
| | Semi-natural green spaces | Main use | 0.75 | 0.50 |
| | Natural areas | Main use | 1.00 | 0.25 |
| Environmental Constraints | No constraints | (P1, P2, P3, P4) = 0 | 0.25 | 1.00 |

(*continued*)

**Table 1.** (*continued*)

| Criteria | Descriptors | Parameters | Public Space Score | Public Facilities Score |
|---|---|---|---|---|
| | Low to medium-low hazard | (P4, P3) < 20% or (P2) < 40% or (P1) | 0.50 | 0.75 |
| | Medium-high to high hazard | 20 < (P4, P3) < 40% or (P2) > 40% | 0.75 | 0.50 |
| | Severe hazard | (P4, P3) ≥ 40% | 1.00 | 0.25 |
| Landscape and Heritage Constraints | No constraints | overlap = 0% | 0.25 | 1.00 |
| | Partially constrained | overlap < 40% | 0.50 | 0.75 |
| | Significantly constrained | 40 < overlap ≤ 90% | 0.75 | 0.50 |
| | Fully constrained | overlap > 90% | 1.00 | 0.25 |

explicitly identify which criterion is responsible for score reductions. For this reason, a parcel-level criticality indicator is introduced based on the minimum value among all evaluated criteria (3). This value captures the intensity of the most critical condition, directly indicating the degree to which a specific factor constrains the transformation potential of the parcel.

The formulas are defined as follows:

$$S_p = \left(\prod_{i=1}^{n} c_{i,p}\right)^{\frac{1}{n}} \tag{2}$$

$$C_p = \min_i \left(c_{i,p}\right) \tag{3}$$

where:

- $S_p$ represents the suitability of parcel $p$,
- $C_p$ represents the lowest-performing criterion for parcel $p$,
- $c_{i,p}$ is the score of criterion $i$ for parcel $p$,
- $n$ is the total number of criteria (in this case, 8).

In addition, the model records the identity of the limiting criterion through the index:

$$I_p = \arg\min_i (c_{i,p}) \tag{4}$$

which identifies the criterion responsible for the minimum score.

Finally, the two suitability maps are generated by combining all the defined criteria and their respective scores within the proposed framework. Suitability is represented through a discretised colour scale, where darker shades indicate a higher predisposition

for the allocation of public spaces or services, corresponding to lower implementation costs. The entire workflow has been automated through the QGIS Graphical Modeler, ensuring the reproducibility and scalability of the model.

### 3.3 Integrating the Suitability Analysis into Proximity Assessments

The parcel-level suitability model identifies where public spaces or facilities can be delivered at lower implementation cost and conflict. Yet proximity (in the X-minute city sense) depends not only on the qualities of individual parcels, but also on their ability to operate as part of a connected spatial system that supports accessibility, continuity, and daily mobility.

This paper, therefore, begins to explore the integration of parcel-level suitability outputs into a network-based proximity model to evaluate spatial relations among facilities (e.g., park-to-school walking continuity) and their coverage. To this end, it proposes the construction of a facility–facility primal graph model [32] that links each candidate parcel to anchor nodes and to other candidates via available street-network edges. In this model, both the node layer and the edge layer represent suitability-driven potential. Candidate nodes are parcels whose suitability for public spaces or public facilities exceeds a given threshold (i.e., 20% highest values). Nodes that are potentially subject to transformation, inherit the suitability score and criticality index from the parcel model, whereas existing public spaces (e.g., schools, parks etc.) represent fixed anchor-nodes. The edge layer represents accessibility-driven feasibility, restricted to connections within a predefined walking-time threshold (namely 15 min). New edges are dedicated pedestrian and cycle paths. Edge costs are computed as shortest-path walking distances or times, optionally weighted by attributes such as sidewalk quality, safety, slope, or permeability. After selecting candidate nodes, and constructing the cost-distance network (with edge weighting), scenario variants – based on different selection logics (e.g., max coverage, minimum cost, ecological) – can be evaluated using decision-oriented planning indicators (e.g., network accessibility, connectivity, redundancy) appropriate to each case.

Importantly, rather than fully applying this model to the case-study analysis, we illustrate the proposal (to be tested in future studies) through an applied example to clarify the model's foundations and discuss its utility for activating parcel-level feasibility (micro-scale) in support of a spatially grounded evaluation of intervention possibilities at the meso-scale, considering both new nodes and links.

## 4 Case Study

The proposed method has been tested within a selected portion of the Municipality of Massa, extending from the Frigido River to the southern boundary with the Municipality of Montignoso, and from the coastline inland to the hilly areas. Massa is part of the urbanised continuum of the Versilia conurbation. As noted by Mara et al. [33], the progressive merging of the urban fabric across adjacent municipalities has diminished the role of historic centres in favour of broader, system-wide dynamics. However, this process has also reinforced the peripheral condition of suburban areas, concentrating

services within emerging local centres while leaving the interstitial spaces increasingly dependent on private mobility.

The case study is particularly relevant due to the coexistence of multiple urban environments within a relatively limited area. The Frigido River divides the municipality into two distinct parts, while the transversal presence of major infrastructures—namely the highway and the railway—further fragments the territory into sectors with differentiated spatial and functional characteristics. The northern area is predominantly characterised by productive and tourism-related activities, whereas the southern part includes a compact urban centre alongside a suburban residential area marked by dispersed settlement patterns. Between the railway and the motorway, a partially urbanised rural landscape persists, where agricultural uses remain active. In contrast, the area between the motorway and the coastline is characterised by an anthropised pine forest interspersed with low-density residential development, mainly composed of detached houses and villas (Fig. 1). These suburban areas share a common condition of limited provision of public facilities and collective spaces. At the same time, the relatively low level of land consumption makes the area particularly suitable for public-led transformation processes aimed at introducing a coherent network of public spaces and services. As illustrated in the left-hand side of Fig. 1, public spaces and services are predominantly concentrated around the compact urban centre, with a limited number of green or sports-related facilities extending towards the coastal area. A clear deficit of public spaces and services can be observed in the south-eastern portion of the study area, particularly within the sprawling residential areas at the foothills (the Turano neighbourhood) and along the coast (the Ronchi–Poveromo district), as well as within the urbanised rural landscape located between the railway and the highway.

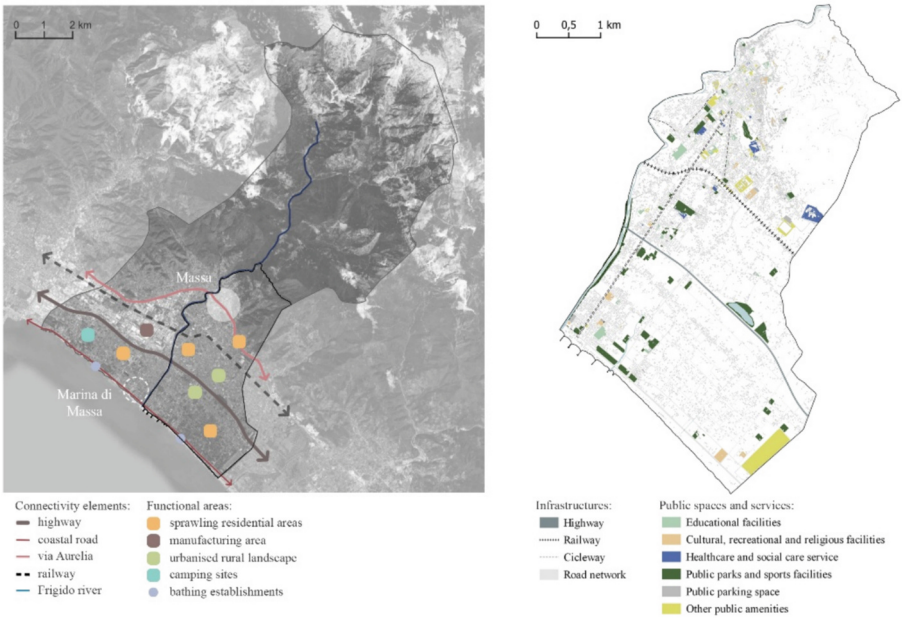


**Fig. 1.** Functional analysis of the case study area within the Municipality of Massa.

## 5 Results and Discussion

The results of the suitability analysis reveal a differentiated spatial pattern in the distribution of potential locations for public spaces and facilities. Overall, the model highlights a distinction between the two types of interventions, confirming the underlying assumption that open public spaces and built public services respond to different spatial and functional conditions.

As illustrated in Fig. 2, a strong potential for open public spaces emerges in the foothill belt and, most notably, in the coastal area of Ronchi–Poveromo. Although parcel size and availability might appear favourable for development, these areas are affected by regulatory constraints and land uses that are incompatible with new construction. In particular, the presence of pine forest and woodland in Ronchi–Poveromo, as well as the DOC Candia wine-producing area in the foothill zone, significantly limits buildability while enhancing the suitability for open public uses. Within the compact urban fabric of Marina di Massa, high density and strong cadastral fragmentation also constrain the possibility of new public building development. A particularly relevant case is represented by the axis connecting the historic centre to the coastal settlement of Marina di Massa, where a marked difference between the two suitability maps can be observed. This axis is recognised as a protected visual corridor (“cannocchiale panoramico”), whose visibility is preserved under DCR 82/2022, thus limiting building potential. Similarly, the area surrounding the artificial lake located above the motorway is subject to environmental and landscape constraints that significantly restrict development, while making it particularly suitable for collective open-air use.

In contrast, the suitability for urban public facilities is more evenly distributed across the central lowland belt. In the urbanised rural areas, despite the strong presence of private ownership, the relative absence of constraints and the low level of land occupation favour the introduction of public facilities, including through new construction.

A closer examination of the criteria affecting suitability reveals that, for most parcels, the most recurrent limiting factor identified by the criticality index ($I_p$) is land ownership. This reflects the predominantly private ownership structure of the area, which represents a major constraint for the implementation of public policies.

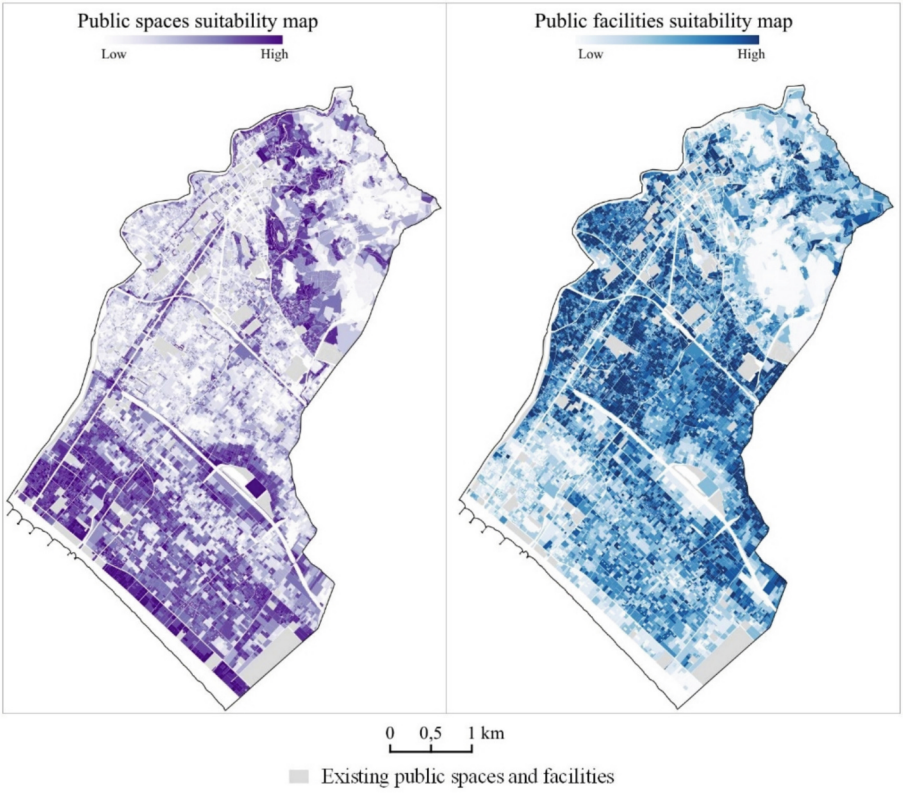


**Fig. 2.** Suitability maps for public spaces and public facilities.

Due to the fragmented distribution of suitable parcels, considering only those allocated to open public spaces makes it difficult to define a fully continuous and integrated network at the scale of the entire study area. However, local opportunities for spatial continuity can still be identified. In the case of public facilities, spatial continuity is easier to achieve, given their concentration in the central areas, although their presence decreases towards the coastal zone. Ultimately, a coherent and effective network can only be achieved through the integration and overlap of the results of the two suitability maps. Given that parcels suitable for built public services may also contribute to the

wider network of public spaces, the analysis reveals a significant potential to support the planning of an interconnected system of public spaces and facilities, enhancing accessibility and addressing the current fragmentation and insufficient provision of public amenities across the study area.

As discussed in Sect. 4, suburban areas are particularly relevant for transformation, as they retain significant room for public intervention due to lower levels of land saturation and service provision, especially within the framework of the 15-min city. An illustrative application is provided by the suburban neighbourhood of Turano, a former satellite of the historic city, characterised by a mix of dispersed settlement patterns and a small, dense core currently lacking adequate collective space.

Considering only the top 20% of suitability values, the Aurelia Road clearly acts as a separator between two distinct urban systems. In the upper part, the compact historic fabric, together with the constraints associated with the foothill condition, primarily supports the allocation of open public spaces. In contrast, the lower part, characterised by lower land occupation and relatively larger parcels, shows a higher potential for the introduction of new public facilities, particularly in the area adjacent to the former wholesale market complex (Fig. 3). This spatial pattern reflects the combined effect of morphological, regulatory, and accessibility conditions captured by the model.

Even from a preliminary observation, a significant deficit of urban green spaces and collective gathering places can be identified, highlighting areas where local service provision could be improved. Notably, the areas adjacent to the school are currently occupied by parking lots, further emphasising the lack of accessible active public space. Considering the full set of most suitable areas, Fig. 3 highlights a high potential for public transformation, particularly in the area south of the Aurelia Road. Here, the concentration of high suitability values suggests the possibility of parcel aggregation, enabling the development of public spaces or facilities at a larger scale. At the same time, multiple opportunities emerge for the creation of an interconnected spatial network.

The following section presents a model representing one possible scenario for network development in this area, derived directly from the suitability-based approach outlined above.

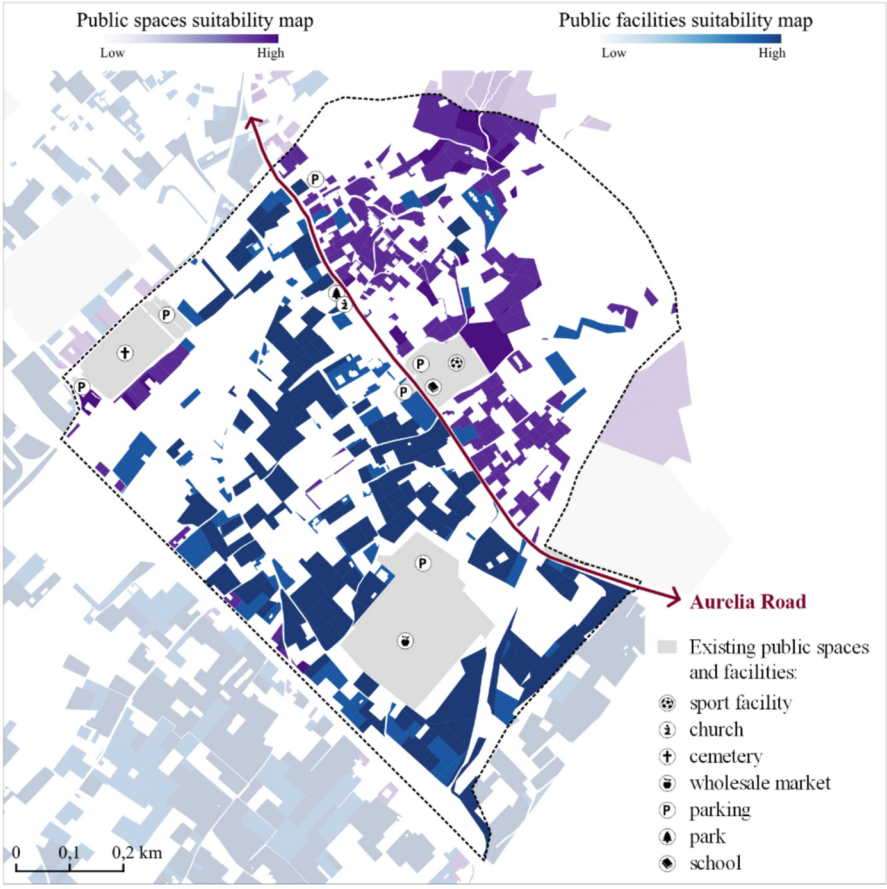


**Fig. 3.** Top 20% most suitable lots for public spaces and public facilities in the Turano study area

### 5.1 From Parcel Suitability to Facility–facility Proximity

This subsection visually demonstrates how parcel-level feasibility can be operationalised through a network model, aligned with the X-minute city framework, which treats the parcel as the generative unit and the network as the integrative mechanism.

Figure 4 provides an initial representation of the proposed facility–facility graph, in which facilities shown in Fig. 3 are modelled as nodes and any pair of facilities is linked by an edge where at least one walking route of less than 15 min exists between them. Outside the study area, connections to the railway station (to the north) and the heart hospital (to the south) have been included, due to the important role of these two infrastructures: the former supports the decarbonisation objectives underpinning the X-minute city model, while the latter has the potential to activate processes of attraction and revitalisation within the surrounding urban fabric.

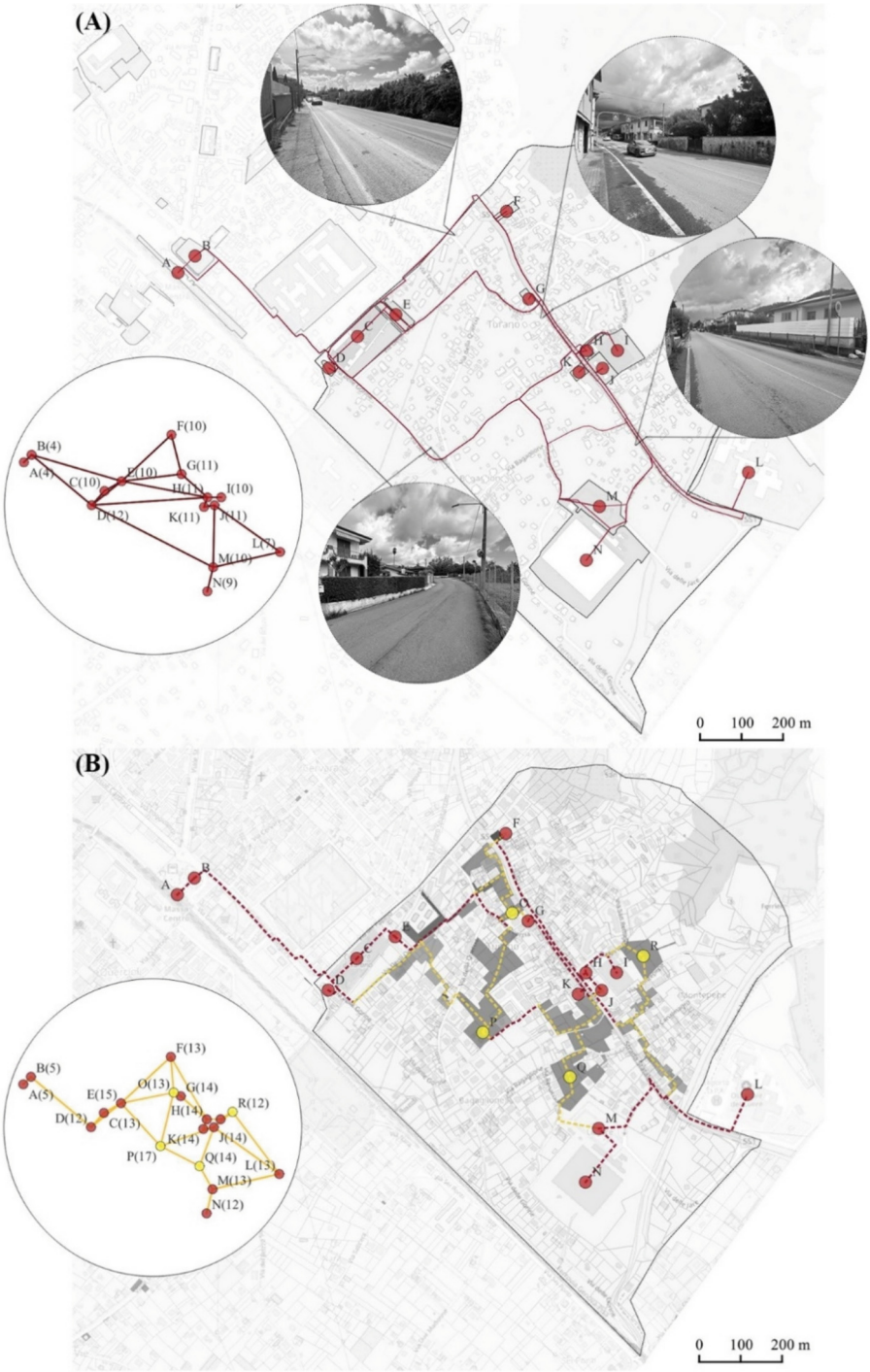


**Fig. 4.** Facility-facility network-based graph model. (A) Current situation; (B) Projected scenario to be assessed.

Figure 4a illustrates the current situation. Although the number of public facilities in Turano is limited, they can nonetheless be interpreted as a proximity network that establishes a baseline "scaffold" for subsequent, decision-oriented scenario-based evaluations. The map shows existing public facilities (red nodes) and the shortest walking connections under 15 min between them (red paths), as returned by *Google Maps* at the time of mapping (March 2026). In its current state, public spaces are unevenly distributed and largely dependent on a limited number of linear connections, with several terminal nodes. Moreover, while some connections fall within a 15-min threshold according to the street network, these routes are not necessarily walkable in practice. Field inspections (see the images in Fig. 4a) revealed a lack of basic pedestrian infrastructure: sidewalks are present along Via Aurelia but remain discontinuous, and are entirely absent on other roads.

Figure 4b then shows a candidate future scenario - to be assessed (e.g., in terms of coverage, cost, and facility centrality). Starting from the top 20% of the most suitable parcels, the scenario combines anchor nodes (existing facilities) with candidate nodes for urban space transformation, together with their network-based connections meeting the same travel-time threshold adopted in Fig. 4a. Connections are enhanced through the introduction of dedicated pedestrian- and cyclist-safe routes, linking both new and existing nodes. In both cases, the basemap is included only to orient the reader; no further spatial statistics, weights, or thresholds are applied beyond the 15-minute cut-off. This representation of the anchor layer (existing facilities), the edge layer (sub-15-minute walking ties), and scenario readiness (candidate facilities plus sub-15-minute walking links) provides a simple entry point for integrating the parcel-level suitability model with a network-based proximity reading, conveying:

- a skeleton of proximity, where existing services already form chains of sub-15-minute connectivity;
- connectivity gaps, where spatial separations exceed walkable thresholds;
- opportunity loci, where the addition of a node or the improvement of a link could bridge weakly connected clusters and strengthen facility-to-facility relationships.

Future work should, therefore, build on this qualitative baseline to support more quantitative evaluations (e.g., via network analytics in Python) of where dispersed fabrics and discontinuous public space would benefit most from targeted service nodes and last-mile pedestrian upgrades.

As noted, this study proposes a preliminary facility–facility graph. The numbers in brackets indicate the proximity-connectivity value of each node, calculated manually by counting the number of shortest paths linking that node to others within the 15-min threshold. In Scenario A, shortest paths are derived from *Google Maps*, whereas in Scenario B connectivity is estimated using path distances and an average walking speed of 4.5 km/h, commonly associated with adult pedestrians [34]. The comparison between the two graphs shows a substantial increase in connectivity in Scenario B, driven not only by the introduction of new public hubs but also by the addition of central connecting routes. Overall, the intervention increases network density, reduces structural vulnerability, and promotes a more cohesive urban system.

In this scenario, the lower area adjacent to the railway is slightly deprioritised, despite the high suitability of some parcels. This reflects emc2-model principles which favour

the concentration of services, activities, and urban life along the main street – here represented by Via Aurelia [8]. Nevertheless, routes that in Scenario A relied on roads within this area can be rerouted onto the new pedestrian-safe network without compromising their 15-min connectivity value.

## 6 Conclusion and Further Developments

This work proposes a parcel-based computational decision-support methodology for mapping urban spatial potential, with particular application to 15-min city planning. Rather than advancing an abstract or purely normative model of proximity, the framework seeks to identify realistic transformation scenarios by taking cadastral parcels as the operative unit and by assessing their effective predisposition to host public spaces and public facilities under existing spatial, morphological, regulatory conditions. In doing so, the methodology brings the 15-min city concept closer to the realities of implementation-oriented local planning, where public action must engage with the material and legal structure of land rather than with idealized spatial configurations. In this sense, the relevance of land ownership is not a secondary aspect, but a confirmation that urban transformation in suburban contexts largely takes place within a fragmented fabric of private property, where the feasibility of intervention depends on the actual constraints and opportunities embedded in land tenure, land use, and development conditions. For this reason, the proposed model is especially suited to local implementation planning, where public objectives need to be aligned with the practical conditions under which transformation can occur.

At the same time, the framework proves to be not only reproducible, thanks to its explicit workflow and criteria structure, but also flexible, since its scoring logic, thresholds, and decision rules can be calibrated according to different planning aims and municipal priorities. This makes it possible to adapt the model to support alternative policy orientations, ranging from more economically driven strategies to more sustainability-oriented scenarios attentive to ecological, social, and public-space quality objectives. In this sense, the framework does not provide a single fixed solution, but a methodological basis through which different public administrations can construct and compare scenario-based strategies according to their own goals and constraints.

Future research should therefore focus on strengthening the robustness and applicability of the framework by improving the integration and spatial consistency of heterogeneous datasets, validating the adopted criteria through expert review and stakeholder interviews, and further extending the model toward more advanced decision-support applications through the introduction of differentiated weights or exclusion thresholds. In particular, parcel-level suitability can be integrated with quantitative network analyses, including facility-level centrality measures (e.g., *closeness*, *betweenness*), as well as street-based representations able to preserve configurational metrics derived from network structure. At the same time, the 15-min accessibility perspective could be broadened beyond walking alone to account for multimodal accessibility and public transport connections, especially those related to strategic nodes such as railway stations. In this way, the model can provide the basis for a more comprehensive and context-sensitive evaluation of how public spaces and facilities may be progressively organized into interconnected proximity systems.

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