Towards a Methodological Framework for Evaluating Urban Resilience: Spatial Indicators for Addressing Complex Urban Systems

Ilaria Cazzola(✉), Benedetta Giudice, Manuela Rebaudengo, and Valeria Vitulano

Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino, Torino, Italy
{ilaria.cazzola,benedetta.giudice,manuela.rebaudengo, valeria.vitulano}@polito.it

Abstract. Resilience is a crucial factor in addressing contemporary challenges in urban development and planning, as cities increasingly face negative impacts of climate change, natural hazards, and rapid urbanization. Particularly, urban resilience is a complex, dynamic, and multilayered concept that refers to a city's ability to withstand and recover from both sudden shocks and long-term stresses. This study aims to develop a catalog of resilience indicators to support planning processes, and intends to test it in a real case study in future research. The methodological approach follows a structured process: (i) a literature review to identify and refine resilience indicators, (ii) the construction of an indicator catalog based on selected sources, and (iii) the application of selected indicators to a case study. The city of Turin (Italy) is proposed as a potential urban context for testing the catalog with a targeted set of indicators, with a focus on the northeastern districts of the city. The application process will involve mapping and analyzing resilience indicators to evaluate and monitor urban transformations resulting from plans and projects, including those linked to the Italian recovery fund (PNRR). This research contributes to the development of tools for evaluating urban resilience through a context-specific and planning oriented approach that seeks to balance natural and human capital.

Keywords: Urban Resilience · Resilience Indicators · Urban Planning

1 Introduction

Resilience plays a crucial role in urban development and planning, as cities face an increasing range of challenges, such as climate change, natural hazards, and rapid urbanization. Over time, various resilience concepts have emerged in various fields [1], resulting in no universally accepted definition. The increasing focus on resilience is also reflected in the expanding body of research on the topic. In urban context, "urban

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15893, pp. 207–221, 2026.
https://doi.org/10.1007/978-3-031-97645-2_14

resilience" can be understood as a complex, dynamic and multi-layered concept that highlights a city's ability to endure and recover from both immediate shocks and long-term stresses. In particular, we adopt the definition given by Meerow et al. [2] which frames urban resilience as: «the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt, to change and to quickly transform systems that limit current or future adaptive capacity» [2]. This definition provides a thorough understanding of urban resilience by highlighting the interconnectedness of urban systems in their different dimensions. Furthermore, this perspective underscores the importance of considering all the components – social, ecological and technical – when applying resilience thinking [3] and resilience evaluation. However, many urban resilience frameworks often overlook these different dimensions, particularly in evaluation, even though, as initially stated, resilience is a complex issue and ideally, all aspects of an urban system should be considered in a resilience evaluation framework [4]. Additionally, the transformative character of resilience has the potential to reframe planning practices and interventions [5]. In this sense, the concept of transformative resilience helps to identify disturbances as drivers of positive change [6], allowing to incorporate in planning practices a more holistic and forward-looking approach to fostering resilient urban environments.

A comprehensive interpretation of resilience in urban systems allows for prioritizing radical and non-linear transformations within the urban fabric, fostering continuous adaptation. The dynamic nature of resilience can activate institutional, organizational and social change rather than simply acting as passive resistance. To achieve this, it is necessary to adopt an interdisciplinary approach that leverages diverse fields to promote systemic modification, with flexibility and responsiveness in governance being essential to effectively implement transformative resilience strategies over the medium to long term across multiple sectors and levels [7, 8].

These considerations have fostered the willingness to understand how these transformative statuses of urban systems could be measured to better support planning processes. In this context, the research aims to conceptualize urban and metropolitan territories as a social-ecological system, understood as dynamic and interdependent systems composed of both social (human) and ecological (natural) components, closely linked through feedback mechanisms. Cities, in view, are not isolated entities but open systems embedded in a complex web of relationships with their surroundings [9–11]. Urban environments, from this perspective, consist of a set of interconnected subsystems: people, communities, economies, societies and cultures [12]. To achieve this, a catalog of resilience indicators has been developed, with the aim of testing it in a real case study in future research. In particular, this paper outlines the methodological steps taken to create the catalog and introduces the city of Turin (Italy) as a potential site for application. The practical implementation of the indicator catalog – through the selection of a specific set of indicators based on a context-specific approach – could be a valuable tool for evaluating urban resilience. This evaluation can focus on the transformations resulting from plans and projects, including those associated with the Italian Recovery Fund (*Piano Nazionale di Ripresa e Resilienza* - PNRR).

The paper is structured as follows. Section 2 presents the research framework. The methodological approach adopted is outlined in Sect. 3, while Sect. 4 briefly introduces the case study proposed for the application. Section 5 details the organization of the catalog. Finally, Sect. 6 offers some conclusive remarks regarding possible implementation.

2 Research Framework: The RETURN Project

This study is part of the project RETURN - Multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate, funded by the European Union Next-GenerationEU. The project aims to enhance the understanding of environmental, anthropogenic and natural risks, especially in the context of climate change. It seeks to develop improved tools and strategies for risk prevention and monitoring, as well as approaches for climate change adaptation and mitigation, improving the use of data and technology and strengthening the connection between research and practical applications.

The project involves collaboration among 26 different private and public entities and is organized into interlinked thematic areas known as "spokes", reflecting its multidisciplinary nature. There are four vertical spokes (VS) that concentrate on specific risks: water, ground instability, earthquakes and volcanoes, and environmental degradation. Three transversal spokes (TS) connect these VS to develop methods and tools for assessing and predicting impacts on urban and metropolitan settlements, critical infrastructure and communities. Additionally, a diagonal spoke (DS) is dedicated to creating innovative methods and models for predicting future climate conditions (Fig. 1).

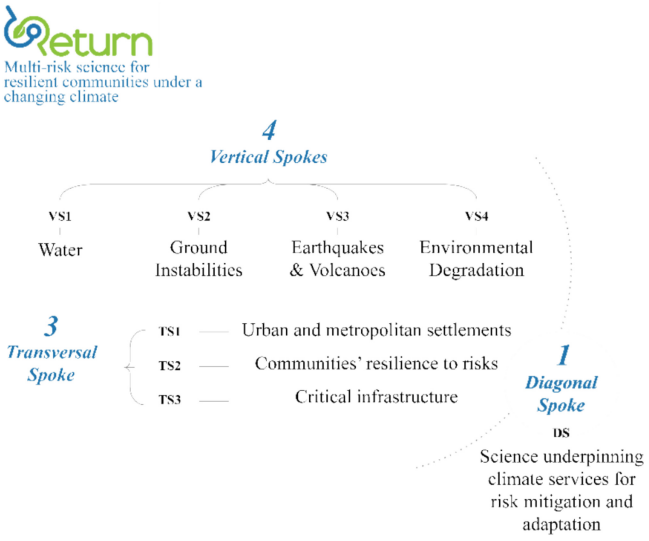

Fig. 1. Structure of the RETURN project articulated in thematic spokes.

More specifically, this research is part of TS1 - Urban and metropolitan settlements. The theme focuses on developing tools and approaches for effective adaptation through multi-risk analysis. It aims to reduce vulnerability and exposure while ensuring the continued functioning of buildings and urban systems during extreme events.

3 Methodological Approach

The goal of this study is to develop and test an effective tool for measuring urban resilience. The methodology is organized into three main phases, preceded by Phase 0 that focuses on defining the research objective and process. Each phase contains several sub-steps (Fig. 2).

Phase 0 involves formulating a precise research objective and question, delineating the study boundaries, developing a conceptual framework, identifying data sources, and defining relevant keywords and search queries. Conducting a preliminary exploration of keywords is essential to ensure that the queries align with the research objective.

Once the research process has been defined, the next step involves conducting the literature review (Phase 1). The purpose of this stage is twofold. First, it aims to explore the extent of existing scientific literature on approaches and methodologies for measuring urban resilience. This involves searching academic databases, applying filters, removing duplicate records, and selecting sources through a two-stage screening process: an initial review of titles and abstracts, followed by a comprehensive full-text reading and qualitative content analysis to ensure the inclusion of only relevant sources in the database. Initially, the search is limited to the Scopus database, a methodological choice shared by all participating research units. Scopus is selected for its capacity to support structured keyword searches and queries, which enhances the transparency and replicability of the process. Moreover, this approach ensures that the review is not limited to sources already familiar to the research components. The multidisciplinary coverage provided by Scopus further strengthens the review's comprehensiveness. In a subsequent phase, grey literature and institutional databases are consulted to address specific gaps observed during the initial review. The second objective of the review is to develop a catalog of indicators. This process involves structuring a table with key information fields. Indicators are then systematically extracted from the selected papers and grouped by thematic categories to help identify and eliminate redundant indicators. Similar indicators need to be standardized and harmonized in terms of terminology and units of measurement. The catalog is progressively updated, with missing information filled in from additional sources as needed. A pre-selection of indicators is made through group discussion to exclude those that are clearly irrelevant. This process also helps identify potential gaps and allow for the inclusion of indicators from non-scientific databases and grey literature, if necessary.

Once this initial extended version of the catalog is completed, a second selection is conducted through group discussion, during which clearly defined criteria are applied to evaluate the eligibility and relevance of each indicator. The outcome is a refined and more targeted catalog.

Based on the selection of case studies, a manageable number of significant indicators will be further chosen from the catalog for testing, taking into account contextual specificity, data availability, required processing methods, and data processability [13]. The

catalog is intended to be a flexible tool and allows for the addition of other indicators if the conditions of the case study are not effectively represented. The case study of the city of Turin (Phase 2) allows for the practical validation of the proposed set of indicators and the assessment of their operational effectiveness in a real urban context. Once the final set of indicators is defined, each one is calculated and mapped using GIS software (QGIS ver. 3.40.6). This step will produce a series of thematic maps that visually interpret urban resilience patterns throughout the study area, that will be analyzed and critically read in Phase 3. Indicators will be organized into groups and will undergo an integrated reading to identify spatial correlations and patterns, areas of convergence, as well as zones with high potential or criticalities.

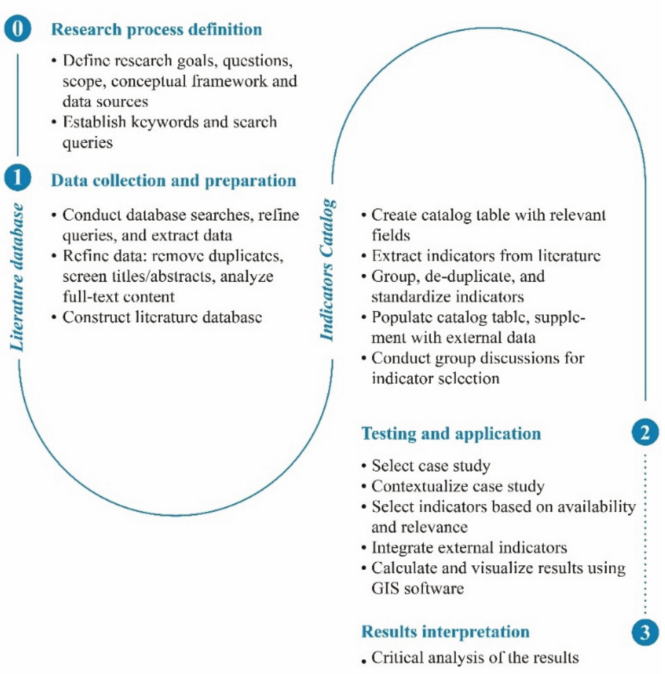

Fig. 2. Scheme of the methodological approach, illustrating its three main phases and corresponding sub-steps.

4 Case Study

The city of Turin is proposed as a potential urban context for applying a selected set of indicators derived from the catalog to evaluate its resilience, particularly concerning past and potential future urban transformations. Since each city differs in terms of disaster risks, demographic characteristics, data availability and collection capacity, and institutional frameworks, it is essential for each city to develop its own tailored set of indicators

[14]. Located in the western part of the Po Valley in northern Italy, Turin boasts a complex landscape shaped by various natural, anthropogenic, and climate change-related risks. The eastern area features hilly terrain, while the core urban area is flat and densely built-up. A significant river system, comprising the Po River and its tributaries (Sangone, Dora, and Stura), supports a network of interconnected green spaces and protected areas that extend to the metropolitan and regional scale [15, 16].

The city faces hydrogeological risks due to the fact that over 65% of its surface is artificial [17]. This limits natural drainage and makes the city more susceptible to flooding, especially during extreme rainfall events. The high percentage of impervious surfaces also contributes to the urban heat island effect, intensifying the negative impacts of heat waves, particularly on vulnerable populations living in the most densely urbanized areas. Turin is also widely recognized as one of the most polluted cities in Italy and Europe, primarily due to its specific morphological position and a relatively slow shift toward sustainable mobility, along with high rates of car ownership [18]. Additionally, the city faces significant socio-economic challenges related to population decline caused by an increasingly aging demographic and a decreasing birth rate.

Over the past decades, urban planning in Turin has undergone significant changes to adapt to unexpected crises and align with international strategies. As a regional and metropolitan capital, the city has historically been shaped by structured planning, while also facing extensive deindustrialization that has prompted major urban transformation initiatives. Today, Turin requires targeted regeneration interventions to enhance resilience to both environmental hazards and socio-economic crises. These interventions should be guided by the framework of the municipal general land use plan, which is currently under revision. The revision process of Turin's municipal plan is time-consuming and influenced by changes within the municipal administration. Additionally, it must align with higher-level planning frameworks. These include regional plans such as the PTR and PPR, regional strategies for sustainable development and climate change adaptation, metropolitan plans such as PTC2 and PTGM, and nature park plans such as Piedmont Po Park Plan.

The application of resilience indicators will focus on the district level, specifically selecting an area within the city's riverine context. This area represents a multifaceted socio-ecological system, allowing for a comprehensive understanding of various dimensions, including environmental, ecological, natural, anthropogenic, and social. Specifically, three neighborhoods in the northeastern part of the city have been chosen: Vanchiglia, Regio Parco and Madonna del Pilone (Fig. 3). These districts provide an opportunity to examine diverse territorial and social conditions. Furthermore, this part of the city is expected to undergo significant transformation in the coming years. Several large-scale interventions are planned, including the construction of Metro Line 2, which is expected to facilitate urban transformations in previously overlooked areas. Another major project is the redevelopment of the former Manifattura Tabacchi industrial site, which will be converted into a new cultural hub and university campus. Additionally, the Meisino Sports and Environmental Education Centre, located near the Po River, will further contribute to the area's transformation. Alongside these major projects, numerous smaller-scale interventions are either planned or already completed, funded through

the PNRR recovery program. These efforts primarily focus on redeveloping public green spaces and buildings, such as schools and libraries.[1]



Fig. 3. The three neighbourhoods of Turin selected for the application and spatialization of the indicators.

5 Results

After establishing the research objective, we conducted preliminary research to identify the most appropriate keywords and databases for the literature review. This initial step also helped set two main limitations to better frame the research: the focus on urban settlements as the contextual framework, and the specific interest in spatial indicators as the object of analysis. Regarding the conceptual framework, we adopted a multidimensional and transformative perspective to capture the complexity and dynamic nature of urban resilience.

This preliminary study enabled the formulation of two queries through an iterative process, which progressively improved the relevance of the results. The first query focused on indicator-related terms, while the second included keywords associated with the assessment, evaluation and measurement of urban resilience.

5.1 Literature Database

Once the final queries were defined, the literature research was conducted on Scopus on April 4, 2024 (Fig. 4). The first query (Query 1) resulted in 477 records, while the

[1] The *Torino Cambia* website (https://www.torinocambia.it/) provides a list of all completed and ongoing projects, with approximately 60 located within the selected case study area.

second one (Query 2) produced 773 results. To refine these results, several filters were applied – publication year, subject area, language and the document type, as detailed in Tables 1 and 2. This filtering process reduced the number of results to 97 for Query 1 and 127 records for Query 2.

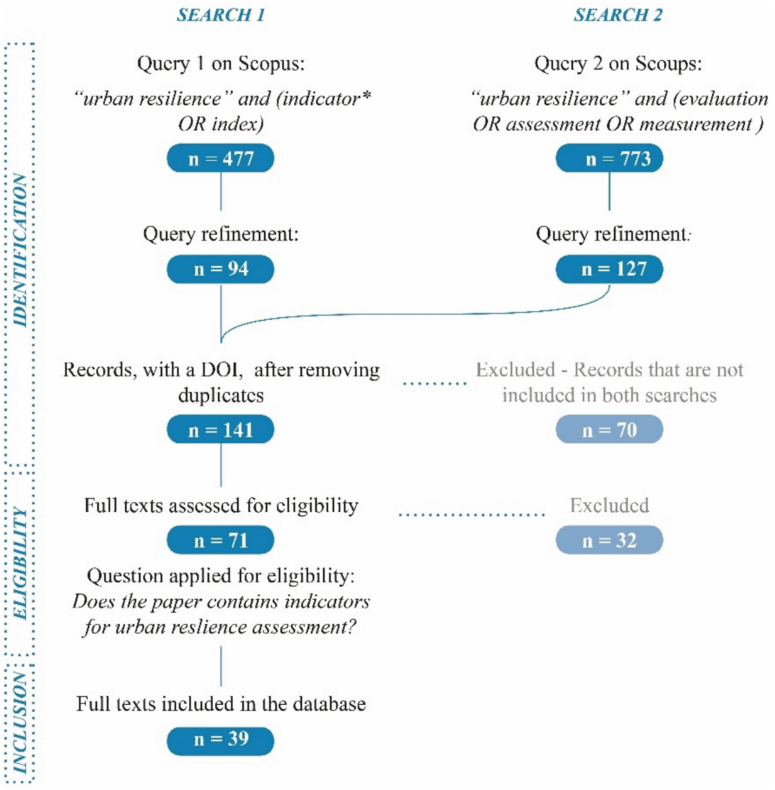

Fig. 4. Number of records at each stage of the literature review process. Accessed on 04/04/2024.

The first query identified studies that explicitly discussed measurement tools, while the assessment-focused string captured discussions of evaluation methodologies and approaches in a broader context.

Several records were found in both searches. After removing duplicates, 171 records with a DOI were left. To refine our selection further, we chose to include only the 71 papers that appeared in both searches.

This initial set of papers underwent a two-step selection process: first, we screened the papers based on their title and abstract, followed by a full-text review. The eligibility criterion applied was: Does this paper contain indicators for urban resilience assessment? The final selection consisted of 39 papers.

Table 1. Refinement process for Query 1: Number of records retrieved from Scopus after the application of each filter. Accessed on 04/04/2024.

Query 1	*Records*
TITLE-ABS-KEY ("urban resilience" AND (indicator OR index)*	477
AND AUTHKEY (evaluation OR assessment OR measurement OR indicator OR index)*	159
AND NOT KEY ("risk assessment" OR "hazard assessment" OR "vulnerability assessment")	142
AND PUBYEAR > 2013 AND PUBYEAR < 2025	135
AND (LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "EART") OR LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO (SUBJAREA, "MULT")	128
AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "bk")	110
AND (LIMIT-TO (LANGUAGE, "English"))	94

Table 2. Refinement process for Query 2: Number of records retrieved from Scopus after the application of each filter. Accessed on 04/04/2024.

Query 2	*Records*
TITLE-ABS-KEY ("urban resilience" AND (evaluation OR assessment OR measurement)	773
AND AUTHKEY (evaluation OR assessment OR measurement OR indicator OR index)*	224
AND NOT KEY ("risk assessment" OR "hazard assessment" OR "vulnerability assessment")	185
AND PUBYEAR > 2013 AND PUBYEAR < 2025	179
AND (LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "EART") OR LIMIT-TO (SUBJAREA, "AGRI") OR LIMIT-TO (SUBJAREA, "MULT"))	171
AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "bk"))	144
AND (LIMIT-TO (LANGUAGE, "English"))	127

5.2 Indicators Catalog

Based on the 39 papers included in the literature database, a total of 970 indicators were systematically collected. For each indicator, the following information was gathered, when available: the indicator name, possible sub-indicators, the resilience dimension,

direction (positive/negative), formula, unit of measurement, definition, and references. A selection process was essential to reduce the number of indicators, as illustrated in Fig. 5. Indicators with similar meanings were grouped to identify redundancies and eliminate duplicates. Although indicators can share similar concepts, they are often described using different wording, units or equations. Following this grouping, a structured process of group discussion and review was conducted. The various pieces of information were combined and harmonized to create a unified version of each indicator that best suits the final goal of measuring resilience. While the indicators derived from the literature formed the basis for this process, they have been extensively modified and refined. Additionally, indicators deemed irrelevant to the research objective were excluded.

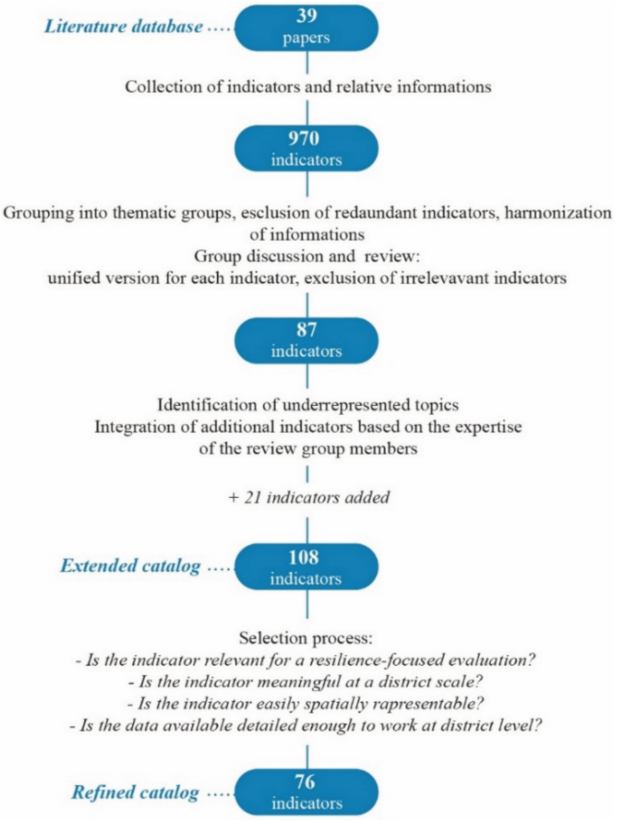

Fig. 5. Selection Process of Indicators and Resulting Numbers.

This process resulted in a refined set of 87 indicators. However, it became evident that certain topics were underrepresented or missing, indicating a need for further integration into the catalog. To address these gaps, 21 additional indicators were included, drawing upon grey literature and the expertise of the research group members, which is grounded in their knowledge and past and ongoing experience. This is particularly relevant since the field background of the research components relates to spatial planning and design

and urban studies, and aligns with the phenomenon well described by Sharifi [19], which emphasizes the need for more integrated approaches to connect land use planning and green infrastructure in urban resilience assessment. This effort culminated in a comprehensive catalog of 108 indicators.

The following attributes describe each indicator:

- Resilience dimension: The dimensions of resilience addressed by the indicator. These include environmental, built environment, social, economic and institutional dimensions. A single indicator can cover one or more dimensions.
- Topic: Thematic categories including buildings, cooperation, demography, ecosystem services, emergency, heritage, income, infrastructure and networks, land use, landscape, natural/green spaces, planning and programming, pollution, resources/resource consumption, and services (Fig. 6).
- Definition: A short explanation of the indicator.
- Frequency: The occurrence of the indicator in the analyzed literature.
- Source ID: Identification number of the source from the literature database.
- Direction: Whether the indicator has a positive or negative effect on resilience.
- Formula: The mathematical representation, when possible.
- Unit of measurement: The unit in which the indicator is measured.
- Minimum Territorial Scale: The smallest geographical unit for which the indicator is meaningful.

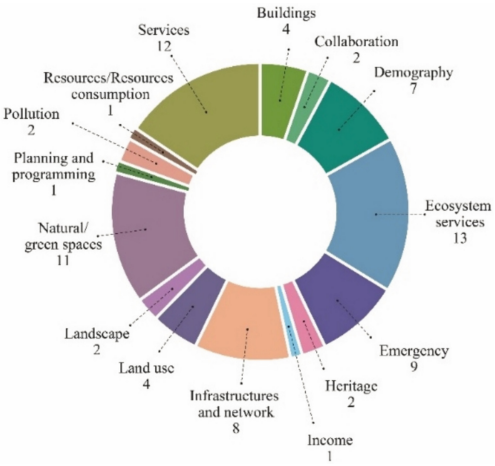

Fig. 6. Distribution of indicators by category in the refined catalog.

At this stage, a second selection was made based on the relevance, calculability, and spatial applicability of the indicators. The following exclusion criteria were applied:

1. *Not aligned with an urban resilience-focused evaluation*: Indicators related to risk, vulnerability assessment, or sustainability rather than resilience;
2. *Not relevant at the district scale*: Indicators not meaningful at the district level, but at smaller or bigger scales;

3. *Difficult to spatially represent*: Indicators that cannot be easily mapped (mainly with the use of GIS);
4. *Data not readily available at the district scale*: Indicators without consistent data sources for a district-level application.

The application of these selection criteria led to a refined version of catalog, consisting of 76 indicators. This includes 60 indicators sourced from the Scopus literature review and 16 additional indicators. While all indicators in the catalog are theoretically intended to be spatialized, the actual application to a specific case study inevitably confronts the issue of data availability. As a result, it is likely that not all indicators will be spatializable in practice, and further selection will be necessary. In this framework, the catalog will serve as the basis for deriving the indicators to be applied to the case study in northeastern Turin. The calculation process is currently underway, alongside the

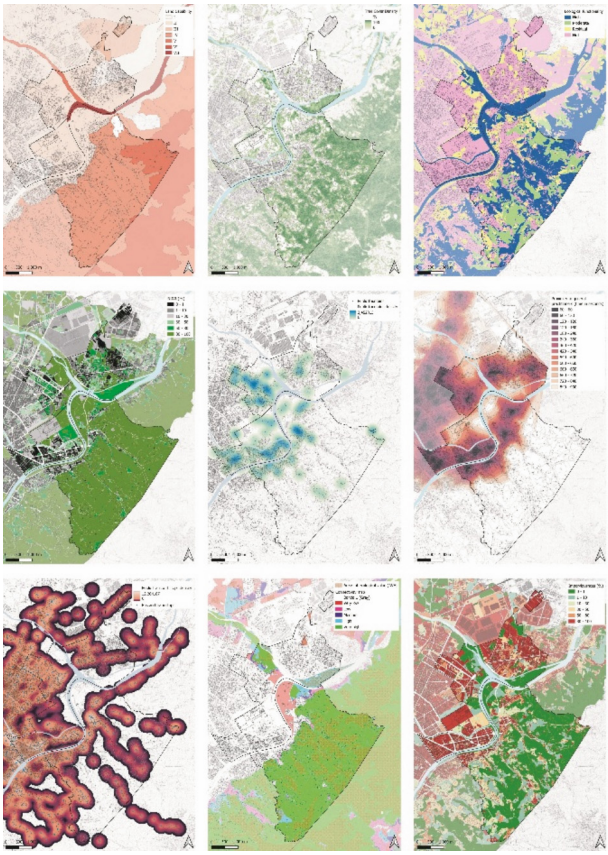

Fig. 7. First examples of the application of resilience indicators in the Turin case study: Land capability, Tree cover density, Ecological functionality, Normalized Difference Vegetation Index (NDVI), Concentration of public water fountains, Proximity to hospitals, Public transport stop density, Imperviousness, Elements of the Ecological Network (ordered from upper left to lower right)

development of visual outputs. These outputs consist of thematic maps that spatialize selected indicators. Figure 7 presents a selection of the outputs currently being developed, offering examples of the various dimensions and components of the urban system considered in this study—including for instance, indicators such as Land capability, Tree cover density, Ecological functionality, Normalized Difference Vegetation Index (NDVI), Concentration of public water fountains, Proximity to hospitals, Public transport stop density, Imperviousness, Elements of the Ecological Network (ordered from upper left to lower right). Once all the maps have been completed, they will contribute to an integrated spatial interpretation of the study area, enabling a critical reading of resilience conditions across the territory.

6 Conclusions

To develop effective methods for adapting to climate change, an integrated approach to urban planning is essential. Numerous studies on disaster risk reduction emphasize the need to combine proactive preventive measures with reactive "building back better" interventions to enhance resilience.

The measurement of urban resilience is a widely studied yet contentious topic. Indicators used in this field may not fully capture all aspects of the issues at hand, particularly when it comes to balancing human and natural capital amidst societal challenges. Much of the existing literature provides generic definitions and formulas designed for application across different territories, which risks inadequately representing the complexity of urban settlements. This research will have the added value of overcoming these gaps and critical issues by offering a more comprehensive and context-sensitive approach to measuring urban resilience. By addressing the limitations of generic indicators and incorporating localized factors, it will attempt to provide actionable insights that better reflect the complexities of different urban environments and facilitate targeted planning decisions.

To do this, this study aims to identify indicators capable of evaluating and monitoring urban resilience through spatial representation using GIS, with an approach oriented toward planning purposes. Therefore, it requires updated, comprehensive, and spatially applicable datasets—an aspect that significantly depends on and varies according to the application phase within a case study. Data availability plays a crucial role in selecting these indicators since, in many instances, the spatial information required for applying a set of indicators is not accessible from current open-source databases. In other cases, some indicators may only be effective for descriptive purposes related to the 'vulnerability status' rather than for directly measuring resilience response.

Recognizing these methodological limitations, the resilience catalog will be finalized in the next phases of the research, using the case study of Turin. Completed PNRR projects could be used, according to a scenario-based evaluation, to monitor potential progress in urban resilience, especially since the PNRR does not include a monitoring program for its interventions. The resilience indicators catalog could serve as a valuable tool in the drafting process of Turin's new municipal land use plan, particularly in relation to the Strategic Environmental Assessment procedures.

The catalog is designed to be a flexible and user-friendly tool, allowing for the inclusion of additional indicators if the conditions of the case study are not adequately represented.

Acknowledgments. This study was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, Mission 4, Component 2, In-vestment 1.3 – D.D. 1243 2/8/2022, PE0000005) – SPOKE TS 1 (2022–2025). POLITO Scientific Supervisor for Spoke TS1 Urban and metropolitan settlements: Angioletta Voghera, Coordinator: Benedetta Giudice, Research group: Grazia Brunetta, Manuela Rebaudengo, Ilaria Cazzola, Valeria Vitulano, Giosuè Pier Carlo Bronzino.

References

1. Davoudi, S., et al.: Resilience: A bridging concept or a dead end? Plan. Theory Pract.Pract. **13**(2), 299–333 (2012)
2. Meerow, S., Newell, J.P., Stults, M.: Defining urban resilience: a review. Landsc. Urban Plan.. Urban Plan. **147**, 38–49 (2016)
3. Berkes, F., Colding, J., Folke, C. (eds.): Navigating Social–Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge (2003)
4. Sharifi, A., Yamagata, Y.: Urban resilience assessment: multiple dimensions, criteria, and indicators. In: Yamagata, Y., Maruyama, H. (eds.), Urban Resilience. A Transformative Approach, pp. 259–276. Springer, Cham (2016)
5. Giovannini, E., Benczur, P., Campolongo, F., Cariboni, J., Manca, A.R.: Time for transformative resilience: the COVID-19 emergency. EUR 30179 EN. Publications Office of the European Union, Luxembourg (2020)
6. Asadzadeh, A., Khavarian-Garmsir, A.R., Sharifi, A., Salehi, P., Kötter, T.: Transformative resilience: an overview of its structure, evolution, and trends. Sustainability **14**(22), 15267 (2022)
7. Brunetta, G., et al.: Territorial resilience: toward a proactive meaning for spatial planning. Sustainability **11**(8), 2286 (2019)
8. Brunetta, G., Voghera, A.: Post-pandemic challenges. The role of local governance for territorial resilience. In Brunetta, G., Lombardi, P., Voghera, A. (eds.) Post Un-Lock. From Territorial Vulnerabilities to Local Resilience, pp. 3–9. Springer, Cham (2023)
9. Douglas, I.: The city as an ecosystem. Progress Phys. Geogr. Earth Environ. **5**(3), 315–367 (1981)
10. Odum, H.T., Sons, J.W.: Systems Ecology: An Introduction. Wiley, New York (1983)
11. Datola, G., Bottero, M., De Angelis, E., Romagnoli, F.: Operationalising resilience: a methodological framework for assessing urban resilience through system dynamics model. Ecol. Model. **465**, 109851 (2022)
12. Folke, C., Biggs, R., Norström, A.V., Reyers, B., Rockström, J.: Social-ecological resilience and biosphere-based sustainability science. Ecol. Soc. **21**(3), 41 (2016)
13. Gómez-Gil, M., Arbulu, M., Hernández-Minguillón, R.J., López-Mesa, B.: On the availability and quality of data in Spain for the development of indicators to measure building renovation policies effectiveness and the decarbonization of the building stock. In: López-Mesa, B., Oregi, X. (eds.), Assessing progress in decarbonizing Spain's building stock, pp. 291–316. Springer, Cham (2024)

14. Figueiredo, L., Honiden, T., Schumann, A.: Indicators for resilient cities. OECD Regional Development Working Papers 2018/02. OECD, Paris (2018)
15. Città di Torino.: Piano strategico dell'infrastruttura verde. http://www.comune.torino.it/verdepubblico/il-verde-a-torino/piano-infrastruttura-verde/ (2020)
16. Giudice, B., La Riccia, L., Negrini, G., Voghera, A.: Strategie per il verde e la collina di Torino. Storie e prospettive. In Giaimo, C. (ed.) Contenuti e strumenti della pianificazione urbana e territoriale. Dalla lezione di Giampiero Vigliano alle prospettive del Green New Deal. Urbanistica Dossier online vol. 27, pp. 79–82 (2022)
17. Munafò, M. (ed.): Consumo di suolo, dinamiche territoriali e servizi ecosistemici. Edizione 2024. Report SNPA 43/24. SNPA, Roma (2024)
18. European Environment Agency (EEA). Europe's Air Quality Status 2024. Briefing no. 06/2024 (2024). https://doi.org/10.2800/5970
19. Sharifi, A.: Urban resilience assessment: mapping knowledge structure and trends. Sustainability **12**(15), 5918 (2020)