Context-Based Indicators and Data-Driven Multi-Level Assessments for SDG-Oriented Urban Regeneration

Maria Rosaria Guarini(✉), Giulia Ghiani, Francesco Sica, and Francesco Tajani

Department of Architecture and Design, "Sapienza" University of Rome, 00196 Rome, Italy
{mariarosaria.guarini,giulia.ghiani}@uniroma1.it

Abstract. The paper proposes a multi-level comparative evaluation methodology based on a data-driven approach for urban regeneration processes, integrating the targets of SDG 11 with the dimensions of urban quality through a system of indicators articulated on several territorial scales.

The methodology avoids the construction of a single synthetic index, providing for the construction of a correspondence matrix, within which binary relationships between indicators, targets and urban quality classes are defined, allowing the weighting of variables according to their thematic relevance and spatial coherence. The model combines weighting procedures with variance analysis to identify intervention priorities, which are subsequently interpreted through SWOT analysis. The study highlights the potential of a context-based approach oriented towards impact assessment for urban regeneration processes.

Keywords: Evaluation · Urban Transformation · Sustainability · Indicators

1 Introduction

Urban regeneration processes, in line with the principles promoted by UN-Habitat [1, 2], are oriented towards sustainability and require the adoption of assessment tools capable of interpreting territorial transformations in relation to the Sustainable Development Goals by translating the principles of sustainability into measurable objectives and targets [3–5]. In this perspective, urban planning aimed at ensuring lasting benefits requires an integrated approach, which involves the use of tools and methodologies capable of adapting design choices to the specificities of the territorial context. At the European level, the Nomenclature of Territorial Units for Statistics (NUTS) classification [6] ensures statistical harmonization and comparability between regions and metropolitan areas. However, this system does not exhaust the spatial complexity of urban transformations, which often manifest themselves at the local scale of interventions.

The abundance of urban data and the diffusion of indicator systems do not always make it possible to intercept the complexity of urban processes or to support effective assessments of the actions to be taken. On the contrary, if properly interpreted, the

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2027
O. Gervasi et al. (Eds.): ICCSA 2026 Workshops, LNCS 16765, pp. 262–281, 2027.
https://doi.org/10.1007/978-3-032-30536-7_17

abundance of data becomes an opportunity for innovative approaches to the planning and management of settlement transformation processes [7].

In recent years, numerous information systems have been developed, such as, for example, the global indicator framework of the 2030 Agenda for Sustainable Development [8, 9], and the database developed by Eurostat [10] which makes it possible to monitor the achievement of the objectives of the European Green Deal [11] by means of twenty-six indicators including, for example, the net index of greenhouse gas emissions, the total economic losses related to climate events and primary energy consumption. These are flanked by numerous thematic databases and territorial observation systems, such as the European Copernicus programme [12], which provides environmental and climate information through satellite remote sensing systems, and services that can be integrated with mapping systems and GIS platforms and territorial geoportals. Classification systems and guidelines for the evaluation of the quality of urban regeneration interventions are also relevant, such as those proposed, for example, in Italy by AUDIS, which identify categories of analysis referring to the environmental, economic, social and morphological-functional dimensions of urban transformation [13]. These approaches are consistent with several international protocols for assessing the urban quality and sustainability of interventions, including the LEED for Cities and Communities, BREEAM Communities and the ITACA Urban Scale protocol, which propose multidimensional frameworks for the evaluation of urban performance and settlement quality [14–16]. Considering the growing availability of data and evaluation tools, there is a need to integrate them into methodological models capable of selecting indicators consistent with both the specificities of the territorial context and with the evaluation objectives of urban transformation processes. GIS-based multi-criteria decision analysis (MCDA) has become increasingly relevant in urban planning studies. These approaches are particularly useful for assessing accessibility, environmental quality, land-use suitability. GIS-MCDA models support the identification of spatial criticalities and potentialities by combining quantitative indicators with territorial representations [17–19]. The study aims to define a multilevel evaluation model aimed at identifying a set of indicators consistent with the evaluation purposes of urban regeneration processes, taking as a reference the targets of the SDGs [20], with particular attention to SDG 11 “Make cities and human settlements inclusive, safe, resilient and sustainable”. The proposed method is based on the integration of the NUTS classification systems and the Local Administrative Units (LAUs) adopted by Eurostat, taken as a reference structure for the organization and reading of data. This approach makes it possible to build a coherent analytical framework across different administrative scales, facilitating the harmonization of information and its comparability. In this context, the methodology has been defined in such a way as to ensure coherence, transferability and replicability, and has been applied to a case study in order to verify its operational effectiveness and ability to support evaluation processes oriented towards the definition of urban regeneration strategies. The paper is structured into three main sections. The first section presents the methodological framework, articulated into four phases. The second section applies the methodology to a case study, following its different stages. Finally, the third section discusses the results and presents the main conclusions.

2 Metodology

2.1 Methodological Process

The proposed methodology is based on a comparative and multilevel approach aimed at identifying multidimensional and multiscale indicators that allow to express evaluative judgments aimed at supporting the definition of strategies and actions aimed at improving the conditions present even in contexts on a limited territorial scale. The aim is to interpret the existing conditions and support the identification of priority actions in urban redevelopment processes. The approach assumes an integrated logic that operates simultaneously on two dimensions: a vertical one of a sectoral nature, referring to the different components of sustainability, and another horizontal, of an intersectoral nature, oriented towards grasping the interrelationships between social, economic and environmental aspects. To avoid sectoral readings of urban phenomena, the interpretative framework of the methodology takes as a reference the United Nations Sustainable Development Goals [21]. In particular, the analysis focuses on Goal 11, which promotes the development of sustainable cities and communities and identifies a series of targets directly related to urban transformation processes. The adoption of this reference framework makes it possible to translate global sustainability objectives into operational territorial parameters and to build an evaluation system consistent with the main dimensions of urban quality. After defining the assessment objectives, the methodological process does not provide for a rigid distinction between the analytical phase and the interpretative phase but is configured as an iterative path in which the different phases interact and overlap, as in Fig. 1 [22, 23].

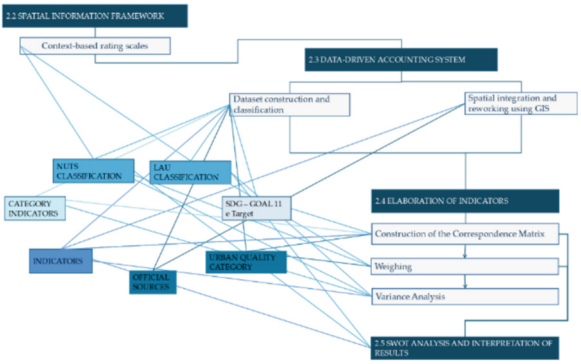

Fig. 1. Methodological process – Source: own elaboration

Context analysis (2.2. Spatial information framework), the construction of the data-driven accounting system (2.3) [24], the elaboration of the indicators (2.4) and the SWOT analysis and the subsequent interpretation of the results (2.5) are in fact interconnected moments of a single evaluation process. This approach makes it possible to structure an analytical framework consistent with the objectives of urban sustainability and to support the definition of strategies and actions aimed at improving the present conditions and

future prospects of the territorial context analyzed, as well as, after their implementation, to measure the results obtained [25–28].

2.2 Spatial Information Framework

The construction of the methodology is placed within a conceptual and informative reference framework that provides for the systematic consultation of institutional and official sources as well as the use of databases recognized at national and European level. From the point of view of sustainability goals, SDG 11 – "Sustainable cities and communities" and its targets (11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.a, 11.b, 11.c) are identified as an interpretative reference. This framework represents the context within which the data are selected and the system of indicators used in the evaluation process is built. The main sources of information include Eurostat databases, permanent population and housing censuses produced by national statistical institutes and public geoportals of spatial and environmental data, including those made available by ISPRA [29] and the Copernicus program. These sources provide access to demographic, social, economic, infrastructural and environmental information covering a recent and consistent time frame. The use of official sources ensures the comparability of data and allows them to be integrated into a multilevel information system consistent with the territorial classifications adopted at European level. Within this process, it is important to distinguish between data and indicators. Data represent the basic information derived from statistical and territorial sources, while indicators are variables obtained through the processing or aggregation of such data and are used to represent and measure specific urban phenomena. The indicator system enables the construction of a synthetic representation of territorial dynamics and supports the subsequent evaluation phase.

Context-Based Rating Scales

Objectives and magnitude of the intervention determine the evaluation's territorial basis for interpretation. The NUTS (Nomenclature of Territorial Units for Statistics) classification is used at the European level to ensure statistical data comparability and support economic and social cohesion policies. This classification has four territorial levels: NUTS 0 (State), NUTS 1 (regional areas), NUTS 2 (subdivision of the previous level into large territorial areas: north, south, centre), and NUTS 3 (subdivision into circumscribed territorial areas, e.g. metropolitan areas) to interpret socio-economic and territorial dynamics at different scales. These levels are flanked by Local Administrative Units (LAU), usually municipal, which execute numerous local regulations and urban planning instruments. Along with these levels, a sub-LAU scale is created for analytical reasons to characterise special phenomena in certain parts of the municipal territory that often do not match urban transformation intervention regions. This scale, which can be subdivided, is not part of Eurostat's classification but can help analyse urban and social dynamics. Data may refer to territorial boundaries that do not necessarily overlap. This condition necessitates an interpretative strategy that accounts for spatial information's multidimensionality and integrates data across scales.

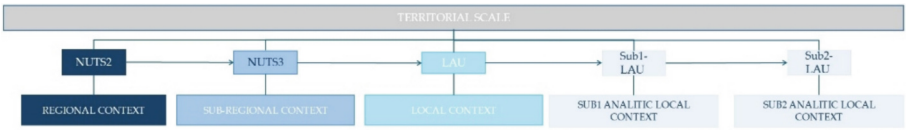

Fig. 2. Territorial scale– Source: own elaboration

2.3 Data-Driven Accounting System

Based on the previously defined reference framework, the available level of information is recognized in order to build a dataset that is consistent with the evaluation purpose. The selection of data/indicators follows three main criteria:

- Territorial coherence in relation to the NUTS/LAU/subLAU hierarchy and the scale of the intervention object;
- Temporal consistency with datasets of recent time frames;
- Relevance to the evaluation objectives by directing the selection towards data relevant to the environmental, social and economic dimensions of urban sustainability, as well as to the targets of SDG 11.
- The survey also makes it possible to verify the type and level of detail of the information available, as well as the presence of data and indicators already georeferenced, an important element for integration into the geographic information system.

Depending on the characteristics of the information available, the indicators derived from the data can be traced back to three main analytical categories, as in Fig. 3.

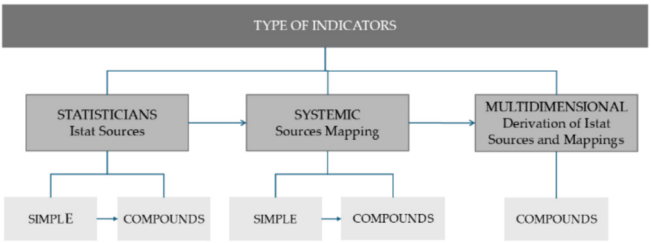

Fig. 3. Type of indicators – Source: own elaboration

In particular, indicators can be divided into different categories according to their nature and the way in which they are constructed. A first category is made up of statistical indicators, which derive from official sources and describe phenomena that can be quantified through direct numerical values. Within this category, it is possible to make a further distinction between simple indicators, when they derive directly from a single data or statistical indicator, and composite indicators, when they derive from the combination or relationship between two or more data or indicators, as in the case of population density. A second category includes systemic, or spatial, indicators derived from official maps and cartographic sources. These can be distinguished into simple indicators, based on direct measurements (e.g., green area per zone), and composite indicators, resulting from the combination of multiple spatial variables (e.g., the ratio between built

and total area). Alongside these, multidimensional indicators integrate statistical and spatial data, enabling a more comprehensive interpretation of urban dynamics. They are particularly relevant in the final analysis phase, as they capture multiple dimensions of the urban context simultaneously. The identification and classification of available information support the construction of a coherent dataset, enhancing the transparency of the evaluation process and providing the basis for assessing the potential impacts of urban transformation processes.

Dataset Construction and Classification

Based on the reconnaissance, the dataset is built and the systematic classification is carried out (Table1). This step allows you to verify the consistency between the level of information available and the objectives of the evaluation to identify the possible need to develop additional indicators.The dataset construction phase translates the criteria identified in the analytical survey into an organized information structure, functional to the subsequent evaluation processing. The purpose of the indicator system is not only descriptive, but also interpretative, as it allows us to build a structured representation of the intervention area and supports planning-oriented assessments.

The construction of the dataset includes a set of common descriptive fields so that each indicator is equipped with a card with the following fields indicated:

- Indicator ID: Progressive number of indicators;
- Indicator: Indicator name;
- Source Survey: source from which the indicator was found;
- Description: Information content of the indicator;
- Determination of the Indicator: formula or method of calculation (method);
- U.M: unit of measurement.

This structure enables the methodological traceability of each indicator.

Each indicator is explicitly associated with the territorial scale of origin, in line with the NUTS/LAU/sub-LAU hierarchy previously defined (Fig. 2). The assignment of the scale is not for descriptive purposes but allows the consistency between the level of the indicator and the level of the intervention to be verified and the subsequent multilevel aggregation to be arranged. At the same time, each indicator is qualified according to the nature of the data, distinguishing between statistical, systemic, and multidimensional indicators as shown in Fig. 3 that they allow you to interpret several dimensions of the urban context simultaneously. The resulting dataset is structured as shown in Table 1.

Table 1. Data Framework - Source: own elaboration

Id	Indicators name	Source	Description	Method	U.M	NUTS 3	LAU	SubLAU	Indicator Statistical (ST)	Indicator Systemic (SY)	Indicator Multidimensional (MU)
n.ID1											
[…]											
n.IDn											

Spatial Integration and Reworking Using GIS
To ensure a context analysis consistent with the evaluation purpose, and therefore the object of transformation, the possibility of producing GIS elaborations aimed at deriving spatial indicators at the local scale through proximity analysis, accessibility analysis and calculation of territorial metrics is envisaged to obtain relevant information at the level of the evaluation under analysis and thus make context-based impact assessments possible. These multidimensional indicators play a fundamental role in describing the functional structure of the intervention area and in identifying the spatial conditions that can support or hinder future urban transformation processes. The information adequacy of the dataset is ascertained by means of a survey in relation to the coverage of the main analytical dimensions of the evaluation system (environmental, social and economic), guaranteed by the availability of indicators referring to coherent territorial levels (LAU and Sub-LAU). On this basis, the correspondence matrix is constructed.

2.4 Elaboration of Indicators

Construction of the Correspondence Matrix
The phases of the methodology indicated so far make it possible to obtain a system of indicators consistent with the scale of the object of intervention. To assume an evaluation function, the criteria identified must be verified in relation to the reference framework articulated in the three dimensions of sustainability and in the targets of SDG 11. To this end, this framework is translated into a multilevel interpretative structure, which allows the different levels of analysis to be organized and related. On this basis, the methodology provides for the construction of a correspondence matrix (Table 2) aimed at explaining the relationships between the criteria considered – the targets of SDG 11 pertinent to urban regeneration processes, the urban quality classes, the territorial level of availability or derivation of the indicator – and the components of the framework.

Table 2. Correspondence matrix - Source: own elaboration

Indicator	SDG 11	Urban Quality Classes				Territorial level		
ID	Target	Urban planning and Architectural	Social	Economical	Environmental and Energy	NUTS	LAU	SubLAu
n.ID1	T.n	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
n.ID2	T.n	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
n.IDn	T.n	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No

The correspondence matrix is constructed by assigning a relationship between indicators and targets of the SDGs and between indicators and categories of urban quality and territorial level, based on the conceptual alignment identified in the planning frameworks.

Weighing
Based on the results of the correspondence matrix, the indicators considered most significant for the purposes of the evaluation are selected, as they are more aligned with

the targets of SDG 11 and can be traced back to the main categories of urban quality. Weighting involves assigning weights to the selected indicators considering the following criteria:

1. *Number of SDG 11 targets to which the indicator contributes*: to each iA score equal to the number of SDG 11 targets to which it is aligned is assigned. For example, an indicator that contributes to two targets receives a score of 2; if it contributes to six targets, it receives an equal score of 6.
2. *Number of urban quality classes affected by the indicator*: the score corresponds to the number of urban quality dimensions affected by the indicator. An indicator that responds to two classes receives a score of 2; if it affects four classes, it receives a score of 4.
3. *Territorial level of availability or derivation of the indicator:* the attribution of the score is calibrated in relation to the evaluation purpose and the scale of the intervention analyzed. The score is awarded in relation to the number of scales considered for each indicator: 1 point for one scale, 2 points for two scales, 3 points for three scales and 4 points in the case of a higher number of scalese.

The "raw" weight of the indicator is determined as the sum of the three components:

Weight W_i= (number of SDG targets involved) + (number of quality classes involved) + (scale coefficient). Since the sum of the three components can generate heterogeneous values, the raw weights are then normalized to a scale of 0–1 to ensure comparability in the aggregation phase:

$$w_i = \frac{w_i - w_{min}}{w_{max} - w_{min}}$$

Standardization makes it possible to make the weights of the indicators within the evaluation system comparable.

Variance Analysis

The analysis of deviations is applied only to the indicators selected as significant and aims to assess the relative positioning of the intervention area with respect to the higher territorial levels. For each selected indicator, a comparison is made between average values on the NUTS 2, NUTS 3, LAU, sub-LAU scales. The relative deviation is expressed as a percentage change with respect to the reference level, in order to identify conditions of advantage, delay or criticality. This multilevel comparison makes it possible to avoid isolated readings by highlighting regional and metropolitan dynamics, reinforcing the context-based approach of the methodology. To make the reading comparable, the deviation can be expressed as a relative change from the reference level:

$$\Delta_i = \frac{V_{area} - V_{ref}}{V_{ref}}$$

The deviation is integrated with the weighing to build, for example, a priority criterion that will be included in the subsequent SWOT analysis:

$$P_i = w_i \cdot \mid \Delta_i \mid$$

The indicators can thus be read by integrating, where possible, the normalized weight and the deviation from the territorial level of reference. This priority index makes it possible to combine the relevance of the indicator in the evaluation system with the intensity of the deviation, supporting the identification of the main critical issues and potential of the area according to their significance for the urban regeneration process.

2.5 SWOT Analysis and Interpretation of Results

SWOT analysis is not used as an autonomous qualitative assessment tool, but as the strategic interpretation phase of the quantitative evaluation process. Weighted scores and multi-level deviations are translated into strengths, weaknesses, opportunities, and threats, based on weighted synthesis [30–33]. In the phase of analysis of the deviations, the value of the indicator calculated for the area of intervention is compared with the territorial reference levels. If pedestrian accessibility to commercial services in the project area is higher than the average territorial levels, these indicators can be interpreted as Strengths of the urban system, as they highlight the presence of a good supply of proximity services and an urban structure favorable to pedestrian mobility. On the contrary, if the indicator shows a negative deviation from the territorial context, it can be classified among the Weaknesses of the urban system, indicating a lack of proximity services or poor pedestrian accessibility to commercial polarities or the data is not available at that territorial level. The SWOT does not take on a merely qualitative character but represents the interpretative translation of a structured evaluation process allowing the identification of priorities for intervention, or not, to support the definition of *ex ante* scenarios, *in itinere* and the *ex post* verification of urban transformations. The final output of the multilevel assessment methodology therefore consists of a decision-making framework consistent with the targets of SDG 11, with the urban quality classes and with the territorial specificity of the area subject to intervention.

3 Demonstration Case

3.1 Definition of the Evaluation Objectives

The evaluation methodology described above is applied to a case study for the definition of a possible urban transformation in the metropolitan city of Rome. The structure of the methodological application to the case study explicitly follows the phases and subparagraphs defined in the Methodology section, to ensure consistency, transparency and replicability of the evaluation process.

3.2 Spatial Information Framework

The area subject to application is the district of *Nuova Ponte di Nona*, falling within the Municipality VI of Rome, falling mainly in the Length (8E) urban area and *Acqua Vergine* (8D) for a small portion. It is an urban area, with a predominantly residential fabric, developed since the early 2000s, with the presence of significant commercial polarity (East Rome) and with an urban configuration that highlights morphological

discontinuities. As an interpretative reference, SDG 11 – "Sustainable cities and communities" and targets 11.1, 11.2, 11.3,11.4,11.5,11.6,11.7, 11.a, 11.b,11, c, as reported above in the methodology considered most relevant to metropolitan urban regeneration processes, are applied. The explicitness of the targets in this phase does not have descriptive purposes, but constitutes the basis for: guiding the selection of indicators, verifying the thematic coverage of the dataset, building a correspondence matrix that makes heterogeneous data comparable with respect to shared and measurable objectives.

Context-Based Rating Scales

In line with the multilevel approach, the area is framed within the NUTS/LAU/sub-LAU territorial hierarchy, identifying the levels of comparison of data and indicators useful both for contextual reading and for the analysis of deviations (Fig. 4). In this framework, for the case of intervention, the availability of data referring to two analytical sub-LAUs (Fig. 4) has been identified, which allow to describe, analyze and represent the socio-economic phenomena of the urban scale within which the perimeter of the intervention area is located.

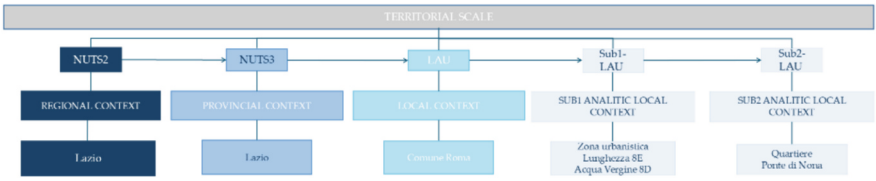

Fig.4. Context-based rating scales: Ponte di Nona - Source: own elaboration

3.3 Data-Driven Accounting System

The data collection was conducted by integrating official statistical sources and georeferenced territorial databases, to build a coherent multilevel information system.

The socio-demographic and housing data were obtained from ISTAT sources grouped in the Statistical Annex (16–12-2024) [34, 35] which contains the permanent census of population and housing, in particular updated data on resident population, age structure, households, housing status, indicators of socio-economic hardship and density.

From these sources, 62 indicators were found available on the LAU scale (Municipality of Rome) and on the two analytical articulations sub1-LAU1 (urban areas 8E and 8D) relating to: total resident population and by age group; incidence of foreigners; population density; number of families; housing crowding index; employment/unemployment indicators. Among the available indicators, those referring to the 8E area were selected, as the data relating to the 8D area, limited to the small portion of the urban fabric in which Ponte di Nona falls, were not sufficiently representative for the purposes of the analysis. From the Geoportal of *Roma Capitale* [36] 28 indicators were extracted on a sub2-LAU-scale relating to: i) public services (schools, libraries, health facilities; ecc); ii) small equipment (fountains, dog areas, parking, columns, ecc).Although some of the indicators are also available at higher territorial scales, the analysis was conducted

with reference to the sub2-LAU scale, corresponding to the Ponte di Nona district, as it coincides with the intervention area. Consequently, for the purposes of the evaluation, the indicators referring to this level were selected and processed as a priority, ensuring consistency between the information base and the scope of application.

Dataset Construction and Classification

In line with the methodology, the dataset is constructed in such a way as to organize the available information as an information base for the evaluation phase (Table 3). Each indicator is associated with a descriptive sheet that explains an identification code, the indicator, the source, the description, the method of determination, the unit of measurement, the distinct territorial scale as in Fig. 2 and the type subdivided as in Fig. 3.

Table 3. Extract of the compiled dataset - Source: Own Elaboration

Id	Indicator	Source	Description	Method	U.M	LAU	Sub1 LAU	Sub2 LAU	ST indicator	SY indicator	MU indicator		
1	Population density -	Istat, Territorial Bases - Year 2021	Ratio between the population residing in the area and the relative surface area in square kilometers of the area	Density = population/area	ab/km^2	Yes				Yes			
2	Total resident population	Istat, Census of population and housing Territorial Bases - Year 2021	Total population excluding homeless	point value from the Cesus/Registry	n	Yes	Yes		Yes				
[n]		[…]	[…]	[…]	[…]	[…]	[…]	[…]	[…]	[…]			[…]

Of the 90 indicators identified, 62 are directly available at the LAU and sub1-LAU scales and contribute to the definition of the socio-demographic framework of the context (SDGs 11.1, 11.3). The remaining 28 indicators of a territorial nature are not immediately available in the required form and require derivative processing, as they are aimed at representing spatial relationships and functional characteristics of the territory. To this end, spatial analysis techniques such as geographically based counting and proximity analysis using GIS tools are used.

Spatial Integration and Reworking Using GIS Tools

In order to obtain quantitative and qualitative information on the area under study, in this case coinciding with the sub2-LAU classification, and to bridge the gap between the administrative scale of the data and the actual scale of the urban intervention, GIS elaborations were carried out that allowed to derive more specific indicators at the local scale through: precise allocation of equipment; buffer construction (300–500 m); calculation of pedestrian isochrones (10–15 min); calculation of percentage indices (built area, land consumed).

The use of GIS software has made it possible to obtain new derived information, such as proximity and accessibility to public services, the distribution of green areas, or

the percentage of housing built in the area. The spatial measurement of indicators was carried out through GIS-based processing at the sub2-LAU scale, corresponding to the intervention area. Buffer distances of 300–500 m and pedestrian isochrones of 10–15 min were adopted to approximate neighborhood-scale accessibility conditions. In particular, 12 multidimensional indicators have been identified, considered sufficient to represent the main dimensions of the urban system as they allow us to build a detailed analytical description of the intervention area, integrating the contextual information provided by the indicators available at the higher territorial levels. In the case study analyzed, the availability, albeit limited, of indicators derived from the scale of the intervention area made it possible to orient the evaluation towards this territorial level, as it is more consistent with the actual scale of the urban transformation process. The sufficiency of the information of the dataset was verified by checking the coverage of the main analytical dimensions of the evaluation system (environmental, social and economic), which were adequately represented by indicators of the Sub2-LAU level. On this basis, the correspondence matrix was constructed.

3.4 Elaboration of Indicators

Construction of the Correspondence Matrix

To avoid sectoral readings and link the global objectives to local urban specificities, the SDG framework is integrated with the urban quality classes recognized in many classification systems and guidelines for the evaluation of the quality of urban regeneration interventions and in the AUDIS framework, divided into: urban and architectural quality, social quality, economical quality, environmental and energy quality. The integration of SDG 11–urban quality, applied within the NUTS/LAU hierarchy, constitutes the interpretative basis for the application analysis. The correspondence matrix developed for 102 (68 statistical, 28 systemic, 12 multidimensional) indicators to which correspondence to the target and to the indicated urban quality is associated. This operation allows to select the indicators most consistent with the evaluation system, which will subsequently be used for the SWOT analysis and for the evaluation phase. Table 4, by way of example, shows some indicators selected by category, to illustrate the method of association between indicators, SDG 11 targets, urban quality classes and territorial levels adopted.

Table 4. Extract Correspondence matrix – Source: own elaboration

Indicator	SDG 11	Urban Quality Classes				Territorial Level		
ID	Target	Urban planning and Architectural	Social	Economical	Environmental and Energy	LAU	Sub1 LAU	Sub2 LAU
[…]								
ST6	11.3			Yes				Yes
[…]								
ST8	11.3		Yes				Yes	
[…]								
ST18	11.3		Yes				Yes	

(*continued*)

Table 4. (*continued*)

Indicator	SDG 11	Urban Quality Classes				Territorial Level		
ID	Target	Urban planning and Architectural	Social	Economical	Environmental and Energy	LAU	Sub1 LAU	Sub2 LAU
[…]								
ST21	11.3		Yes	Yes				
[…]								
ST31	11.1		Yes	Yes			Yes	
[…]								
ST42	11.3 11.7 11.a	Yes	Yes				Yes	
[…]								
ST56	11.1	Yes	Yes	Yes	Yes		Yes	
[…]								
MU64	11.1 11.3 11.a	Yes	Yes	Yes		Yes	Yes	Yes
[…]								
SY78	11.3	Yes	Yes	Yes			Yes	Yes
SY80	11.3 11.a	Yes	Yes				Yes	Yes
[…]								
MU82	11.a 11.3 11.6	Yes	Yes	Yes	Yes			Yes
[…]								
MU88	11.3 11.6 11.7	Yes	Yes	Yes	Yes			Yes
[…]								

Weighting

Based on the indicators selected through the correspondence matrix, the weighing phase is carried out, aimed at quantifying the relative relevance of each indicator within the evaluation system in respect to the Sustainable Development Goals. Table 5 shows the raw weights and the corresponding normalized values, calculated according to the methodology (see paragraph 2.4).

Table 5. Weighing Extract – Source: own elaboration

ID	Indicator	Wi Raw weight	wi Normalized weight
[…]			
ST6	Old-age index	4	0,17
[…]			
ST8	Prevalence among young people aged up to 24	3	0,00
[…]			
ST18	Employment rate (aged 20–64)	3	0,00
[…]			
ST21	Proportion of households at risk of financial hardship	4	0,17
ST22	Proportion of substandard housing	4	0,17
[…]			
ST31	Average property value of residential dwellings	4	0,17
[…]	…		
ST42	Total number of schools	6	0,50
[…]			
MU64	% of residential buildings in the area	8	0,83
[…]			
SY74	Car-sharing parking spaces	7	0,67
SY78	Libraries	6	0,50
[…]			
MU82	Walking distance to local shops: 10 min	8	0,83
[…]			
MU88	Index of tree-lined areas within the local area	8	0,83
[…]			
MU90	Detached and semi-detached houses	7	0,67

The normalized weights were calculated by a linear transformation on a scale of 0–1, using the minimum and maximum values of the raw weights (Wmin = 3; Wmax = 9). This operation made it possible to preserve the relative differences between the indicators, while ensuring comparability in the aggregation phase. It should be noted that indicators with a weight of 0.00 will not be used directly in the construction of the priorities envisaged in the analysis SWOT.

Variance Analysis

Only metrics where the sub1-LAU level and territorial reference level LAU could be

compared were analyzed for deviations. The indicators in Table 6 were selected using the aforesaid approach to analyses deviations for application. This decision preserves the analytical framework's completeness, avoiding the omission of key indicators, while preserving quantitative comparison methodological consistency. The deviation sign is unchanged from the observed values. Thus, greater levels imply favorable conditions for positive indicators and crucial situations for negative indications.

Table 6 shows an excerpt of the results of the variance analysis for a subset of selected indicators, to illustrate the calculation procedure.

Table 6. Variance (example) - Source: own elaboration

ID	Indicator	Δi Variance	wi Normalized weight	Pi
[…]				
ST6	Old age index	-0,36	0,00	0,00
[…]				
ST22	Rate of improper housing	-0,99	0,17	0,17
[…]				
MU64	% Residential buildings on the territory area	-0,88	0,83	0,11
[…]				

The findings indicate a partial compliance with SDG-related indicators, although do not indicate favorable demographic or housing conditions; rather, they highlight a context of socio-demographic fragility, housing inadequacy, and limited service provision, which constrain the overall performance of the urban system.

3.5 SWOT Analysis and Interpretation of Results

SWOT analysis, the interpretative synthesis of quantitative results, yields a framework in which the main strengths are a basic endowment of services, fair pedestrian accessibility, and the availability of school equipment, which create relatively favourable conditions compared to the reference context and provide an infrastructural base for urban quality interventions. These elements have strong structural criticalities. The key drawbacks include restricted public rail access, a largely residential and low-density urban form, and fragmented proximity services. Demo-graphic dynamics can contribute to a socio-territorial picture of fragility. This presents numerous big opportunities. Public housing and basic services can help implement integrated urban regeneration policies and proximity-based settlement patterns. Green spaces, albeit undervalued and under integrated into the urban system, have untapped potential that can be realised via focused redevelopment and enhanced connectivity. However, risk factors remain. Limited local services and housing vulnerability may exacerbate functional marginalisation and private car dependence, lowering quality of life and social inclusion.

From this evidence derives the opportunities and threats that guide the priority actions of intervention as summarized by the SWOT Analysis reported in Table 7.

Table 7. SWOT Analysis - Source: own elaboration

S Indicators	⊕ **Strengths**	**W** Indicators	⊖ **Weaknesses**
ST42 MU82 MU83 MU84 MU88	Presence of basic services in the local fabric; Discreet pedestrian accessibility to proximity services; Presence of school equipment; Provision of green spaces, with potential for urban enhancement and integration; Proximity to the main road network (Grande Raccordo Anulare).	ST6 ST56 MU64 MU82 MU83 MU84 MU90	Limited accessibility to public rail transport; Urban structure with low density and prevalence of residential; Fragmentation of proximity services; Socio-demographic fragility of the context.
O Indicators	⊕ **Opportunities**	**T** Indicators	⊖ **Threats**
ST42 MU60 MU84 MU88	Presence of ERP assets as a regeneration lever; Potential development of the 15-minute city; Potential redevelopment and enhancement of the green system; Integration between services, sustainable mobility and public space.	ST22 SY72 SY76 SY77 SY78 SY80	Risk of functional marginalization; Risk of functional polarization of the urban system around the shopping center; High dependence on the car; Poor enhancement of public spaces and greenery.

The SWOT analysis, built on the integration of weights and deviations, allows us to identify the priorities for intervention in a structured way. These priorities have been translated into a system of strategies (Table 8), defined according to a binary correspondence: SO – Strategies (Strengths–Opportunities), WO – Strategies (Weaknesses–Opportunities), ST – Strategies (Strengths–Threats), WT – Strategies (Weaknesses–Threats).

Table 8. Strategic Implications (SO, WO, ST, WT)- Source: own elaboration

SO – Strategies (Strengths–Opportunities)
Enhancing the green system to build an integrated urban ecological network Strengthening proximity services to support the 15-min city model Integrating schools and services as multifunctional civic hubs
WO – Strategies (Weaknesses–Opportunities)
Regenerating ERP assets to increase functional mix and urban density Enhancing sustainable mobility to compensate for weak rail accessibility Reorganize fragmented services by creating local centralities
ST – Strategies (Strengths–Threats)
Strengthening and diversifying local services to reduce trade polarisation Enhancing and connecting the existing green system to structure an urban ecological network Using schools and services as social anchors
WT – Strategies (Weaknesses–Threats)
Reducing car dependency through alternative mobility Increase functional density by adding new services Activate social inclusion policies

4 Discussion and Conclusions

The application of the proposed evaluation model demonstrates the effectiveness of a data-driven and spatially explicit approach for integrating heterogeneous indicators across multiple territorial scales, enabling a multilevel interpretation of urban systems.. By combining socio-economic, morphological, and accessibility-related variables within a unified analytical framework, the model supports a comprehensive assessment of urban performance that goes beyond purely descriptive analysis. The results indicate that the indicators exerting the highest influence on the evaluation outcomes—namely low settlement density, fragmentation of the urban fabric, and limited accessibility to major transport nodes—have a statistically significant impact on overall system performance. This finding suggests that urban criticalities are not primarily related to the mere availability of services, but rather to the structural capacity of the urban system to ensure their effective accessibility, spatial distribution, and functional integration. In this respect, accessibility emerges as a key latent variable, mediating the relationship between physical infrastructure and actual service usability. Particular attention is given to multi-scalar indicators, especially those related to pedestrian accessibility and spatial proximity. Although these indicators are not always directly comparable across different territorial scales due to issues of normalization and data resolution, they provide analytically robust insights into local spatial dynamics. Their inclusion allows the identification of spatial patterns and latent territorial characteristics that are not captured by conventional statistical indicators alone, thus reinforcing the interpretative depth of the model. The comparison between administrative indicators and spatially derived metrics highlights a critical methodological aspect. While administrative data provides a standardized and comparable framework, they often result in a partial and static representation of urban phenomena. Conversely, the integration of GIS-based spatial elaborations enables the capture of relational and network-based dynamics, offering a more accurate representation of urban complexity and functional interdependencies. The relationship matrix and associated weighting scheme represent each indicator's relative value in the evaluation framework. The weighting procedure, based on statistical dispersion measures and expert-driven calibration, gives environmental quality, accessibility, and urban compactness variable importance depending on the regeneration strategy and territorial context. This flexible framework makes the model more adaptable to different planning circumstances. Study methodological flaws are also revealed. First, deviation and variance studies are limited to a selection of indicators due to data availability and resolution differences among territorial sizes. This issue shows that spatial planning data infrastructures need more harmonization and interoperability. Second, although consistent with normalization and weighting processes, indicators with zero or negligible weights raise important problems about variable selection and model sensitivity. It emphasizes the need for sensitivity and robustness assessments to assess results stability under different weighting methods. The integration of weighting procedures with variance-based analysis enables a transition from a purely descriptive framework to an evaluative and decision-oriented approach. A SWOT analysis should not be seen as a qualitative add-on, but as the practical translation of a quantitatively grounded priority framework. Strategic actions like improving accessibility networks, rebalancing service distribution, promoting selective densification, and valuing environmental assets are directly derived

from the model's analytical outputs and consistent with the main structural weaknesses identified. Future methods may allow stakeholders to choose indicators, design weighting systems, and analyze outcomes. Integration would improve technical evaluation and decision-making, legitimizing and contextualizing planning outcomes. Integrating dynamic and time-dependent metrics to track urban system evolution is another development. Time-series analysis and longitudinal datasets would improve the model's urban transition monitoring and evaluation. Multi-temporal, adaptive decision-support system for strategic planning and policy changes is possible using the framework.

Acknowledgments. This work stems from ongoing research conducted within the Department of Architecture and Project at Sapienza University of Rome, in the context of the project "Rome 2050: Extra-ordinary and Possible City" (RD 12318AA79203DC), and is further developed as part of the doctoral activities of the PhD School in Architecture and Construction of the City.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article that has to be referred equally to all the authors.

References

1. United Nations: World Urbanization Prospects: The 2018 Revision. United Nations, New York (2019). https://unhabitat.org/topic/urban-planning
2. United Nations: New Urban Agenda. In: Proceedings of the United Nations Conference on Housing and Sustainable Urban Development (Habitat III). United Nations, Quito (2016)
3. European Commission: Sustainable development in the European Union – Monitoring report on progress towards the SDGs in an EU context. Publications Office of the European Union, Luxembourg (2023)
4. United Nations: Sustainable Development Goals. https://www.un.org/sustainabledevelopment/
5. Guarini, M.R., Mosquera-Adell, E., Mosquera-Pérez, C. (eds.): Urban Resilience and Heritage Management. MDPI, Basel (2025). https://doi.org/10.3390/books978-3-7258-5092-1
6. Eurostat: Nomenclature of Territorial Units for Statistics (NUTS) and Local Administrative Units (LAU). https://ec.europa.eu/eurostat/web/nuts
7. Bibri, S.E.: Data-driven smart sustainable cities of the future: urban computing and intelligence for strategic, short-term, and joined-up planning. Comput. Urban Sci. **1**, 8 (2021). https://doi.org/10.1007/s43762-021-00008-9
8. European Commission: EU SDG indicator set. https://ec.europa.eu/eurostat/web/sdi
9. United Nations: Transforming our world: the 2030 Agenda for Sustainable Development. United Nations, New York (2015)
10. Eurostat: Eurostat database. https://ec.europa.eu/eurostat
11. European Commission: The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal
12. European Commission: Copernicus programme. https://www.copernicus.eu
13. AUDIS. Rigenerazione urbana e qualità della trasformazione. Linee guida per la valutazione dei progetti urbani. Associazione Aree Urbane Dismesse (2017)

14. U.S. Green Building Council. LEED for Cities and Communities Rating System (2019)
15. BRE Global. BREEAM Communities Technical Manual (2012)
16. ITACA. Protocollo ITACA a scala urbana (2016)
17. Carter, A., Roberts, P.: The evolution, definition and purpose of urban regeneration. In: Roberts, P., Sykes, H., Granger, R. (eds.) Urban Regeneration, 2nd edn., pp. 9–43. SAGE Publications, London (2017)
18. Chakhar, S., Mousseau, V.: Multicriteria decision making, spatial. In: Shekhar, S., Xiong, H. (eds.) Encyclopedia of GIS, pp. 747–753. Springer, Boston, MA (2008). https://doi.org/10.1007/978-0-387-35973-1_839
19. Moreno, C., Allam, Z., Chabaud, D., Gall, C., Pratlong, F.: Introducing the "15-Minute City": sustainability, resilience and place identity in future post-pandemic cities. Smart Cities **4**(1), 93–111 (2021). https://doi.org/10.3390/smartcities4010006
20. Alleanza Italiana per lo Sviluppo Sostenibile (ASviS): Goal e Target: obiettivi e traguardi per il 2030. https://asvis.it/goal-e-target-obiettivi-e-traguardi-per-il-2030/
21. United Nations: Sustainable Development Goal 11 – Make cities and human settlements inclusive, safe, resilient and sustainable. https://www.un.org/sustainabledevelopment/cities/. Accessed 25 Oct 2023
22. Tedesco, C., Castellani, F., Meschini, E.R.: La rigenerazione urbana "creativa" attraverso gli sguardi della pianificazione e delle arti contemporanee. In: Urbanistica e Paesaggi in trasformazione (2025).https://air.iuav.it
23. Gallo, P., Donato, A., Caruso, E., Lingua, V.: Innovative tools for urban resilience and public health in inner areas (2025)
24. Autore, P., Mattioli, E., Ghezzi, G.: La mappatura: criteri, fonti e indicatori. Economia della Cultura (NS/2026), 133–141 (2026).https://doi.org/10.1446/120000
25. Ermolli, S., Galluccio, G.: Data-driven urban regeneration: university housing in the ex-Corradini factory in Naples. TECHNE – J. Technol. Arch. Environ. **24**, 218–228 (2022). https://doi.org/10.36253/techne-12863
26. Wang, X., et al.: Municipal and urban renewal development index system: a data-driven digital analysis framework. Remote Sens. **16**(3), 456 (2024). https://doi.org/10.3390/rs16030456
27. Özdemir, S.A., Çöğürcü, M.T.: A data-driven urban regeneration index using AHP and fuzzy logic for sustainable redevelopment planning. Int. J. Urban Sci. 1–27 (2026).https://doi.org/10.1080/12265934.2026.2636018
28. Sica, F., De Paola, P., Tajani, F., Doko, E.: Spatio-temporal ontology of indicators for urban landscapes. Land **14**(1), 72 (2025). https://doi.org/10.3390/land14010072
29. ISPRA: Banche dati e indicatori ambientali. Istituto Superiore per la Protezione e la Ricerca Ambientale (2024). https://www.isprambiente.gov.it/it/banche-dati
30. Hill, T., Westbrook, R.: SWOT analysis: It's time for a product recall. Long Range Plan. **30**(1), 46–52 (1997)
31. Pickton, D., Wright, S.: What's SWOT in strategic analysis? Strateg. Chang. **7**(2), 101–109 (1998)
32. Gürel, E., Tat, M.: SWOT analysis: a theoretical review. J. Int. Social Res. **10**(51), 994–1006 (2017)
33. Dell'Ovo, M., Maiullari, D., et al.: A participatory SWOT-based approach to nature-based solutions within urban fragile territories: operational barriers and strategic roadmaps. Land **14**, 1847 (2025). https://doi.org/10.3390/land14091847

34. ISTAT: Tavole statistiche regionali – Lazio. Istituto Nazionale di Statistica (2026). https://www.istat.it/produzione-editoriale/annuario-statistico-italiano-2024/
35. Roma Capitale: Annuario statistico 2024. Ufficio di Statistica – Roma Capitale (2024)https://www.comune.roma.it/web-resources/cms/documents/Annuario_2024.pdf
36. Roma Capitale: Geoportale di Roma Capitale. https://geoportale.comune.roma.it