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Steering net zero land take urban growth. A decision support method applied to the city of Castelfranco Emilia, Italy

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Abstract. The primary aim of the research is to provide a flexible and easy-to-apply method which makes it possible to identify the most suitable areas to be densified and the most critical ones, where the priority is to maintain green spaces. The method is structured into 5 main phases: collection of relevant indicators, their categorization and weighting through the involvement of experts, normalization and the calculation of synthetic indexes through GIS. The method has been applied on the territory of the medium-sized municipality of Castelfranco Emilia in the Emilia Romagna region, where the Regional urban planning law is forcing municipalities to design urban plans with a clear target of net zero land take by 2050 but can be easily scaled to different contexts. The results clearly show which urban areas are most suitable to be densified and their characteristics hampering or favoring densification.

Keywords: Urban Densification, Urban Planning, Sustainability, Land take, Decision Support tool, Indicators

1 Introduction

Nowadays, cities face numerous environmental problems such as pollution, effects of climate change, depletion of natural resources that affect quality of life of people living in the urban environments. One studied and constantly monitored phenomenon, which contributes to most of these problems is land take, which is considered as the loss of undeveloped land to human-developed land [1]. This phenomenon involves many areas within the European territory, provoking a political response from the European Commission with the EU Environment Action Programme to 2020 (7th EAP) which set the goal of no net land take by 2050 [2]. This is an important milestone for urban planning: soil is considered a non-renewable resource and therefore must be preserved and desealed according to a circular approach. In Italy land take is higher than in the rest of Europe [3], with rate of 6.9% of land taken in 2015, almost 3% above the EU average. This trend is constantly growing: ISPRA reports that by 2021 7.6% of the national territory is consumed (or artificialized) [4]. The values are even higher in some areas of the Italian territory, such as in Emilia-Romagna, one of the most economically dynamic regions and therefore affected by more marked urban development dynamics: land taken due to new infrastructures, residences or, more generally, urbanization is close to 9%, being one of the regions in Italy with highest rates of land take.

To counteract this trend and in line with the European decisions, the Emilia-Romagna Region has decided to drastically limit land take by approving a new urban planning law (LR 24/2017) which introduced a land take target equal to 3% of the urbanized territory in 2017 to be reached by 2050. This represents the maximum overall sizing of the new developments allowed by the new General Urban Plans (PUG) that municipalities of the region will have to approve within 5 years since the LR 24/2017 approval.

It is therefore clear that any forecast of future urban growth in Emilia Romagna must necessarily converge towards densification strategies, which do not consist on an exclusive vertical, compact and quantitative densification but a mixed use densification, which limits land take by increasing existing volumes or reusing abandoned areas or degraded or empty lots within urban boundaries and, at the same time, increasing the quality of the urban environment and life of residents, bringing services, greenery and public infrastructure where they are lacking [5].

Although densification may appear as a winning strategy to improve urban quality and efficiency in monofunctional and low-density contexts [6-7], it might generate a counterproductive effect in contexts where density is already high, in which a further artificialization of the soil or a densification of functions might determine environmental issues, reducing urban green areas and resilience towards climate change effects. Some scholars [8-9] identify a research gap concerning the need to deepen the investigation of densification and its positive and negative effects, with special focus on the loss of green spaces, to develop planning strategies that consider these aspects, therefore this research aims at contributing to overcome this gap.

Starting from these assumptions, the research proposes a method to orient densification interventions towards sustainable scenarios, which do not hamper livability and efficient urban organization and do not undermine the local resources [10]. Therefore, the research questions considered are the following: what are the relevant urban aspects at the basis of the concept of sustainable densification? How to orient sustainable densification processes?

This method is based on calculation and mapping of simple indicators through GIS systems that are summarized in a synthetic index, aimed at quickly identifying the urban areas which are most suitable for densification interventions and those areas that present criticalities that could undermine urban quality. This makes it possible to orient strategies, actions and urban planning rules more effectively, according to specific local constraints, in order to determine sustainable building rights and development conditions afterwards. The proposed method is quite simple with the aim of being easy to be applied by local technicians working in municipalities.

The paper is organized into four main sections: presentation of the method and its main phases, application to the case study of Castelfranco, Italy, presentation of results coming from the method application, discussion of results and conclusions.

2 Materials and Methods

An analytical method, based on a spatial multicriteria analysis (SMA) and a selection of key indicators is proposed. SMA is frequently used for assessing different urban features and scenarios, such as seismic risk and vulnerability [11-14], urban infrastructures [15], mobility patterns [16-19] and the value of urban ecosystem service [20]. In the case of this research, SMA aims to assess which areas are most suitable to be densified or, conversely, which areas must undergo a reverse process to guarantee efficiency and urban livability, i.e., adequate spaces in which the inhabitants are able to meet their expectations in terms of well-being and quality of life. The method is based on five main stages:

1. Collection and clustering of relevant urban indicators, chosen in the sustainability domain.
2. Selection and weighting of the most appropriate set of indicators to measure and describe the process of urban densification.
3. Indicators calculation and mapping.
4. Normalization and final index calculation.
5. Densification assessment.

2.1 1Phase I: Collection and clustering of relevant urban indicators

The first phase of the method focused on collection of relevant indicators capable of measuring urban transformation processes oriented towards sustainability in general and urban densification processes in particular. Therefore, a literature review of indicator-based sources and assessment methods was conducted to identify, on the one hand, the sustainability domains considered as most relevant in the literature and, on the other hand, the most recurrent indicators capable of measuring urban sustainability and the effects of urban densification. The review has been conducted by seeking both relevant scientific literature and nonscientific reports and literature referring to similar frameworks and methods already applied in several contexts and related to sustainable cities and densification.

Sixteen main references were identified [21-34] and a total of 172 indicators were collected and classified into five main domains: environment, spatial planning, social structure, governance and local economy.

The identified domains were further divided into 20 different categories in total and then into 56 parameters, to which one or more indicators were associated. The categories further specify the domains, while the parameters identify the aspect to be measured by the indicators. For each indicator, the "resolution" – municipal or sub-municipal – was also identified to highlight the indicator's ability to show differences within the urban system analyzed. This characteristic was crucial for the final selection of the indicator set, made in the next phase of the method.

2.2 Phase II: Selection and weighting of the most appropriate set of indicators

Starting from the 172 indicators identified, those that were considered key to assessing the suitability of densification interventions were selected. Therefore, the indicators and their parameters and categories were considered in relation to: relevance for measuring direct effects or context conditions related to densification interventions, the ability to detect different situations within the same urban system, and the prevalence of use in the literature. Consequently, 28 indicators were chosen and grouped to form 17 parameters, 8 categories and 3 out of 5 domains among those previously identified:

1- Environment: it comprises categories and parameters related to impacts due to increased densification that could undermine environmental sustainability and livability such as pollution, and performance that can be indirectly improved through densification strategies, such as energy efficiency.
2- Spatial planning: categories and parameters belonging to this domain are fundamental for describing the general framework and organization of the urban context in terms of densities, presence and proximity to services and green spaces, and assessing the sustainability of densification processes.
3- Social structure: indicators relating to social aspects have received little attention so far, even though they provide valuable information on socio-economic fragilities distributed within the city that can be considered in the framework of a just densification. In principle increasing densification that reduce the level of public green spaces and facilities would be more problematic in areas with high socio-economic fragilities than in other areas with similar urban characteristics but with lower levels of socio-economic fragility.

Despite the selection made, the domains identified comprise a vast range of urban topics, with the intention of considering all possible direct and indirect implications that a densification intervention may generate on a given territory.

For each indicator, a brief description, unit of measurement and data needed for calculation are provided. In addition, the direction (i.e. the relationship between the growth/decrease trend and the associated positive or negative condition) was also defined.

Table 1. List of the 28 selected indicators. The last column indicates the direction: (+) the higher the value of the indicator, the more favorable the densification; (-) the higher the value of the indicator, the less favorable the densification.

Domain	Category	Parameter	No.	Indicator	Direction
Environment	Energy	Efficiency	1	Energy performance index.	+
	Pollution	Lighting	2	Light pollution.	-
		Acoustic comfort	3	Population exposed to a daytime sound level above 65 dBA of the total.	-

		Smog and pollutants	4	Inhabitants exposed to emission levels above 40 µg/m3 of PM10 and NO2.	-
Urban Planning	Built environment	Density	5	FAR surface ratio.	-
			6	Population density.	-
			7	Correct urban compactness (built volume / existing public spaces).	+
		Housing asset	8	Age of buildings.	-
		Urban uses	9	Mix use	+
	Mobility and transport	Accessibility to basic services	10	Accessibility to public facilities.	+
		Road reports	11	Road space for public and/or pedestrian transport.	+
		Public transport and shared mobility	12	Proximity to train stations.	-
			13	Proximity to a public transport stop: bus/metro.	-
			14	Proximity to bike sharing stations.	-
			15	Proximity to car-sharing stations.	-
		Cycling network	16	Proximity to a cycle path.	-
		Connectivity	17	Density of road intersections.	+
	Green and permeability	Parks and green areas	18	Proximity to a green space.	-
			19	Proximity to municipal vegetable gardens.	-
		Soil permeability	20	Degree of soil sealing.	-
Social structure	Population	Socio-economic fragility	21	Elderly population (≥65 years) (%)	-
			22	Foreign population (%)	-
			23	Presence and distribution of social housing on the territory.	+
			24	One-member households (%).	-
			25	Households with 5 or more members (%).	-
			26	Average household income	-
		Occupation	27	Employment rate	+

Formation	28	Number of graduates	-

The last task is the weighing of the selected parameters and indicators to highlight any differences firstly between parameters and secondly among indicators used for measuring the same parameter. This task was conducted by involving a group of experts in the field of urban planning. They have been interviewed to evaluate the importance of the selected parameters in leading sustainable densification processes by assigning a weight from 1 (not very relevant) to 5 (very relevant). In case of more than one indicator describing a single parameter, the expert could also rate the indicators if any differences in terms of importance was detected. Experts were also allowed to amend or integrate the list of proposed parameters and indicators. Each indicator and parameter thus received a weight, resulting from the average of the weights obtained by each expert. This task is particularly relevant in the current practice, allowing to consider specific priorities a territory might have.

2.3 Phase III: Indicators calculation and mapping

In addition to the construction of a set of indicators, the assessment model requires the mapping of indicators to highlight the spatial differences of parameters value across the territory, recognizing that the city is a highly heterogeneous environment. For this reason, each indicator is mapped in a GIS environment, through a rasterization process. This task requires the definition of the minimum rasterization cell, which must be chosen according to the urban context to be studied, assuming that it is possible to distinguish the different types of urban tissues, on which the PUG then defines the transformation rules. Each indicator is calculated by considering the identified mesh and will affect only the already urbanized territory, being only the one subjected to densification.

2.4 Phase IV: Normalization and final index calculation

Each of the proposed indicators assesses a specific aspect that positively or negatively affects the sustainability of the urban fabric in terms of density.

To obtain a synthetic picture of suitable urban areas for being densified, a final synthetic index was calculated. The index allows assessing the impacts of possible densification scenarios and is the result of the overlap of each indicator; therefore, it requires that each indicator is normalized before being summed. The normalization process expresses the indicators value in a range from 0 to 1, also taking into consideration their direction. Then each indicator value is multiplied by the weight obtained in Phase II, and the results are summed, in case a parameter is described by more than one indicator. The same procedure is foreseen for normalizing the parameters values and categories values, thus obtaining partial indices by parameter and by category.

The result obtained by this process is a cumulative normalized index, that synthesize the attitude of different urban areas to be densified.

2.5 Phase V: Densification assessment

The normalization and index calculation phase paved the way for assessing the goodness of specific urban areas to be densified by providing diversified and complementary information. The calculation of partial indices by category and eventually by parameter allows mapping and assessing where densification can be allowed or limited according to specific urban features. Indeed, partial indexes mapping is a crucial step for isolating specific aspects and assess how the different areas perform. Consequently, it is possible to identify sustainability conditions and requirements that make densification interventions sustainable once a certain condition has been improved.

The final index mapping expresses an overall aptitude for densification where higher values identify areas more suitable to accommodate densification interventions; conversely, areas with low scores indicate the presence of possible limitations to densification.

3 Application of the method to the territory of Castelfranco Emilia

The procedure has been applied in the territory of Castelfranco Emilia, an Italian town of about 33.000 inhabitants in the Emilia-Romagna Region, Italy. The city is located around 14 km from Modena and 27 km from Bologna. In addition to the main centre, Castelfranco, the Municipality counts eight hamlets: Cavazzona, Gaggio, Manzolino, Piumazzo, Panzano, Rastellino, Recovato, Riolo.

The method has been applied to the first four only, which are the most populated and susceptible to be further developed and densified. The indicators that could be calculated with the data available were 18 out of 28 (no. 1, 2, 5-13, 16-20, 25 and 26). However, they represented a relevant sample of indicators, being able to ensure a good coverage of the different domains and categories identified, as well as having obtained the highest scores in phase II.

The mesh chosen for all the indicators calculation and mapping is equal to one hectare (100x100 mt), representing the basis on which all indicators, partial indices and the synthetic index have been calculated. These tasks have been developed by using GIS. The values of the final synthetic index and partial indices were obtained thanks to a series of normalization operations, including the weights attributed to each parameter and indicator by the experts. The parameters that have obtained the highest weight are: accessibility to basic services, soil permeability, followed by energy efficiency and parks and green areas. Since the experts had the possibility to also weight indicators, those that received the highest weight were proximity to a public transport stop: bus/metro, degree of soil sealing, followed by energy performance index, FAR surface ratio and proximity to a green space.

4 Main results

The maps of the synthetic indicator calculated for the urbanized territory of Castelfranco Emilia were thus obtained. They express the aptitude of the different territorial cells to be densified. The final index obtained is the result of the normalization of the 18 indicators grouped in the different categories and domains and considers the weights provided by the experts. (Fig. 2).

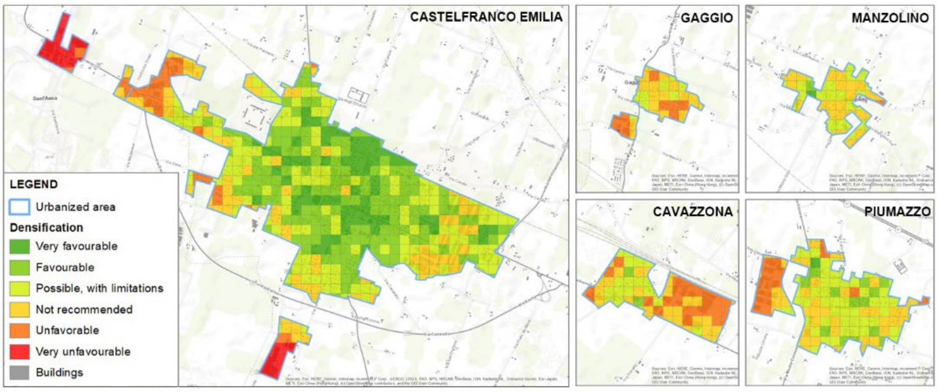

Fig. 1. Mapping of the final index for the different urban areas.

The main centre has optimal conditions for densification but also cells in which this strategy is highly critical. The most central areas, except for the historical core, obtain a very good evaluation to be densified, especially in the areas near the station, located in the north part of the town. Gradually, moving away to the south, east and west, the attitude to host densification interventions decreases. The hamlets, on the other hand, do not appear to be privileged places to be densified: in all the four hamlets the values of the final index obtained refer to medium-low attitudes.

To understand the reasons why a zone has resulted as not suitable to be densified, it is necessary to analyze the performance to densification obtained by category. The mapping of the partial indices calculated by category highlights opportunities or limitations to densification according to specific urban features (Fig 3). Notably each map obtained highlights specific critical issues that must be taken into account for developing more targeted and informed actions. For example, areas of the main centre most suitable for densification are the most served by public transport and the richest in services. On the other hand, if we consider the categories related to greenery or the built environment, the distribution of cells that present optimal situations for being densified is more variable and is not necessarily in favor of most central areas. Therefore the areas assessment is based both on the final and partial indices mapping.

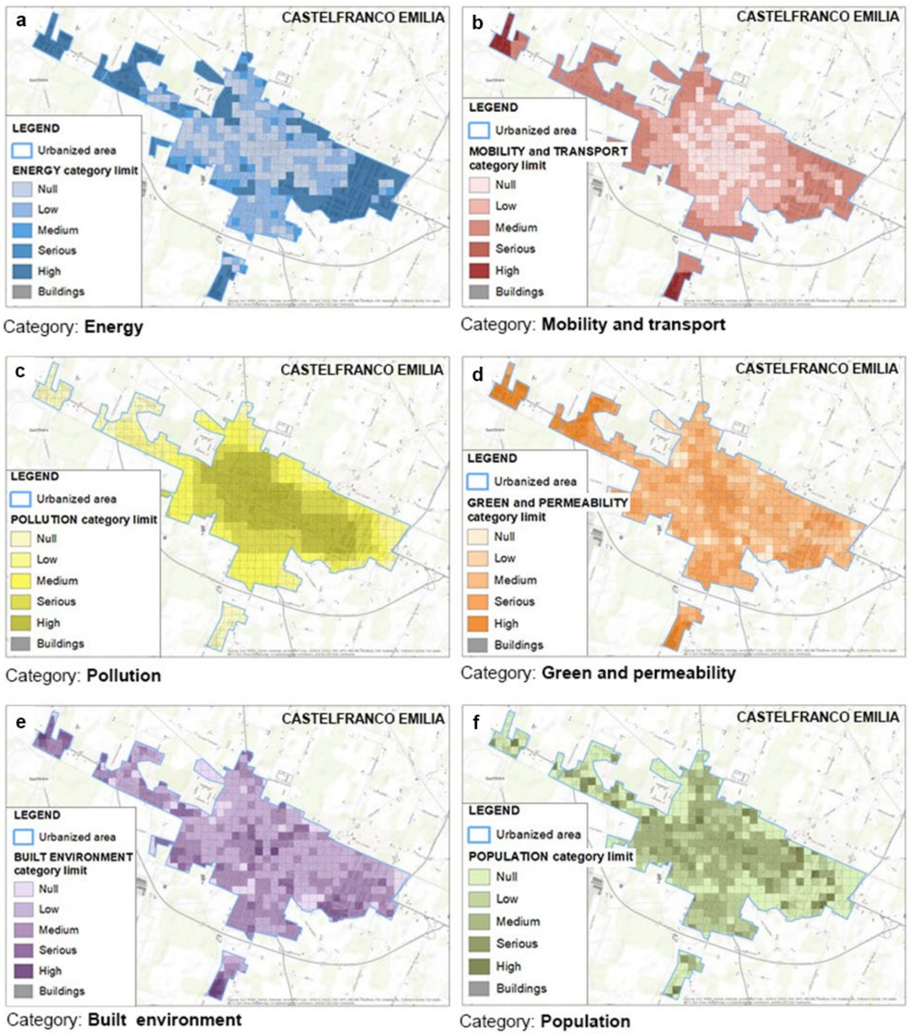

Fig. 2. Maps of the six categories of indicators for the urban area of Castelfranco: (a) energy, (b) mobility and transport , (c) pollution (d) green and permeability, (e) built environment, (f) population. The higher the color intensity, the lesser the possibility to densify.

5 Discussion and conclusion

The method proposed in this study can be a useful tool to guide urban densification strategies, aimed at limiting land take and urban regeneration. Using indicators, which have been weighed by the involvement of experts, the method allows to differentiate the urban tissues according to the greater or lesser attitude to host densification interventions respectful of sustainability conditions. The method therefore proposes the calculation of partial indices, related to each category of indicators, isolating specific causes affecting a greater or lesser attitude of specific areas to being densified. At the same time, the method provides a synthetic index that gives an overall assessment, to allow the planner to take decisions on how to modulate and differentiate building rights depending on the performance achieved by the different urban contexts. The information provided by partial and overall indexes allows planners identifying the causes of low performance and eventually foreseeing sustainability conditions that increase specific performance, making densification interventions sustainable. For instance, if there is a strong criticality regarding the good presence of green and permeability conditions, densification can be possible if the interventions clearly improve the current levels of permeability and greening.

Although the results emerging from the synthetic index mapping as well as from each of the partial indices by category represent a first reference to support decisions in the planning phase, these results must in any case be analyzed and interpreted in the light of context wise factors that have to be considered: it is clear that densifying areas with a prevalence of tertiary or industrial buildings or in the historic center will not be possible or acceptable, therefore they should be eventually discarded. In this sense, the planner plays a crucial role in using the method and interpreting the results obtained.

The set of indicators and indices allows supporting the planning phase by building different densification scenarios. In fact, these indicators can be changed according to different hypothetical strategies adopted and verify if critical situations arise, and consequently adopt corrective measures.

Moreover, the method can be easily adapted and replicated to different contexts thanks to the wide set of indicators collected, that can be further selected both according to the available data and the strategic objectives and priorities that a given territory can manifest. In addition, the planned and implemented weighing process is a key element in adapting the method to different realities, which also identify different priorities in relation to the strategic choices that are made during the drafting of a new urban plan.

Finally, the method is easily applied by technicians who are often unable to do overly complex processing.

Despite its positive aspects already mentioned, the method can be further refined, being a first attempt to systematize relevant indicators to govern densification. Therefore, it has the potential of being improved with more sophisticated analysis, such as the pair correlation analysis, to see if and how the selected indicators influence each other, or by enriching some domains with specific insights, such as the use of simple indicators for mapping ecosystem services and green areas, which are often complex to calculate due to lack of data or structured knowledge.

Moreover it can be integrated into the Strategic environmental assessment (SEA) processes accompanying the municipal urban plans design, to orient the definition of norms managing volumetric right and regulating volumetric incentives in those contexts that can host volumetric addictions without compromising the sustainability of the entire intervention.

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